TU Delft

MOT2910
MASTER THESIS PROJECT

ON:

AIRCRAFT SPECIFIC CARBON EMISSION CALCULATIONS FOR AIR FREIGHT TRANSPORTATION

A SYSTEMATIC APPROACH TO MODEL DEVELOPMENT TO PROMOTE SUSTAINABLE PURCHASING AND GREEN MARKET POSITIONING AT POSTNL

Aug 17
2020

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Aircraft Specific Carbon Emission Calculations For Air Freight Transportation: A Systematic Approach to Model Development to Promote Sustainable Purchasing and Green Market Positioning at PostNL

Master thesis submitted to Delft University of Technology

in partial fulfilment of the requirements for the degree of

MASTER OF SCIENCE

in **Management of Technology**

Faculty of Technology, Policy and Management

by

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To be defended in public on August 17, 2020

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Acknowledgment

This thesis project is the final step towards completing my Masters of Science in Management of Technology program, which was an extraordinary journey that has made me a better person. At TU Delft, you are greeted with a surprise each day. Some days are filled with stories of incredible success, whilst some days can be rough and challenging. But both experiences are equally critical for polishing your personal growth, learning essential life skills, and making you feel proud of every single credit on the genuinely received grade sheet. This achievement is not possible without the help of numerous people who have motivated me to reach this point and have supported me continuously.

I would like to express my gratitude and appreciation to the members of my thesis committee, without whom this project would not have been possible: Dr. L. Hartmann, Dr. T.W. (Theo) Fens, and Prof. Ir. Paul C. Roling. I would like to thank Dap, my first supervisor, and chairperson, for giving me the opportunity to work on this kind of research and to connect me to the right people at PostNL. I would also like to thank him for his guidance and feedback whenever I had doubts about the research process. Theo and Paul's feedback and suggestions further helped me develop the final version of this research. I would like to thank all of them for their support and understanding over this period of time.

It was a blissful experience working at PostNL. The internship opportunity I had with PostNL was an excellent opportunity for my career path to learn and evolve. So I find myself a very fortunate person as I got the opportunity to be part of it. I am always fortunate to have the opportunity to meet so many wonderful people and professionals who have driven me through this internship. I would also like to take this opportunity to express my gratitude and special thanks to Mrs. Iris Rem and Mrs. Blide Duk who, despite being extremely busy with their duties, took the time to listen, direct and keep me on the right track and encouraged me to carry out my graduation project at their valued organization. I would also like to thank them for their efforts to make the process simpler for all the corporate arrangements at PostNL.

I would like to express my deepest gratitude to Mr. Peter Bas Stoffer and Mr. Ahmed Forruk for their participation in useful decision-making and for providing the necessary advice and guidance. I choose this moment to remember their contribution with gratitude.

It is my duty to acknowledge my feelings and to record my best wishes and my sincere appreciation to Mr. Dennis Mes, Mr. Marc Wagemans, Mr. Elroy Tervelde, and Mr. Eildert Panman for their careful and precious guidance, which was extremely valuable for my research both theoretically and in action.

I would also like to thank my close friends and my family in particular, for their unwavering support and help in writing this thesis and in all of my studies till date.

Rishabh Chaturvedi

Delft, The Netherlands

August 17, 2020

Executive Summary

Commercial greenhouse gas emissions from aviation are proliferating, as is the concern among freight carriers to minimize their carbon footprint. From a corporate point of view, the United Nations International Civil Aviation Organization (ICAO) expects aircraft emissions to triple by 2050, with aviation accounting for 25% of the world's carbon budget (ICAO, 2017). While ICAO and the International Air Transport Association (IATA) release annual overview statistics on the aviation industry and its related business economy, relatively few research data on fuel consumption, fuel quality and carbon emissions are available at global and regional levels, respectively. Policymakers and top decision-makers at transportation and logistics companies such as PostNL cannot determine the exact amount of carbon emissions associated with departing flights and needs a more robust model to determine marginal emissions due to cargo freight. To solve this problem, the research predominantly aims to answer the following research question: ***"How can PostNL be facilitated in calculating aircraft specific carbon emission factors, which can be used for accounting purposes, to promote sustainable purchasing and green market positioning?".*** Using empirical data from public, private-owned confidential data sets, and the PianoX aircraft emissions modeling, this research outlines a consistent and globally dispersed methodology for estimating CO2 emissions for air freight.

An extensive review of the literature was carried out in the field of the emergence of "Sustainability Concept" and antecedent research in the Netherlands. This was followed by evaluating the current situation and the emergence of the supply chain processes. The study also describes and analyzes the operational process at PostNL and discusses the current methodology used at PostNL, i.e. DEFRA method for carbon emission calculation. Later, the flaws in the model were evaluated and addressed. Based on the review of the literature on antecedent research and the analysis of different carbon emissions calculation methodologies being used internationally in various institutions, a method was proposed for the calculation of Co2 emissions due to air freight. In order to measure commercial fuel consumption, many publicly available data sources were collected and incorporated with Piano X, an aircraft performance and design platform from Lissys Ltd. The data on the fuel-burning process and projected Co2 emissions were then compared and validated with the ICAO dataset and later implemented in the model proposed. This was followed by the creation of a conceptual simulation and optimization model build using VBA in Excel, which helps the company in making data-driven air transport procurement decisions taking into account tradeoffs between carbon emission, lead time, and cost to gain a strategic business advantage. Strategic goals were broken down into the priorities of the individual divisions at PostNL, expressed with the goal values of the lead time and the performance metrics for cargo costs. A graphical comparison was followed with the EU ETS datasets and the DEFRA datasets to compare and correlate the results obtained using the proposed methodology. The result also helps PostNL drive business sustainability in their partnerships while maintaining their flexibility and bargaining power with suppliers.

The limitations and errors with the research were acknowledged in the areas of uncertainty due to the use of publically available information and the absence of the inclusion of dynamically changing time-dependent variables, including privately owned airline data. It was also concluded that

logistics companies such as PostNL should always bear in mind that, often drastically, the logistics networks may shift. New ways of doing business, such as coopetition and better modeling, can help to increase effectiveness. Scenario planning and better business management approaches will have an advantage in improving the transportation and logistics industry to face the demands of the future and become ever more competitive and sustainable.

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List of Abbreviations.

AF: Aviation factor
API: Application Programming Interfaces
ATC: Air Traffic Control
BEBRU: Brussels, Belgium (Airport Location)
CAA: Civil Aviation Authority
CF: Component Freight
CSR: Corporate Social Responsibility
CW: Weighing factor for cabin class
DC: Distance flew (km) between the origin and destination airports.
DOW: Dry Operating Weight
EDC: European Distribution Centre
EF: Emission factor for jet fuel (kerosene) combustion
EF_{Region} : Emission factor [kg CO2 / t*km] per world region
EI_{CO2} : CO2 [kg / kg fuel] emissions index
ELUPEG: European Logistics Users Providers and Enablers group
EMS: Express Mail Service
ETADD: Addis Ababa, Ethiopia (Airport Location)
EU ETS: European Union Emissions Trading Scheme
$FB_{Flightblock}$: Total Fuel Burn of aircraft [kg fuel] to that region
GCD: Great Circle Distance
GUI: Graphical User Interface
IATA: International Air Transport Association
ICAO: International Civil Aviation Organization
IPS: International Postal System
LSMSU: Maseru, Lesotho (Airport Location)
LTO: Landing and Take-off Cycle
MEW: Manufacturers Empty Weight
Mf: the total freight amount carried per plane (t per passenger).
Mf: total freight amount carried per plane (t per passenger).
M_{fuel} : uplift fuel(kg)
Mp: average mass per passenger plus their luggage (t per passenger).
Mp: average passenger mass plus passenger baggage (t per passenger).
MZFW: Maximum Zero Fuel Weight
N_{maxa}: Passenger capacity (passenger number) of an aircraft.
NOx: Nitrogen Oxide
OEW: Operation Empty Weight
PAX: Passengers
PLF: The Passenger Load Factor
SET: Small Emitters tool
TOW: Take-off weight
UDF: User-Defined Functions
VBA: Visual Basic Applications
ZAJNB: Johannesburg, South Africa (Airport Location)
ZFW: Zero Fuel Weight

List of Definitions.

Scope 1 (direct) emissions are the ones from activities managed or regulated by the company.

Scope 2 (indirect energy) emissions are those released into the atmosphere, associated with the absorption of purchasing power, heat, steam, cooling, and other indirect background activity. Such indirect emissions are a result of an organization's energy needs but occur at sources that the organization does not own or regulate.

Scope 3 (other indirect) emissions originate from activities occurring at sources not controlled or regulated by an agency and not listed as Scope 2 emissions. Types of Scope 3 emissions include corporate travel by means not controlled or operated by an organization, waste management, goods, or an organization's purchases of gasoline. Scope 3 emissions can derive from or downstream of an organization's operations.

Receptacle: A receptacle is any location used to place outgoing mail or receive incoming mail by the postal service or by postal clients.

Depeche: The path of transport is derived from the consignment identified with the receptacle code. If the consignment is incomplete, the Depeche (Departure) path is extracted.

LEG 1: The shipment is collected and transferred to the nearest collection and distribution center. Following this process, the path of transport is derived from the consignment identified with the receptacle code.

LEG 2: It is the transportation process that involves direct and indirect routes connecting different package collection and distribution centers according to the unique identification number of the shipment.

LEG 3: The process which connects the end receiver of the shipment to the distribution center where the package has arrived closer to the destination.

Chapter 1. Scope of Research

1.1 Introduction.

Traditional Freight transport accounted for almost 22 percent of Greenhouse Gases (GHG) emissions in the year 2010 (World Health Organization (WHO), 2016). Specific effects of this climate change caused by greenhouse gases included extreme weather, smog, air pollution, food supply shortages, and intensified wildfires affecting millions of lifeforms. Following this event, the fight to climate change has risen on top to be the main agenda for transportation companies and governments all around the world.

The term "sustainable freight transportation" was first introduced by Jeon (2005) to analyze and measure the effectiveness of these traditional transportation systems, in conjunction with its environmental and climate impacts. Further, climate changes and relevant environmental issues have caught the attention of relevant stakeholders such as companies, research institutions, and governments, encouraging them to consolidate sustainability in their business and operational processes (Pieters et al., 2012). In 2013, the *Intergovernmental Panel on Climate Change* (IPCC) released a global climate report that measured the effects of human activity-related changes to the atmosphere between 1750 and 2011. The report targeted more contributing greenhouse gases such as carbon dioxide and tiny particles such as aerosols (Stocker et al., 2013). It was concluded that climate change is mainly an issue of too much atmospheric carbon dioxide (Co2). This carbon pollution is mostly caused by burning fossil fuels like coal, oil, and gas or chopping down trees. It was also seen among the entire transportation system that at present, air freight transport accounts for 2 percent of global carbon emissions, with maritime shipping accounting for 4 percent.

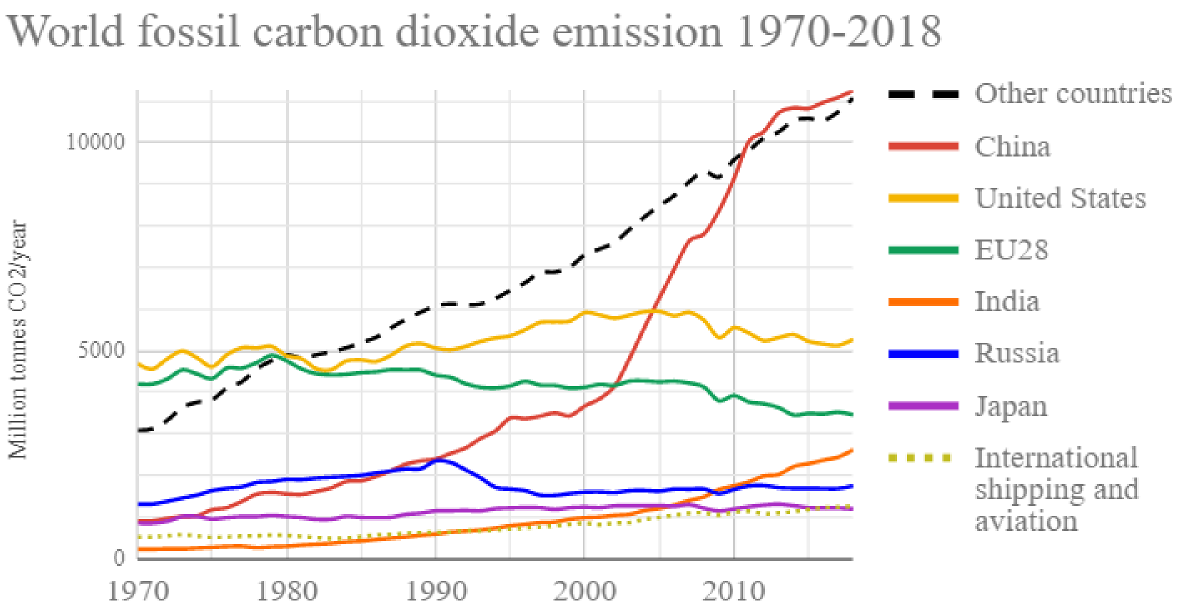

Fig 1. Global emissions of carbon dioxide from 1970 to 2018, including the top six producing nations and confederations (EDGAR, 2019).

According to the UN Intergovernmental Panel on Climate Change, air transport Co2 emissions are expected to increase by 3 percent by 2050. However, the actual impact of aircraft Co2 emissions is nearly three times higher than surface emissions because, at higher elevations, aircraft release carbon dioxide into the atmosphere where more damage is done according to *Time for Change* (Plumer, 2019). It was also fascinating to find out that there were many heat-trapping gasses, but Co2 placed itself at the highest risk of irreversible changes if it tends to settle in the atmosphere unabated (Stocker et al., 2013). Following this, the usage of innovative operational models and strategies by transportation companies, as well as the government to reduce the levels of Co2 emissions, was noticeable in major European countries. However, with the simultaneous increase in the land and air traffic levels and carbon emissions in major cities like Berlin, Amsterdam, and London, it was concluded that more emissions than less are expected by 2030 and later (UNFCC, 2018).

Surprisingly, it was observed that, in recent times, The Netherlands is becoming a European leader in making it is freight transportation processes more sustainable and minimizing carbon emissions. The Netherlands is a relatively small European country with a high population density, where around 16 million people live in 41543 km square area (Kaledinova et al., 2015). As predicted, the urban occupancy is going to be about 93 percent of the Dutch population by 2025 (Pieters et al., 2012). Freight transport is experiencing a considerable increase due to economic globalization and the need for smaller and more frequent shipments. Although the Netherlands has an eminent inland water transportation system, the country predominantly relies on air and land transport for more than 87 percent of the total freight transport. The Netherlands logistics market currently ranks fourth in the World Performance Index for logistics (Dr. Jim Yong Kim, 2018) and is known for incorporating the most efficient sustainable business practices in Europe. This showed that sustainability is considered to be one of the prime agendas of the logistics service providers in the Netherlands (Ploos van Amstel, 2012). However, The Netherlands government expects the sector to lead in Europe by 2020 and later by the development of more sustainable logistics and freight transport throughout Europe and all over the world. According to the Paris Climate Agreement, by 2050, the temperatures of the world should remain within a maximum of two degrees of increase. The Netherlands agreed to this deal, setting a target of reducing CO2 by 49 percent by 2030 and being fully CO2-neutral by 2050. Hence, sustainability is considered a vital driving force for all further recommendations and implementations of new-age technology and practices in the Netherlands (Logistiek, 2011).

1.2 Research Problem and Objective.

PostNL is a major public mail, parcel, and e-commerce corporation with operations in the Netherlands, Germany, Italy, Belgium, and the United Kingdom (PostNL, 2019). As a logistics company, PostNL is aware of the environmental impact that it has. As the organization provides its programs and services in nearly 180 countries around the globe, the most crucial goal is to develop creative solutions to help itself reduce the overall effect of carbon emissions on the environment. The company agreed to cut the Co2 emissions by 55% by 2020 relative to 2007 and by 78% by 2030 (PostNL, 2019). PostNL has also planned to incorporate internal carbon prices in their (strategic) investment decisions shortly in order to drive more cuts steps. Subsequently, the company aims to become a global sustainable player in the logistics and supply chain sector, with last-mile emission-free deliveries worldwide by 2030 (PostNL, 2019). It was also interesting to know that the company announced long-term goals in October 2018 to deliver emission-free by 2025 in 25 Dutch cities. PostNL has also managed to decrease Co2 emissions by 4 percent in 2018 compared to 2017. After 2017, the organization has lowered the cumulative pollution for scope 1 and scope 2 emissions by 61.4 percent (PostNL, 2019). The International Air Cargo Association has recognized the importance of environmental responsibility and is collaborating with industry and policymakers to tackle the problem with the goal of decreasing annual fuel consumption by 1.5 percent by 2020, aiming to reach carbon-neutral growth, with a net carbon emission of 50 percent by 2050. The question is that with the air cargo industry picking up and pollution becoming a topic of concern, more stringent regulations on air freight can be put in place that could boost industry growth (ICAO, 2017).

Where it is not possible to directly measure emissions, carbon calculations for air freight are used instead to provide an estimate. These carbon calculations are used for pollution monitoring by states, for corporate social responsibility commitments by businesses, and also by people who wish to reduce their own environmental impact. Government departments and environmental agencies, environmental organizations, international trade bodies, and carbon offset firms have built a host of different calculators ("Air emissions calculations," 2020). Sadly, as there are no two equivalent methodologies, which contributes to variance between estimates, the approach necessarily involves a degree of approximation and judgments to be made, as well as arbitrary assessments on carbon emission limits and the actors to which they should be assigned ("Air emissions calculations," 2020). The calculations often vary in complexity concerning the level of data input required and the variety of data sources from which they draw. The' right' calculations should be easy to use but rely on input data and sound processing of high quality. It should also be sufficiently robust to represent some improvement in a user's actions in an observable decrease in the measured carbon footprint. The research tests the usage of carbon calculations/methodologies for aviation emissions - an environment that is particularly sensitive to assumptions made - also and introduces a new approach for PostNL to measure the carbon emission by marginal cargo freight in different aircraft for its export routes. The research also involves the introduction of a data-driven simulation and optimization model for decision making, taking into account tradeoffs between carbon emission, lead time, and cost ratios to gain a strategic business advantage for PostNL. This new methodology would mark a step-change in complexity and precision for measuring emissions from specific aircraft using relevant emission factors and would have the characteristics to make it an international benchmark for use by freight logistics companies like PostNL and for their industry CSR studies.

1.3 Research Question.

This study aims to answer the following research question, as discussed in the research problem and objective section.

RQ:

"How can PostNL be facilitated in calculating aircraft specific carbon emission factors, which can be used for accounting purposes, to promote sustainable purchasing and green market positioning?"

To answer the research mentioned above, the following secondary research questions are formulated.

Sub questions:

1. ***Which variables are relevant in calculating an aircraft-specific carbon emission factor for airfreight transportation?***
2. ***How can PostNL be facilitated in making data-driven air transport procurement decisions taking into account tradeoffs between carbon emission, lead time, and cost to gain a strategic business advantage?***
3. ***How can PostNL drive business sustainability in their partnerships while maintaining their flexibility and bargaining power with suppliers?***

1.4 Research Design and Methodology

1.4.1 Research Design.

The research layout is developed using the methods of the Onion Study (Saunders et al., 2015). The approach to analysis is classified analogous to the layers of an onion, according to the onion technique. As such, to reach the following layers, the first and the outermost layers have to be stripped off. Namely, these layers (Saunders et al., 2015) are:

1. Research philosophy.
2. Approaches.
3. Strategies.
4. Choices.
5. Time Horizons.
6. Data Collection and analysis.

Research theory helps a researcher to shape a system of beliefs and conclusions about the creation of science, which is what science is all about (Saunders et al., 2015). The layer deals with establishing the positions of a researcher in order to plan an appropriate research project properly. Three main research premises are stated: ontology, epistemology, and axiology (Saunders et al., 2015), and one of them is chosen for this study after sufficient justification has been given. Ontology is characterized as the assumptions made about the nature of reality and thus forms the way science objects are perceived and studied (Saunders et al., 2015).

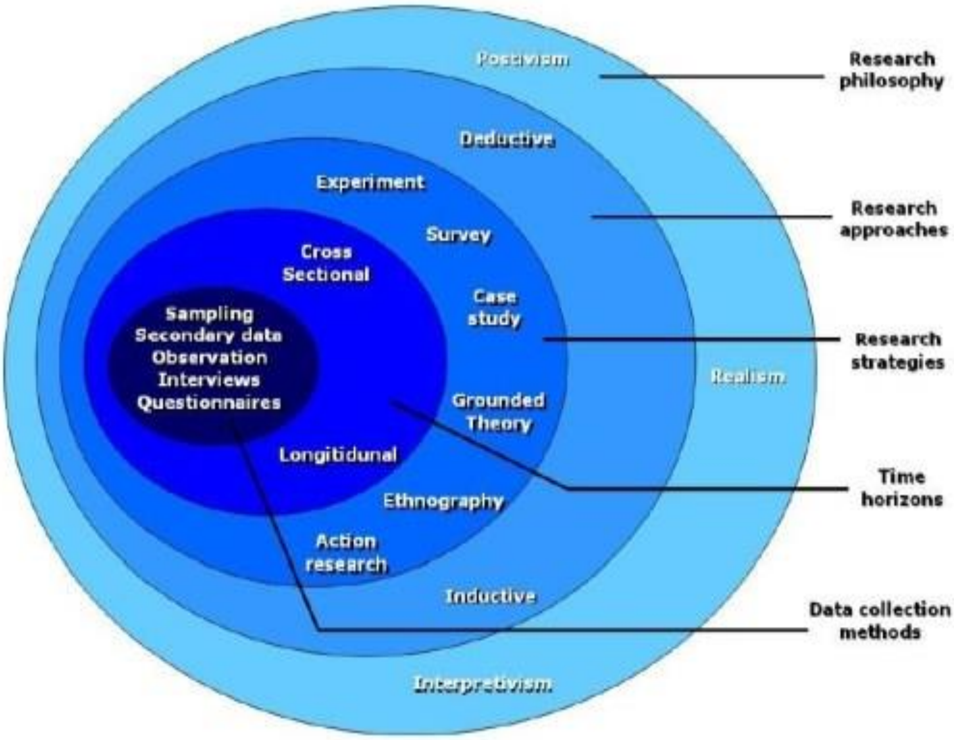

Fig 2. Saunder's Research Onion Approach (Saunders et al., 2015).

A researcher's ontology will thus determine how he or she views the world, and ultimately determine what to do with research. Two kinds of ontology prevail, namely, realism and relativism. Realism refers to the idea of one unchangeable truth in existence, and that truth can be measured by objective measurements, which can be generalized even further. On the contrary, relativism is the idea that truth depends on the context that changes based on the experiences of an individual, and is thus non-generalizable. On the other hand, epistemology is concerned with the assumption regarding knowledge and knowledge transfer from one individual to another (Burrell et al., 1979). The epistemological principles are useful in the sense of business and management where several types of data (for example, textual data, visual data, information, interpretation) are appropriate (De Cock & Land, 2006; Gabriel et al., 2013; Martí & Fernández, 2013; Saunders et al., 2015). Two epistemological principles prevail: first, knowledge should be uncovered by objective measures, and study should be carried out using the methodology of an outsider. This theory is called the ETIC approach and is based on the point of view of intuition in ontology so concluding ontology and epistemology are not equally synonymous, as the former determines the latter, i.e., the researcher's confidence in truth influences the researcher's interaction with his or her work (Killam, 2013). Likewise, scholars who believe in relativism interpretation of science are using the second approach (EMIC) of epistemology where their effect is either accepted, denied, or supported (Killam, 2013). The third approach, axiology, states the role of ethics and values within the process of research (Saunders et al., 2015). Since an individual's principles are a guiding force of his / her behavior, the values expressed by the researcher form the basis for his / her analysis or judgments (Heron, 1996). In reality, the researcher's principles are expressed in every research process, even the techniques for data collection (Saunders et al., 2015).

For this research, a realist ontological and ETIC epistemological approach is proposed. This is because, as established earlier, a quantitative approach will be adopted to answer the research question, which stated in the previous section. This approach is classified as an experimental study that involves gathering information through public and confidential company records with the participants of the research and exploring their experiences (Killam, 2013; Smith, 2006). Using the aforementioned experimental methodology, the information will be collected using the data collection methods (discussed later) to analyze the data and taking into account all the possible variables to derive the carbon emission factors per aircraft type per route and to calculate the marginal carbon emissions by specific cargo weight. This involves theory development followed by the hypothesis generation, which will lead to a result after going through a continuous process of experimental analysis.

Onion's second layer is devoted to the approaches to the development of theory. For structuring the study, three types of methods prevail inductive, deductive, and abductive reasoning (Saunders et al., 2015). If an inference is drawn from a coherent set of premises, and the conclusion is true when all premises are true, the approach is called deductive reasoning (Ketokivi & Mantere, 2010). On the opposite, there is a loophole in inductive reasoning between the observed assumptions and the inference backed by the finding (Ketokivi & Mantere, 2010). Unlike the first two in which the inference is extracted after the assumptions, an abductive argument starts with an observable' surprising fact' becoming the conclusion rather than a hypothesis (Saunders et al., 2015). This discovery forms the basis for the creation of plausible assumptions that are necessary to produce the inference mentioned above, thereby explaining why the hypothesis is valid (Saunders et al., 2015). Besides, when the study starts with the creation of a literature-based hypothesis, the deductive approach is accompanied by the implementation of a research methodology and methods to evaluate the said theory. Conversely, the inductive method is taken into account if the study starts by collecting data to investigate trends and anomalies in order to create a conceptual framework. Finally, if a researcher needs to explore a phenomenon, explain patterns and themes that are tested by additional data, the abductive approach is chosen.

For the proposed research, it is clear from the research question and the sub research questions that the study has to be experimentally tested, and a cause and effect relationship has to be established. This process would help in solving the problem statement. Therefore the deductive reasoning method is recommended based on the above definition of the approaches. Many explanations are provided for the decision. Firstly, quantitative experiments are synonymous with deductive reasoning, which is the essence of the work (Saunders et al., 2015; Sekaran & Bougie, 2016). Secondly, a cause and effect relationship can be deducted using experimental analysis in this research. This would help in using various variables in theory to prove the hypothesis correct and objectively generalizable.

The third layer discusses methodological options for the research design (quantitative, qualitative, or mixed methods). The conceptual analysis of this work will also describe the methodological choices, similar to the previous two layers mentioned earlier. The quantitative choice deals with a technique of data collection that will generate numerical data, such as questionnaires, graphs, and statistics (Saunders et al., 2015). On the other hand, for any data collection technique which generates non-numerical data, qualitative methodology is used (Saunders et al., 2015). Data analysis in the quantitative approach includes coding, keying, and analyzing (Sekaran & Bougie, 2016), and the study explores the relationship between variables (Saunders et al., 2015). The quantitative approach can either be a mono-method quantitative analysis, meaning a single data collection tool (e.g., questionnaire) is used, or a multi-method quantitative study, using more than one data collection method (e.g., questionnaire and systematic observation) (Saunders et al., 2015). The quantitative techniques viz. need to follow various structured procedures — data editing, data transformation, frequency calculation, standard deviations, and scattering, among other statistical information. Also, as previously established, quantitative research is associated with hypothesis testing, which is performed by removing errors, followed by the use of several hypothesis testing methods such as one-sample t-test, paired sample t-test among several others (Sekaran & Bougie, 2016). The data sets are often so large that software programs such as SPSS, VBA, R, MATLAB, or Mplus could be used, among others.

As regards qualitative analysis, there is a conventional three-step process prevailing. Such are data reduction, display of data, and conclusions (Sekaran & Bougie, 2016). Data reduction is a process where data is selected, coded, and categorized, while data display is how data is presented, such as a graph, matrix, pattern illustration, etc. (Sekaran & Bougie, 2016). Eventually, the data presented encourages conclusions drawn on the basis of the trends found in the data. The above three-step process, however, is not a static but a continuous and iterative process. The qualitative analysis is characterized by a naturalistic and immersive research process (Saunders et al., 2015). This means that the researcher is required to conduct his or her research in a natural setting to facilitate confidence-building and to gain access to the participants' in-depth understanding. In order to develop a report and gain cognitive access to their data, the researcher must also interact with the participants (Saunders et al., 2015). A qualitative study comes in two ways close to quantitative: mono-method, and multi-method. This study involves several document reviews and observations which have been given equal importance in the process. The quantitative approach seems much more suitable than qualitative for this analysis. Thus, for this research, the third layer of research onion is chosen as a quantitative multi-method choice.

Onion's fourth layer deals with research approach choices, which is expected to be a methodological relation between the existing theory and analysis methodology for collecting and analyzing data (Denzin & Lincoln, 2011). There is a range of research methods, including experiments, surveys, case studies, and grounded theory, but not limited to them (Saunders et al., 2015). All analysis methods are related to the above analytical options, theories, and approaches. Among these, experiments and surveys relate to quantitative research (Saunders et al., 2015), the case study is associated with an in-depth investigation of a case (for example, a person, a group, an organization or an association, etc.) (Yin, 2009).

This research, however, proposes experiments, model development, and analysis as the principal strategy for research. This technique was developed to examine, describe, and to explain variables and collected data that would promote the interpretation of real scenario interactions among datasets (Charmaz, 2006; Glaser & Strauss, 1967; Suddaby, 2006), which is also the objective of this study. Experimental Analysis offers a systematic approach for collecting and analyzing qualitative data, allowing data to be gathered, analyzed, and interpreted (Charmaz, 2006), which is once again useful for this work. Experimental Analysis would thus provide a valuable and evolving method for the conduct of quantitative research. Under this strategy, variables would be categorized and studied separately, depending on literature choices (Charmaz, 2006; J. Corbin et al., 2015; J. M. Corbin et al., 2008). The process is then accompanied by a continuous experimental cause and effect processes in which the collected data is analyzed to determine similarities and differences from the previous data, thereby ensuring simulation and optimization of data which would help PostNL make strategic business choices considering variables such as price, cost, lead time and carbon emissions. (Saunders et al., 2015). All of the above aspects of these experiments will result in the study is highly oriented, ultimately resulting in general hypotheses being formulated.

Onion's fifth layer deals with selecting a time horizon. The distinction must be taken in this layer between cross-sectional studies and quantitative studies (Saunders et al., 2015). The cross-sectional experiments include the analysis at a specific time period of a particular phenomenon. That type of time horizon is of interest to time-constrained studies, such as academic research (Saunders et al., 2015). The advantage of using a cross-sectional analysis is to allow multiple variable comparisons (IWT, 2015) potentially. On the other hand, longitudinal studies give the researcher a control measure for one or more factors (Saunders et al., 2015). Both time horizons are not mutually exclusive, and studies can be begun as a cross-sectional sample and then shifted to longitudinal to track the variables changing over a certain period of time. Because of its aforementioned benefits, the cross-sectional study is proposed for the purpose of this research, which is a master's thesis with a time-constraint of six months.

Onion's sixth and final layer deals with strategies and procedures for the processing and analysis of data. This is covered in the next research methods section.

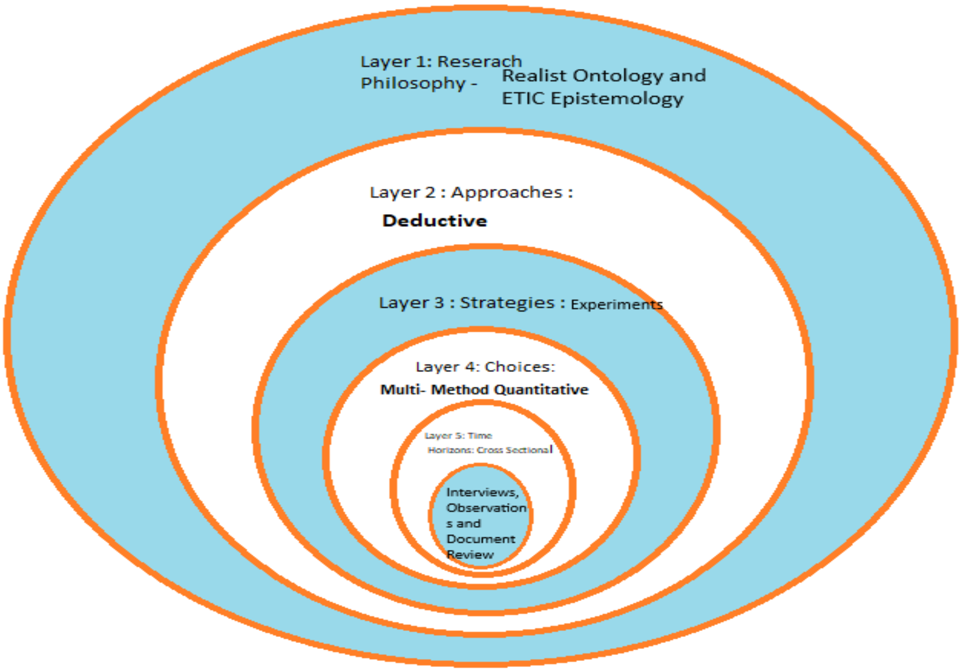

Fig 3. Proposed Methodology as per Sander's Onion Research Paradigm

1.4.2 Research Method.

This section discusses the method by which the data will be gathered and analyzed. There are several forms of data collection, including interviews, assessments, questionnaires, analyses, and unobtrusive approaches (Sekaran & Bougie, 2016). The choice of methods depends on multiple factors such as research questions, study objectives, facilities available, data type, and time horizons. The research to be done is primarily based on the usage of quantitative data. Quantitative data is anything about statistics and percentages, as opposed to qualitative data. Studies also focus on quantitative data to measure features, beliefs, habits, and other identified variables with a reason to either backup or contradict the theory of a particular phenomenon by contextualizing the data obtained by surveying or interviewing the research sample. As a researcher, I have the choice of either going for online data collection or using traditional methods of data collection by appropriate research.

Nonetheless, to extract conclusions from the quantitative data collected, numerical, methodological, and mathematical methods are required. The data collection methods used primarily focus on document/literature review, observations, and interviews. This has been described in detail below.

1) **Document/Literature review:** Data analysis is a data collection method that is used when reviewing current records. It is an efficient and effective method of collecting data and handling it in a way such that it is a practical tool for acquiring expert evidence from the past. In addition to improving and supporting research by offering a supplemental examination of the research data paper, it has emerged as one of the valuable approaches for gathering quantitative data from research. Some forms of the literature review are discussed below.

1.1 Public Records: Legal, current records of an agency are reviewed for further study under this review paper. For example, annual reports policy guides, student activities, academic gaming practices, etc.

1.2 Private Records: Like public documents, this form of document review deals with individual accounts of the actions of individuals, behavior, wellness, physique, etc.

2) **Observations:** Researchers gather quantitative data by systematic observations in this approach by using methods such as counting the number of individuals present at a particular time occurrence and at a particular venue or number of persons attending the event at a designated location.

   2.1 Organized observation: The observer may make close observations about one or more particular ctivities in a more detailed or organized environment as opposed to naturalistic or individual observation in this sort of observation process. In a formal experiment, the participants concentrate only on very specific behaviors of interest, instead of analyzing anything. It allows them to measure the actions they observed. If observations involve a decision from the observers – it's also represented as coding, involving a collection of explicitly defined target behaviors.

Quantitative data is not a question of convergent reasoning, but of divergent thought. It deals with factual evidence, measured reasoning, and rational attitude when relying on empirical and unchanging information. Data collection methods are more frequently used to gather quantitative research data, and the results depend on the larger sample sizes commonly represented by the population researcher intending to study.

3) **Interviews:** Since the intent, priorities, and well-defined research questions are already outlined, unstructured interviews for this study are not preferred. Similarly, as this research is a master thesis project with a six-month time-constraint in which the intent, priorities, and well-defined research questions are already outlined, semi-structured interviews are also not preferred either.

1.5 Research Framework

The research structure helps to create a connection between the research problem and the research objective. It's a schematic illustration of showing the study goal and the measures planned to accomplish it. This helps the reader understand the knowledge gap that needs to be addressed and critical areas where the knowledge required can be acquired to help meet the goal (Verschuren et al., 2010). Study recommendations are performed, as suggested by Verschuren et al. (2010), and goals are categorically accomplished and delineated in a graphic format, as shown in Figure 4.

Chapter 1 helps the reader understand how the design of the research is being carried out. As explained in previous sections about the indulgence of a quantitative approach, this chapter offers a brief overview of the study, data collection, and analytical approach involved in the methodology for the study. It also provides an overview of how the literature review was performed over the whole project.

Chapter 2 uses literature as a medium to clarify the theoretical context of the study. This chapter discusses the motivation of the researcher to find the gaps between studies and his motive in including and exempting particular literature from the overall review. This chapter helps us understand antecedent research that led to the emergence of the "Sustainability Concept" in the Netherlands and also discusses the current situation regarding sustainability in various logistics companies in the Netherlands and the EU, keeping in mind the actions of the governments and other stakeholders on them. The review also helped in evaluating the previous research done on the subject and discusses the current carbon calculation methodology used by PostNL using DEFRA calculations. It helps in identifying the gap in the study of knowledge leading to the research question and sub research questions.

Chapter 3 sets out an extension to the literature review and discusses different aircraft calculation methodologies currently used by major transportation companies or government organizations. This is followed by a comparison and sample calculations using different methodologies leading to the selection of a particular methodology for the model development and calculations.

Chapter 4 discusses the input datasets used in the research process. This chapter also focusses on the selection of the data and talks about data cleaning, categorization, and the overall preparation process of the input data for the model.

Chapter 5 bridges the gap between different methodologies and identifies variables to propose the new methodology to facilitate sustainability and better decision making at different departments at PostNL. The chapter also discusses the procurement decision-making simulation model and the optimization model to tradeoff between cost, lead time, and Co2.

Chapter 6 sets out specifics of the data analysis. This chapter deals primarily with the analysis of the data obtained through different data collection methods, which are already discussed. Different graphical interpretations are studied and explored. The steps involved in the study were clarified in greater detail. The chapter explains the different phases of the research, data cleaning, simulation and optimization model development, and resulting conclusions.

Chapter 7 is the summary of the recommendations with a possible research suggestion and also contains the concluding remarks to the research.

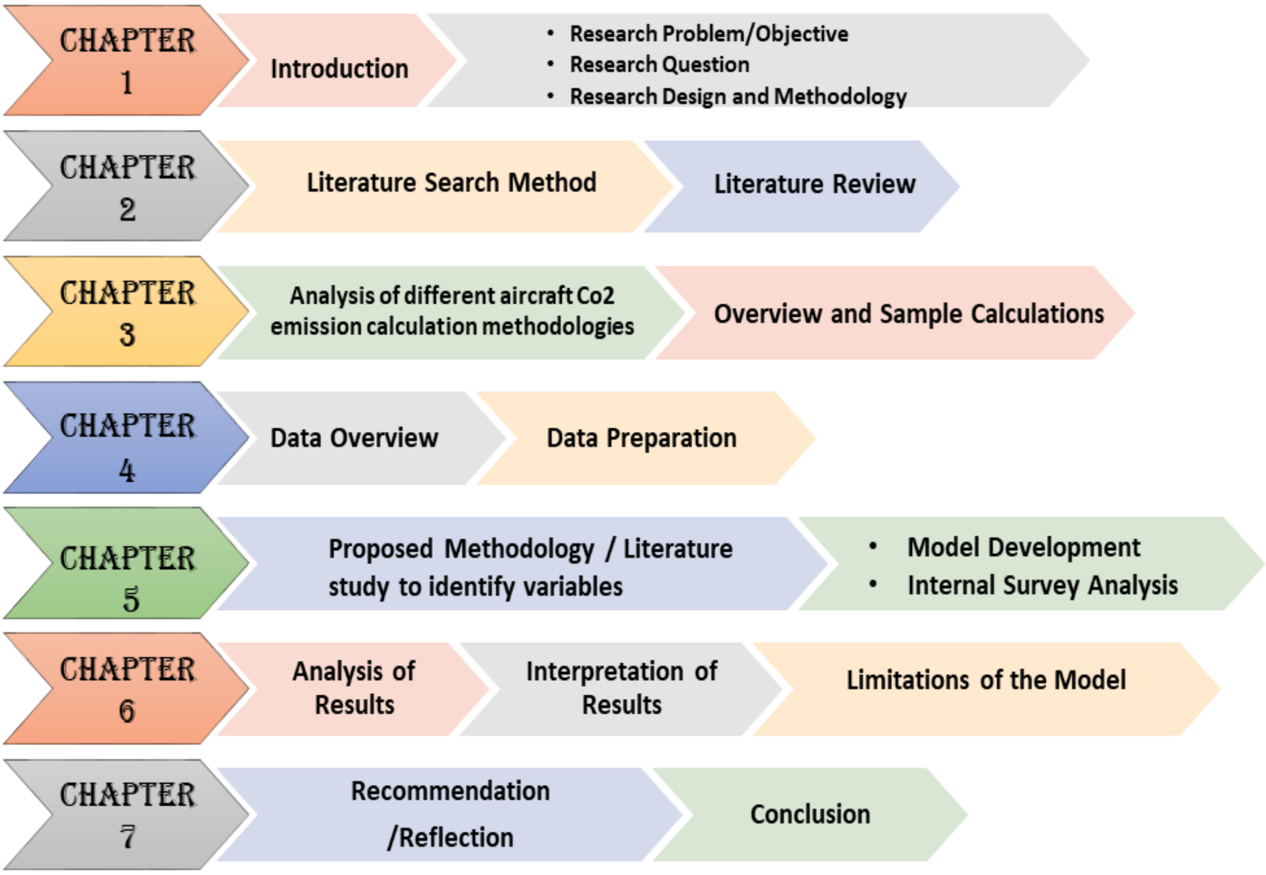

Fig 4. Research framework.

Chapter 2. Literature Review and Conceptual Framework

2.1 Literature Search.

The courses that I took in my bachelor studies, as well as in the first year of Masters in TU Delft, helped me in gaining in-depth knowledge about new sustainable and niche technologies and their transition to become more and more sustainable to survive in the current market. Following this, I started to correlate these transitions to environmental, economic, and societal changes. After grabbing a graduation project opportunity at PostNL, I was highly motivated to work on transport and logistics sustainability in the Netherlands, and this literature review helped me to focus on it. Soon, I identified several appropriate sources specifically to find the information and address the research question. Subsequently, I also succeeded in reviewing various online repositories and databases and restricted my scope to using recognized academic directories focused on the quality of publicly published articles and links to peer-reviewed journals covering social sciences, marketing, infrastructure, and associated transport economics studies. I decided to use numerous keyword searches through libraries such as Scopus, ScienceDirect, and Google Scholar (Scopus, 2019; ScienceDirect, 2019; Google Scholar, 2019) to identify the most relevant articles in these peer-reviewed publications to extract the scientific work presented in this literature review. I have also made sure that before reviewing them, I took note of the citation index and the impact factor of these papers to maintain the credibility of this literature review.

2.1.1 The Search Method

With an initial idea of how carbon emissions through air freight transport impact the environment and how carbon calculations are conducted throughout different organizations primarily focusing on PostNL, I was able to hypothesize and formulate my keywords, which were, respectively, "C02 emissions," "air freight transport," "Co2 emissions calculations," "sustainability," "PostNL" and "Netherlands." The keywords listed were put through a filter of' Article Title' and' Abstract' and were restricted to works that had been peer-reviewed. The independent keywords helped me understand the topic of the research, but they did not reveal findings related to the whole study's research question.

The keywords were used in the search to narrow the search to the' Title of the article' after integrating them with conditional expressions such as "AND and" "OR." It was found that from 1000 plus articles which were generated by using keywords in isolation, combinations such as' "Carbon emissions,'' Sustainability' and' freight transport' were reduced to 520 articles by' Title of the article,' Abstract, Keywords;' and further reduced to 52 articles by the 'title of the article.' Nevertheless, with more variations in the combinations of keywords such as:' greenhouse gas emissions' AND'air freight calculations' AND' sustainable development,' more than 150 articles were listed by' Title of the article, Introduction, Search terms' and limited by' Title of the article' alone to just 22 articles.

Through quickly going through the most relevant articles on the selection processes, it showed that extensive research on sustainable air freight transportation and carbon calculations in Europe was identified as a new research area based on the date of publication. It was also quite easily understood that companies and governments are continuously adopting new strategies and business processes to sustain in the market. Mendeley and Zotero were used to import the publications required for critical analysis and detailed citation as the main referencing program (Mendeley, 2019). As a beginner, I also managed to collect other guided keywords of vocabulary that were created systematically in the database, such as "sustainability development," "innovation," "carbon calculations," and "PostNL." Since the work is inherently causal and explorative, the publications that come across using vocabulary keywords have been used ranged across multiple key journals and have not been limited to a particular set of papers.

2.1.2 Research: Included and Exempted.

The use of keywords proved quite advantageous in understanding the study related terms, sub-fields, and the theory revolving around traditional as well as sustainable freight transport in the Netherlands. The interplay, causality, and exploration of different dimensions related to the research question was an essential next step in the literature search process. However, special attention was inclined to include overall theories related to the new age sustainable air freight transportation and its carbon calculation in the new commercial logistics sector. The study primarily focused on air freight transportation, as most of the relevant data were available publicly and through the confidential files and datasets of PostNL for this scope and also because air freight transportation is regarded as one of the most significant contributors to the carbon emission problem in the world. The literature review also gave special attention to the study of case studies and surveys. Also, It was found that there was a broad harmony of the obligation to control or reduce the amounts of CO_2 produced shortly in PostNL and other relevant stakeholders, and every relevant article was considered as a part of my study. The keywords used were restricted to 'Article title,' which helped me to relate the literature source to the directions to answer the research question in a fitting manner.

Keywords restricted to 'Abstract' and some qualitative studies such as summaries, and interviews were excluded from the literature review study. The study also excluded distinct technical dimensions that varied depending on the weather conditions and other situations. These variables were assumed to be non-effective on an average period and excluded from the scope of the research in defining the number of carbon emissions emitted by specific aircraft per tonne per kilometer. The region of the study was primarily focused on the Netherlands (in the EU) and the export routes of the air freight transportation of PostNL to approximately 180 different locations throughout the world, and a causal and explorative research study was conducted across this field.

2.2 Critical Literature Review

2.2.1 The Emergence of "Sustainability Concept" and Antecedent Research

Going back to the roots, it can be easily seen that in the Netherlands, attention to sustainable urban freight transport and a fight towards curbing carbon emission has a long tradition. In the year 1990, a total of 163 million tons of Co2 were emitted nationwide (Olivier et al., 2019). The energy sector accounted for the most Co2 emissions in absolute numbers, 48 billion kilograms followed by 35 billion kilograms from the industrial sector, and 30 billion kilograms from logistics transport ("Netherlands Co2 emissions", 2018). This created a situation of panic among the Dutch government, related stakeholders, and other organizations that led to the first experiments to sustainability in the early 1990s. These experiments contributed to a five-year trial period in several cities in the Netherlands (Duin, 1997) and culminated in a shift in policy and business process management towards making freight transportation more sustainable. Soon, the emergence of the industrial logistics network in 1995 resulted in a change to control and promote progressive urban freight policies to curb emissions.

To improve the already existing regulations and take into account the views of different stakeholders involved in the businesses, led to the development of three process management models, which were to be implemented in the three major cities of the Netherlands in accordance with the stated interactions between the municipalities and the actors. The models are discussed briefly as follows:

- **The Amsterdam Model** (1995) – All relevant actors decided unanimously to take the best measures, and the municipality eventually agreed on the legislation and standards. Exemptions were also made for particular situations (Van Duin, 1997).
- **The Groningen Model** (1996) –All relevant actors decided unanimously on the measures to be taken, and the innovation was facilitated by regional coverage of private cities (Van Duin, 1997).
- **The Hague Model** (1995) – The rules were collectively decided upon by all the actors. The municipality acted as a facilitator, and the actors shared fewer rules, regulations, and responsibilities for implementation (Van Duin, 1997).

Even after all these efforts, the number of emissions started to increase rather than decline by the year 2000. This led governments, academicians, and organizations to consider thinking about more rigorous approaches to curb the problem. Soon after this, a survey (PSD, 2002) conducted in 2002 extrapolated Van Duin's study by showing a growing political interest in making freight transport sustainable among 278 municipalities in the Netherlands with the involvement of more than 15,000 inhabitants, which was roughly about 20 percent of municipalities. This survey also helped in growing awareness among the residents about the popularity of sustainable strategies and newer business processes approaches among major logistics companies such as PostNL that could curb emissions.

2.2.2 Current Situation

Recently, for the past couple of years, climate change has again been an important topic of debate. As emissions of greenhouse gas (GHG) increases global warming, it is necessary to reduce carbon emissions. To make this happen, governments and organizations have started adopting newer rules and regulations. The Netherlands signed the UN Climate Agreement in 2015, with the core goal of "strengthening the international response to the threat of climate change by holding this century's global temperature increase well below 2 degrees Celsius and promoting measures to minimize further the temperature rise to 1.5 degrees Celsius" (UNFCCC, 2018).

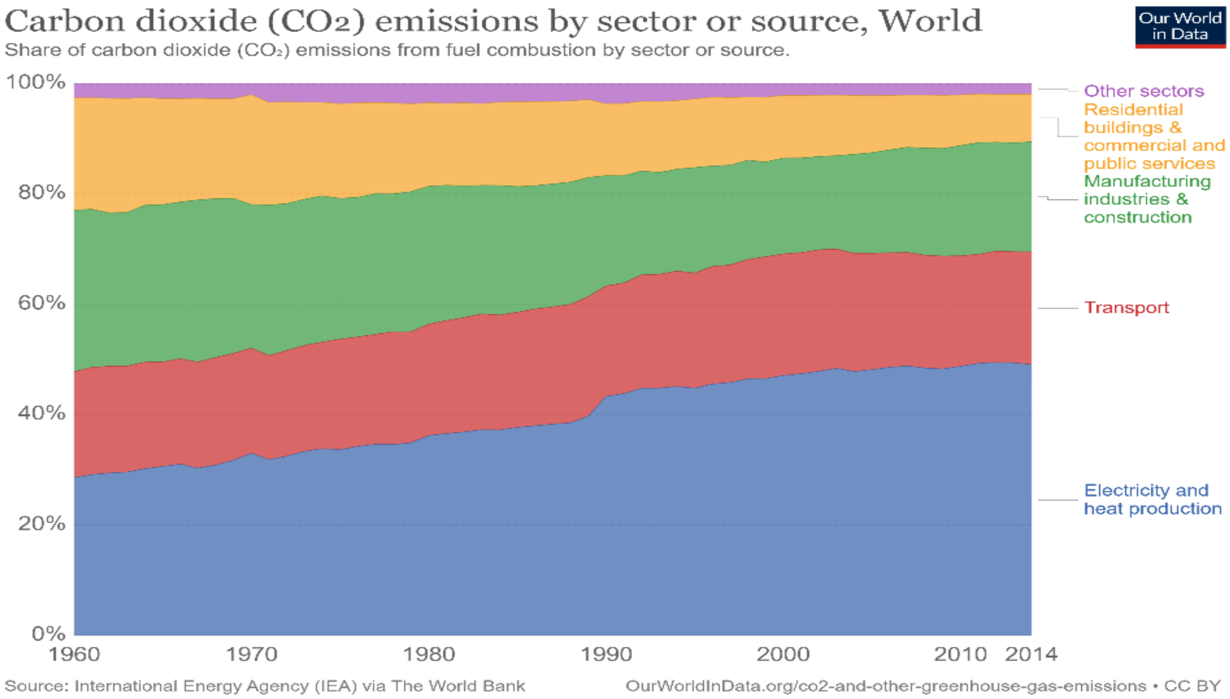

Fig 5. CO2 emissions by sector or source (Ritchie & Roser, 2017).

Also, It is worth noticing that the Dutch logistics sector is an integral part of the country's economy, adding 40 billion euros, i.e., 8.5 percent to the country's GDP and approximated 10 percent of jobs in 2016 (van Buren et al., 2016). It was also transparent from the report by *Van de Meulen* and *Kindt* (Pieters et al., 2012) that 21 percent of carbon emissions within the Netherlands was due to transportation, air transport, i.e., private and freight, was responsible for a majority of the emissions at 14 percent, followed by inland shipping, railways and land transport at 5 percent, 0.3 percent, 1.8 percent, and 7 percent respectively. Freight transports comprised 36 percent of the carbon emissions within air logistics transport and a considerable 6 percent of carbon emissions in the Netherlands (Kaledinova et al., 2015). However, it was surprising to know that last year, in the Netherlands, Co2 emissions were at the same level as in 1990, according to Statistics Netherlands (Ministerie van Economische Zaken, 2019). Although other greenhouse gas emissions-methane, nitrous oxide, and other fatal gases were halved in that period. In 2017, gross emissions of greenhouse gases were 13 percent lower than in 1990 ("Netherlands CO2 emissions", 2018).

With the ever-increasing demand for a cleaner and environment-friendly air freight transport by the European Union (Commission, 2018), it is believed that sustainability has to be an essential part of the current supply chain. Also, the statistics explain that the air freight transport sector is critical in contributing to national carbon emissions. Hence, it is clear that the need to monitor or reduce the emission rate of CO2 produced by air freight transportation shortly is vital for the overall development of the country and its fight to become sustainable. The Dutch government expects to lower carbon emissions from the Netherlands by 49 percent by 2030 in comparison to the 1990 levels; however, it was also observed that most of the significant logistics companies such as PostNL still had an emerging political focus on sustainable air freight transportation during this time frame (Ministerie van Economische Zaken, 2019).

2.3 The Emergence of New Supply Chain Processes

An influential study in the field of sustainable air freight transportation was conducted by Broks (2005) to explain how the modern supply chains are influenced by three key features of the current market environment, namely inflation, more competitive and innovative goods, and shorter product life cycles, and empowered consumers. The study helped in understanding how globalization ultimately leads to more extensive, diverse transportation supply chains as the primary link. It was found out that the specialization of production on the international market has allowed the growth of globally interconnected supply chains that involve air freight movements around the world several times in different production phases. Adding to this, some years later, Berman (2010) explained how with the broader range and size of transporting freight on the global market, present-day transport has fundamentally become a central link between local, territorial, domestic, and international sources and destinations. In identifying and bargaining with supply chain, suppliers, and transport service providers, reliability requirements are now part of the regular price and quality assurance considerations (Halldorsson et al., 2010). Top logistics companies such as PostNL make purchasing decisions focused on the need for a cleaner environment, as well as imposing controls on their dealers and transport service providers.

Davies (2008) points out significant performance indicators that are important in the same way in order to support sustainable air transport approaches. In particular, this seems to be the case given that the existing commonly used transportation performance indicators, consistency indicators, and time indicators such as process time and lead time do not competently address the reliability and sustainability dimensions of air freight transportation (Davies, 2008).

Since many freight companies such as PostNL are subcontracting their equipment or partnering with many suppliers to deliver goods, contract requirements are now in place that allows or enables these external parties to use green practices. For consideration, when outsourcing is a major part of the operating profile of DHL, DHL has started discussions with its general contractors to boost profitability and maintain emission control whenever necessary (Denning et al., 2010). It was useful to know that Denning's (2010) study was conducted following the performance indicators explained by Davies (2008). Alternatively, this has created a situation of urgency among other logistics companies to become greener in order to have a strategically competitive edge in the current market.

Organizations are also beginning to develop comprehensive indicators that track their supply chain improvement programs, including pollution and cost impacts. A 2010 AMR report by Biederman (2010) surveyed 158 transportation and supply chain administrators and observed that its most crucial sustainable transport strategies were: fuel elimination (46 percent); route management and distribution capacity (44 percent); continuing travel and freight co-mingling (37 percent); use of alternative fuels (34 percent); and reduction of empty miles (32 percent). The impact of these parameters on the carbon emission levels and how the companies are incorporating technical and non-technical advancements is essential in understanding the current state of the logistics sector. However, on the customer-delivery side, customer service systems are an area of organizational action. Customer assistance programs offer consumers an allowance on full shipments and truck-load orders to promote sustainable practices. To explain this, Lapide (2010) advocated how in contrast, customers are paid an additional fee by many emerging logistics companies for swift and emergency orders requiring the use of relatively emissions-efficient modes of transport and for goods requiring marginally less shipping than full containers or full truck loads. This is achieved by the usage of more and more air freight transportation modes, which leads to an increase in the carbon emissions levels in the atmosphere.

In a study conducted across more than 15 companies across the Netherlands around the same time as Kusumal's study, Biederman (2008) found out how logistics companies used a wide range of operating approaches to limit the adverse impact of air freight transport on the environment. He also explained how the efforts were driven primarily by an increasing awareness that lowering carbon emissions from freight can also drive quality and productivity. Undertakings commonly seen to improve carbon production and fuel efficiency are introducing more power-efficient technology, turning to renewable sources of energy, and improving the efficiency of transport operations.

More often, air transportation carriers also follow appropriate routing strategies to improve operational efficiencies and reducing carbon emissions. Sowinski (2007) studied and contributed to efficient routing strategies used in many logistics organizations. The goal is to schedule routing through a series of steps based on the best possible path and to ensure drivers spend as minimum time as necessary on each stop (Sowinski, 2007). This reduced travel duration contributed to lowering vehicle emissions. Following this study, Stoffel (2009) advocated and conducted a more practical oriented research on how a multi-year UPS program called 'Delivery Flow' entails process improvements such as reducing routes, reducing idle periods, combining several shipments into one unit, and planning packages in the exact order they are delivered. The program has already diverted a hundred million miles from UPS shipping routes since 2003, cutting fuel consumption by 10 million gallons and more than a hundred thousand metric tons of carbon dioxide.

2.3.1 DEFRA Emission Factors – Use in Carbon Calculations for the UK Department of Energy, Food and Rural Affairs (DEFRA).

In 2002, the UK Government started documenting greenhouse gas emissions associated with an organization's operations ("Government emission conversion," 2020). In this approach, the organizations had to convert air freight activity data such as distance traveled, liters of used fuel, or tons of carbon emissions disposed of. Such conversion factors became known as DEFRA factors, which included the principles to be used for those transformations and with step-by-step instructions on how to use the factors ("Government emission conversion," 2020). The UK Government produces a new set of conversion factors each year, along with a methodology paper explaining how the conversion factors are derived. These emission factors are intended to represent the average emissions per passenger kilometer from the three different service aircraft types. Actual emissions can differ significantly by aircraft type in service, load, cabin level, flight route-specific conditions, etc. The emission factors refer only to the direct emissions of carbon dioxide (Co2), methane (CH4), and nitrous oxide (N2O) from aviation. Currently, there is ambiguity about the other non-Co2 climate change impacts of aviation (including water vapor, contrails, NOx, etc.) that can be compensated for indicatively by adding a multiplier. The specific factor to be added is subject to uncertainty but was calculated in 1999 by the IPCC to be in the range 2-4, with the existing best research evidence suggesting a factor of 1.9. PostNL soon adopted this methodology in its carbon calculations.

2.3.2 Carbon Emission Control At PostNL.

Within the total Co2 emission of PostNL, the transportation phase (leg 2) of the volumes posted by the Cross Border Solutions(CBS) department is considered a significant contributor. The PostNL Group has an obligation of annual reporting of Co2 emissions. In 2010, PostNL began reporting with mostly manual effort to calculate the emissions. Their first goal was to reduce the amount of manual labor by automating this study and, second, to have a better insight into the impact of the scope 3 emissions on overall Co2 emissions. The Executive Board formally agreed in 2019 on a science-based target, which included both scope (1 + 2) and scope 3 emissions (PostNL, 2019). This ensured the business units to track and reduce Co2 emissions and inspect the resultant figures. Route Management and International Road Transport (RMRT) department are responsible for international transport architecture, planning, and implementation. The department is expected to store the Co2 emissions of the direct and indirect transport volumes of CBS in order to contribute to the total PostNL target of Co2 elimination (PostNL, 2019). As a business unit, CBS is responsible for its Co2 emissions, which it has entrusted with reducing the volume emitted by RMRT. Consequently, in addition to an inventory of the current Co2 emissions, the departments also play a role in various Co2 initiatives aimed at achieving the Co2 reduction targets set. This Co2 model is used for analysis, mostly by using more direct flights to determine potential Co2 reductions in air routes.

2.3.2.1 Operational Process Of The Transportation Phase.

After the delivery of a postal object (letter, package, EMS, empty bag) to (or in some situations is itself) a receptacle, this receptacle is allocated to a transport consignment and dispatch for distribution and financial purposes. Later, the consignment may be shipped via an aircraft, truck, or by a ship/boat, depending on the type of transport. Sections within the transport process (LEG 2) are used to differentiate between direct transport and indirect transport(PostNL, 2019). Primary transport has only one segment, while indirect transport is divided into multiple segments where the form of transport can differ.

Definitions of transport setups are:

- **Direct Flight:** containers are delivered to the airport of origin, and from there, the flight goes directly to the destination country airport. There is only one segment in this situation;
- **Indirect Flight:** consignments are delivered to the airport first, and the road is split into two or more parts from there. The route may include two planes, but it may include a truck, vehicle, and airport system as well. In this group, the consignment will pass through multiple countries before entering its final exchange office of the destination.
- **Indirect truck and flight:** The shipments are first transported abroad to a trade office. From there, the freight is delivered directly or indirectly to the exchange office for the final destination.
- **Direct truck:** consignments are shipped directly to the final country of destination;
- **Boat:** consignments are first transported to the Rotterdam Harbor; from there, the shipment is transported to the final country of destination.

The path of transport is derived from the consignment identified with the receptacle code. If the consignment is incomplete, the Depeche path is extracted. Following this event, Direct transport has been described as all transport routes which have only one segment (see Types 1a, 3 & 4 in Figure 6, for example). This form of transport may be a direct flight, bus, or cruise. In general, the time period selection is based on the "close consignment" date (PostNL, 2019). This is a timestamp showing the moment the consignment is about (98 percent) fit for shipping. In some cases, the "actual close consignment" date is absent with the consignment, in which case the specification of the time period is based on the "actual close dispatch" date.

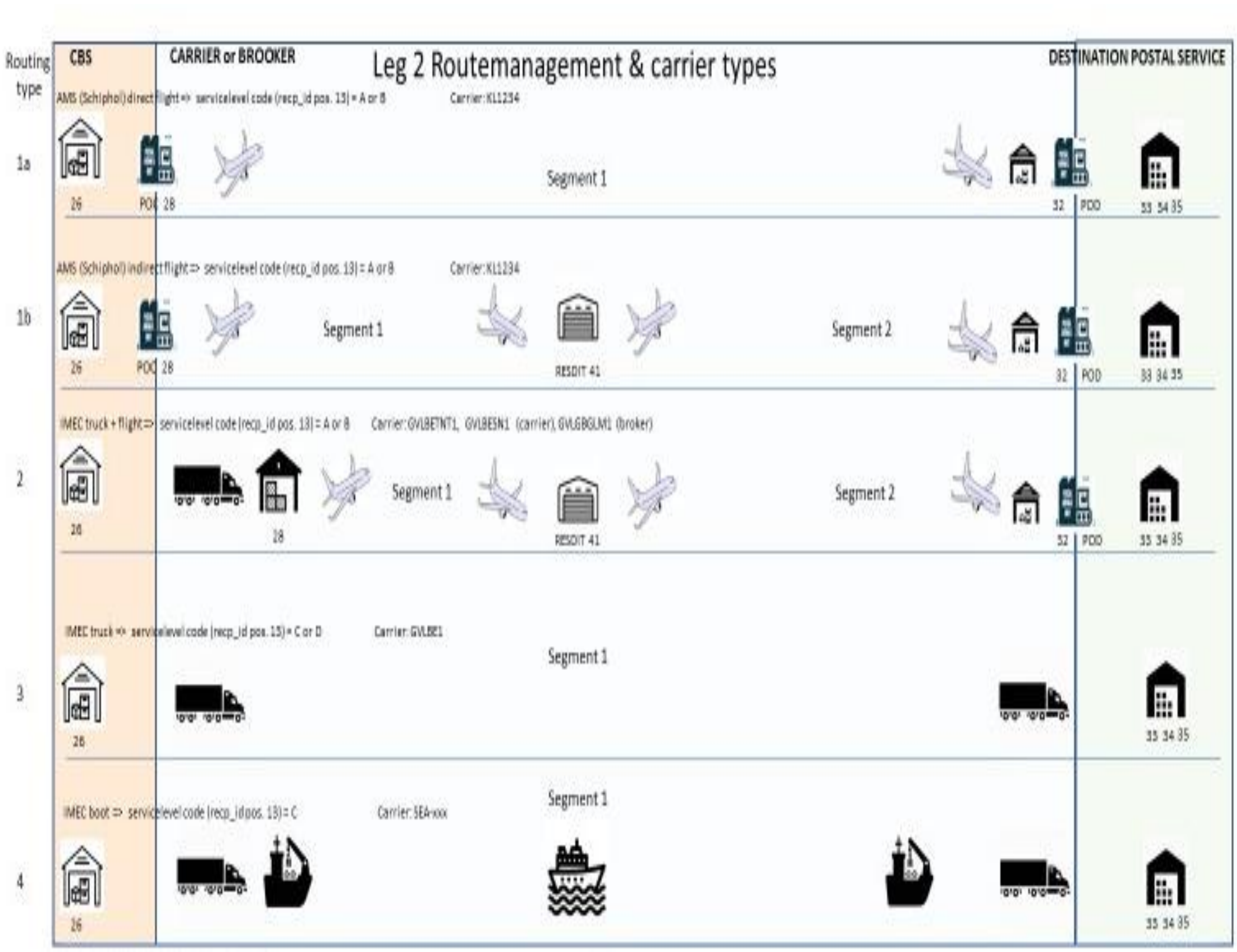

Fig 6. Types of transportation (as described by Route management in 2018).

2.3.2.2 Methodological Framework of the Current Carbon Calculations at PostNL .

a) Great Circle Distance Method for Transportation Via Plane

The distance in Euclidean space between two points is the length of a straight line, which separates them, but there are no straight lines on the sphere. Geodesics replaces straight lines in spaces to curvature (Kifana & Abdurohman, 2012). Geodesics on the sphere are circles on the sphere whose poles correspond to the middle of the sphere, and they are called large circles. The Earth is nearly spherical, so measurements of great circle distance give the appropriate distance between points on the surface of the Earth within approximately 0.5%. (PostNL, 2019). The correction factor should include distance flew emissions above the GCD, piling, traffic, and weather-driven corrections. According to EIG, the actual distance flew in Europe as opposed to GCD in the scheduled flight schedule is up to 11 percent different (*ICAO*, 2017).

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GCD	Correction to GCD
Less than 550 Km	+50 Km
Between 550 Km and 5500Km	+100 Km
Above 5500 Km	+125 Km

Table 1. GCD correction factor used(*ICAO,* 2017)

The basis for the great circle distance is the receptacle identifier's first 11 locations. The path is extracted from receptacle marker positions 1-5, which are used as a guide to accessing the route's starting location (identifying the country of origin and airport) (PostNL, 2019). Positions 7-11 identify the exchange office at the destination. Both are used as a key to obtain the related airport's latitude and longitude information. In the method that measures the great circle size, these coordinates are used.

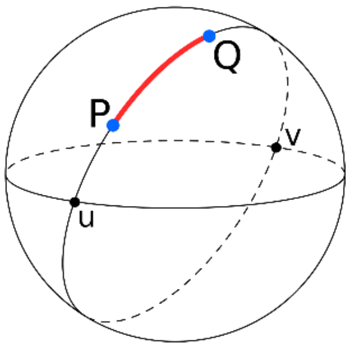

Fig 7. Pictorial Representation Of The Great Circle Distance (PostNL,2019).

1. Current Methodology

Following this, The PostNL Group provided a benchmark for carbon emission monitoring using the DEFRA carbon emissions criteria identified by the UK Department of Energy, Food and Rural Affairs (DEFRA). This agency publishes its conversion factors criteria periodically to convert data based on events into greenhouse gas emissions. Group Accounting focuses on these findings quarterly on the causes of the previous year's change (PostNL, 2019). In order to report on CBS's greenhouse gas emissions in the transportation phase (LEG 2 data on traveled distance per route and kg tones transported need to be converted into carbon emissions). Based on the provided information, this can be done in several ways. The Defra factors differ as per the range and flight type, which is mentioned below:

DEFRA emission calculated for freight

Flight Type	Route Distance	DEFRA Factor per tonkm
Domestic flight	<500 Km	2.70488 kg Co2
Medium-haul flight	500-1600 Km	1.05849 kg Co2
Longhaul	>1600 Km	0.770081 kg Co2

Table 2. Representation of Defra Emission Factors ("*Government emission conversion,*" 2020).

The following methodology helps in the calculation of carbon emissions for distinct air freight transportation to multiple export routes from the Netherlands:

Total carbon emission per route = *Distance flown directly between two airports (km) x total weight of receptacles transported on this route (kg) x appropriate DEFRA factor based on the flown distance* (PostNL, 2019).

Example:
A freight is flown from Chicago (US) to Frankfurt (DE). Based on a great circle calculation, the distance between both airports in a straight line is 6927 km. In total, 229,9 kg of receptacles were transported. 6927 km x 229,9 kilogram(= 1.593 ton-km) x 0,770081 (DEFRA factor for long haul freight) = 1.226 kgCO2 emission.

2.3.3 Problems with the DEFRA model for Co2 emission calculations.

PostNL uses an average DEFRA factor that ranges over different aircraft types and along the designated route of freight movement, which makes the carbon calculation assumption less accurate than anticipated. These emission factors are intended to represent the typical emissions per passenger kilometer from the three service aircraft types, namely domestic, medium-haul, and long haul flights. Real emissions can differ significantly by aircraft type in service, load, cabin level, flight route-specific conditions, etc. Also, the DEFRA doesn't include emission factors for commercial flights carrying additional cargo freight, which is one of the essential operations activities within PostNL. The following research methodologies aim at providing aircraft specific carbon emission factors to end up in the calculation of carbon emissions, which are close to the exact value and can be used for PostNL for future reporting and accounting purposes. This would help PostNL make more optimal transport decisions across variables, particularly on the long trail of destinations. This would also help the company to make data-driven tactical tradeoffs between variables such as CO2, costs, and lead time supporting decision making.

Chapter 3. Identification of Different Emission Calculation Methodologies

3.1 Analysis of different Aircraft Co2 emissions calculation Methodologies.

1. ICAO Carbon Emissions Calculator.

The ICAO methodology uses the data currently available on a variety of aircraft to quantify aviation emissions per passenger using a distance-based approach. To implement this strategy, ICAO has developed formulas for fuel consumption and is committed to continually tracking and identifying improvements in the data used to accurately calculate emissions. To provide a minimum amount of user input to provide flight information at any time, this methodology has been developed (ICAO, 2017). This uses market estimates for the various variables that leads to the individual passenger's calculation of air travel-related pollution. Since passenger aircraft emissions are determined by continuously changing variables specific to each flight, consideration is given to the effect of these flight parameters as average factors. Although these factors can not be captured on a flight-specific basis, this approach considers them in order to establish a more reliable flight emission estimate and to inform the public and industry on how these factors influence the emission rate of an individual passenger. The following approach for the ICAO Carbon Emission Calculator describes the use of various variables in consideration.

Methodology.

The ICAO Carbon Emission Calculator allows the user to identify an aircraft directly from the origin and destination airports. Afterwards, each aircraft is converted into one of the 312 comparable aircraft types to measure the fuel consumption for the trip. The amount of Co2 footprint assigned to each passenger flying between these two airports is multiplied by 3.16, which is a constant representing the number of tonnes of CO_2 produced by burning a tonne of aviation fuel. (ICAO,2017). The average fuel consumption for the journey is weighted by the departure frequency of each type of aircraft that corresponds. This is then divided by the total number of passengers classified in the economic equivalent. The estimation of flight emissions is explained in the subsections below, step by step (ICAO, 2017).

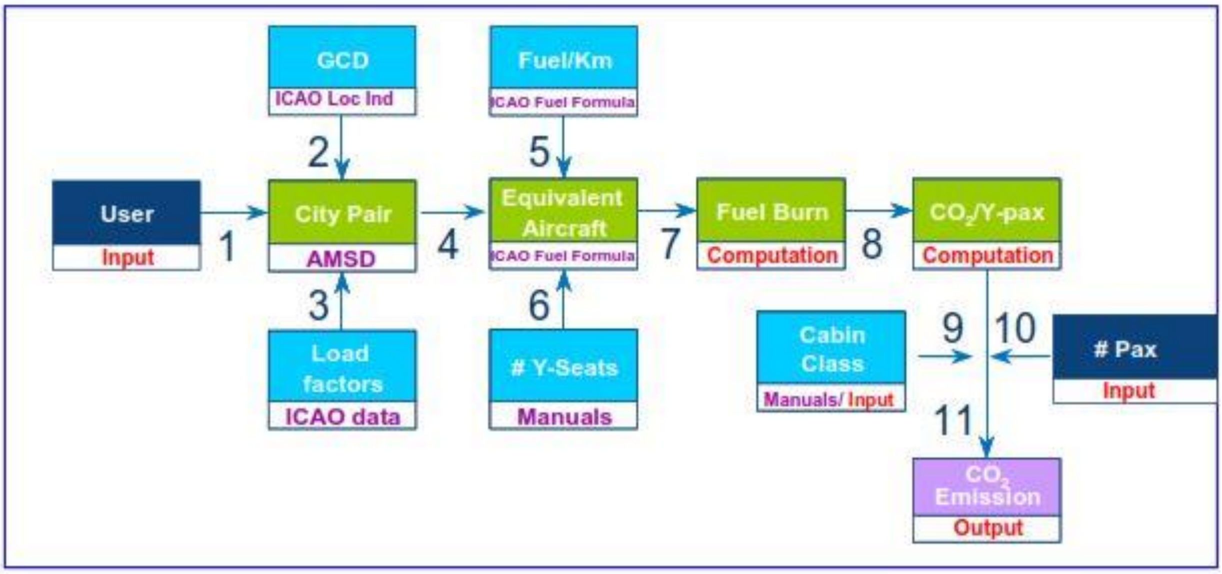

Fig 8. ICAO Emission Calculation Methodology (ICAO, 2017)

Step 1 (User Input): The user enters both origin and destination airports. The report consists of all retrieved direct or non-direct flights serving the pair of cities. The calculator does not calculate accumulated emissions for journeys with a different number of flights. Flights that share code are considered as one flight (ICAO, 2017). It prevents a possible duplication of flight departure counts that would otherwise affect the calculation. The origin and destination database contains single routings with multiple stops, for single flight numbers (ICAO, 2017). Therefore the passenger does not need to know, nor do they need to enter the entire flight itinerary.

Step 2 (Trip Distance): The set of ICAO position indicators contains the longitude and latitudes coordinates for the airport. The Great Circle Distance (GCD) is then estimated from these coordinates (ICAO, 2017).

Step 3 (Traffic Data): The user-defined city-pair is assigned a passenger load factor, based on the respective route groups. Based on 53 international route groups plus 11 domestic and 11 intra-area areas, load factor data are obtained from the database (ICAO, 2017).

Step 4 (Aircraft mapping): The scheduled aircraft is described from the scheduled flight database and connected to the database of aircraft fuel consumption dependent upon ICAO Fuel Consumption Formula. Unless the scheduled aircraft is in the database, the aircraft is converted into one of the 312 related types of aircraft found in the aircraft fuel consumption database (ICAO, 2017).

Step 5 (Fuel Burn Data): The fuel-burning relation to flight distance is extrapolated from the ICAO Fuel Consumption Theory. Variables are known as passenger load factor, flight duration, block time, the proportion of total payload given by passenger traffic, cabin flew class, and type of comparable aircraft flew (ICAO, 2017). The amount of fuel used on a route is the weighted average of the total fuel consumed, based on the aircraft type frequencies being flown.

Step 6 (Economy Class (Y) Seat Capacity): The maximum number of Y-seats that can be installed per equivalent aircraft is determined from cabin floor plans. This "virtual" all-economy configuration allows calculation of cabin class factor (ICAO, 2017).

Step 7 and 8 (Co2 per economy passenger): The methodology calculates the Co2 associated with each passenger using the trip frequency, equivalent aircraft fuel consumption, passenger to seat load factor and passenger to freight load factor for the route category and the number of Y-seats, as follows:

Co2 per pax = 3.16 * (total fuel * pax-to-freight factor) / (number of y-seats * pax load factor)

Where,
Total fuel = Weighted average of fuel used by all flights leaving the source airport to get to the destination airport. The weighting factor for each comparable type is the number of departures ratio to the total number of departures.
Pax-to-freight factor = The ratio is based on the number of passengers and the cargo of mail and freight transported in a community of routes (ICAO, 2017).
Y-seat number = the total number of economic equivalent seats available on all flights serving the city pair.
Pax load factor = Depending on the number of passengers transported and the number of seats available in the route segment concerned, the ratio determined from the ICAO statistical report.
3.16 = constant representing the number of tonnes of CO2 produced by burning a tonne of aviation fuel.

Step 9 and 10 (Cabin Class): A multiplicative cabin class factor is applied to change the CO2 per Y-passenger (ICAO, 2017).
Step 11 (Result- Passenger Co2 output): The amount estimated for the carbon emission.

2. **The MyClimate flight Emission Calculator.**

The calculator for aircraft emissions shall take into account the direct and indirect CO2-equivalent emissions per passenger over a given flight time. The emissions measured reflect an average distance between a given origin pair and destination airports.

General Methodology.

The measurement of the flight emissions is explained step by step in the following paragraphs. The variables employed are all based on literature findings and recent statistics. Calculations and estimates of pollution wherever possible are in accordance with the European standard DIN EN 16258.

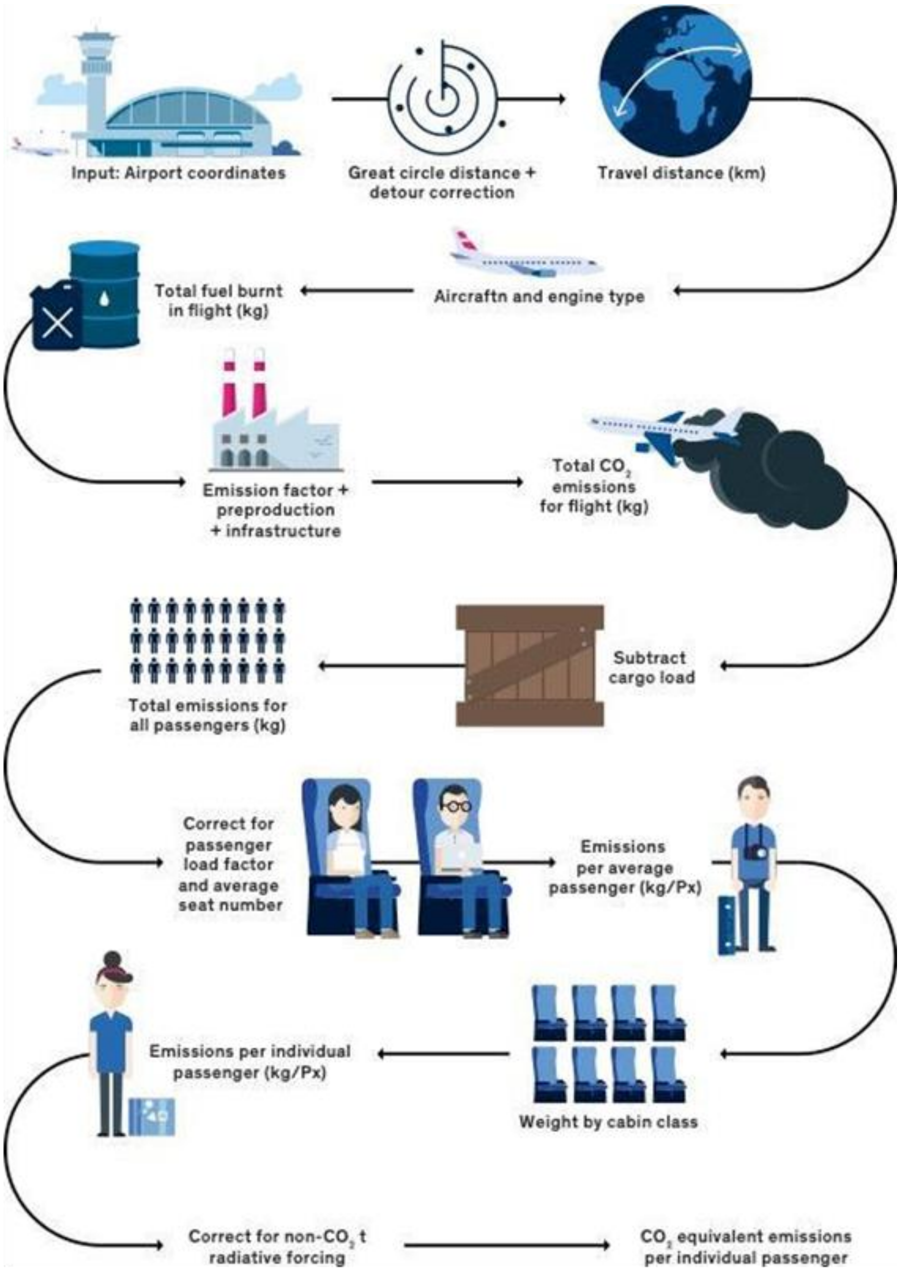

Fig 9. Myclimate emissions calculation methodology (Kettunen, 2005).

1. Flight Distance.

The flight distance between two airports is based on the distance from the Great Circle, the closest airport distance to each other. For non-direct, i.e., stopover flights, the two phases are dealt with as single flights. The method differentiates between short-haul (< 1500 km) and long-haul (> 2500 km) flights, while aircraft size and passenger load factors depend on the distance of travel. As there is no distinct short-haul limit, the method interpolates to get a smooth transition between 1500 and 2500 km for flight lengths. The regular flight distance between the two airports is often slightly higher than the shortest distance at the airport. Extra mileage is due to air traffic control systems, tropical storms, or other weather phenomenon and leads to inefficiencies. Although global additional-mileage figures are not reliable, prevalence estimates are 6-8 percent above the US and 10 percent above Europe (Kettunen, 2005). For this reason, it meets the approach suggested by the European standard (DIN EN 16258, 2012). Across all flights, an additional mileage/distance correction of 95 km is applied.

2. Fuel Consumption.

The fuel consumption per distance is based on the fuel-burning levels used on short-haul aircraft and long-haul flights. Emissions from the fuel burnt per airplane kilometer were based on EMEP / EEA's Air Pollutant Emission Inventory (EEA 2016) guide. On each flight, a constant amount of fuel is applied to compensate for the aircraft's use during landing and take-off (LTO) and during the taxi process (earth movement at the airport) (EEA, 2016). The weighted average fuel consumption for separate flight distances is determined according to this system. A generalized fuel consumption function of any flight distance is approximated for both short and long-haul flights with a second-order polynomial fit (ICAODATA, 2019). The weighting scheme includes the most commonly used short-haul aircraft (such as Airbus A310, Airbus A320) and long-haul aircraft (such as for example Boeing 747, Boeing 777, Airbus A330 and Airbus A340).

$$f(x) + LTO = ax^2 + bx + c$$

With x = GCD + DC, where GCD is the Great Circle Distance [km], DC is the Extra Mileage Correction [km], and LTO is the extra fuel used per landing and take-off period. The fuel consumption is interpolated linearly for distances of between 1500 and 2500 km.

3. CO2 Emissions and Fuel preproduction.

Calculator estimates for Co2 emissions from the pre-production of jet fuel/kerosene (including processes for shipping and refining) and fuel combustion (IPCC, 2013). The emission factor for the combustion of jet fuel (kerosenes) is 3.15 kg CO_2e / kg (ECOINVENT, 2018).

4. Cargo Load Allocation

Passenger aircraft frequently carry substantial amounts of freight and mail, especially on long-haul flights with wide-body planes. Moreover, some of the aircraft's total emissions have to be allocated to the freight. To keep in compliance with the European standard (DIN EN 16258, 2012), air freight is now allocated by weight (mass approach). Air cargo emissions are substantially higher due to its more substantial weight (LH, 2014) on international flights.

5. Co2 Emissions per passenger

On short-haul and long-haul flights, Co2 emissions per airplane are spread over the average number of passengers. Passenger numbers are described here as the number of seats per aircraft type (ICAODATA, 2019), multiplied by the International Air Transport Association 's passenger load factor (ICAO, 2018).

6. **Seating Class Weighting Scheme.**

Aircraft passenger capacity is often restricted because first, and business class seats take up more space. In other words, if the cabin space was minimized, the same aircraft could carry more passengers. Therefore, the emissions calculator makes cabin class selection. The emissions are assigned to the various cabin classes in the chosen cabin class according to the average seat area (Seatguru, 2012). For each category of aircraft, the cabin class weighting factor is determined and then weighted by the weighting scheme mentioned above.

7. **Non Co2 effects of Aviation.**

Aircraft emits not only CO2 but other driving agents that influence Earth's radiative equilibrium and thus the atmosphere. Aviation pollution, among other factors, also leads to short-term increases in tropospheric ozone due to nitrogen oxide (NOx) emissions. New studies recommend an RFI factor of 2 for total CO2 emissions from aircraft based on the objective review of the current scientific publications (Jungbluth & Meili 2018, Kollmuss & Crimmins 2009). MyClimate has already decided to multiply the expected CO2 emission by a factor of two to reduce the warming effects due to non-CO2 aircraft emissions (Jungbluth & Meili, 2018).

8. **Aircraft Infrastructure emissions.**

Aircraft are manufactured first, then repaired, and disposed of at the end of their life. The pollutants associated with these operations are used as a component allocating the pollutants to the total number of kilometers traveled. Furthermore, flying requires a particular infrastructure; it also contains absolute emissions from airport operations (Messmer & Frischknecht, 2016).

9. **Formula.**

   The following formula is used to calculate the total CO2-equivalent emissions:

$$E = \frac{ax^2 + bx + c}{S * PLF} * (1 - CF) * CW * (EF * M + P) + AF * x + A$$

   Where,

E: Passenger CO2 eq [kg]
x: flight distance [km] defined as the GCD sum, large circle distance and DC, distance correction for detours and holding patterns, and inefficiencies of the air traffic control system [km]
S: Maximum number of seats (total with all cabin levels);
PLF: The Passenger Load Factor
CF: Component Freight
CW: Weighing factor for cabin class
EF: emission factor for jet fuel (kerosene) combustion;
M: Multiplier accounting for impacts other than CO2
P: CO2e emission factor for preproduction of the jet fuel, kerosene
AF: aviation factor
A: Pollution from services at airports
The part ax+ bx + c is a nonlinear f(x) + LTO approximation
LTO: Fuel consumption including taxi [kg] during the landing and takeoff cycle
Short-haul is defined as x<1500 km; long haul is defined as x>2500 km. Linear interpolation is employed in between.

3. Cargo Carbon Calculator – Zurich Airport.

At only 2 percent of all anthropogenic CO2 emissions, global aviation 's exposure to climate change is relatively small.
As an airport operator, Flughafen Zürich AG is part of the aviation network and is committed to climate-protecting growth in aviation. However, it accounts for just around 10 percent of the Co2 emissions from the airport sector (ACERT, 2016). The airport operator has set targets for reducing Co2 emissions to 30,000 tons by 2030. Flughafen Zürich AG currently produces some 25,400 tons of Co2 in Scopes 1 and 2. The Scope 3 gross (complete from origin to destination) emissions totaled 3.5 million tons in 2014. It includes all regional air traffic as well as aircraft control for all airport passengers, and all surface road traffic.
After consultations with stakeholders in Switzerland's air freight industry and on the basis of studies on carbon emissions from cargo operations at Zurich airport, Zurich airport did studies into a system for quantifying carbon emissions from cargo operations at Zurich airport, not just at the airport or aircraft, but in the (door-to-door) shipping method. The study objective was to facilitate freight operators in calculating their carbon footprint from air cargo operations via the airport in Zurich. However, the main objective is to provide accurate information and a range of indices for emissions.

Methodology

The traffic and cargo data 2014 for Zurich airport has been analyzed in-depth to establish emission factors. Additionally, freight handler supplement information has been considered. The amount of traffic (number of trips per year), capacity (tons of cargo/mail per flight), length of trip (distance traveled), and fuel consumption for the trip (depending on the means of transport) were analyzed for each transport section in the calculations. Practically all cargo is mixed belly-freight with hardly any dedicated freight flights. In the end, the efficiency of passenger transport was split (ACERT, 2016).

Based on industry observations and results, it is recommended that the Great Circle Distance (GCD) correction factor be adopted to accommodate the GCD for diversions. The table below indicates the suggested factor for GCD correction.

GCD	Correction to GCD
Less than 550 Km	+50 Km
Between 550 Km and 5500Km	+100 Km
Above 5500 Km	+125 Km

Table 3. GCD- Detour Correction Calculation Table (Zurich, 2013).

The details used to measure the aircraft emission factors are the types of aircraft serving the relevant destination country, the appropriate flight block distance, and the total weight, consisting of passengers and freight (Zurich, 2013).

The following equation has been applied for the estimation of the standard aircraft emission factor:

$$EF_{Region} = \frac{FB_{Flightblock} * EI_{CO2}}{Distance_{Flightblock/Region} * Payload}$$

Where to:

EF_{Region} = Emission factor [kg CO2 / t*km] per world region

$FB_{Flight\ block}$ = Total Fuel Burn of aircraft [kg fuel] to that region

EI_{CO2} = CO2 [kg / kg fuel] emissions index

DistanceFlightblock /Area = Flight block distance [km] per particular region of the world

Payload = Passenger number (to 100 kg each),

+ Per passenger seat (with 50 kg each)

+ Empty seats (assumed to be 90 percent average seat load factor)

+ Cargo Freight(kg)

The emissions for an aircraft cargo shipment to a particular region are calculated using the equation:

CO2 [kg] = EF_{Region} [kg CO2/t*km] * Flight distance (GCD + correction factor) [km] * cargo mass [t]

4. Atmosfair Flight Emission Calculator.

Atmosfair is a German non-profit organization actively contributing to CO2 mitigation through the promotion, production, and funding of renewable energy in more than 15 countries around the world. The organization depends solely on private individuals and companies making voluntary climate payments. Intending to decarbonize the world economy, Atmosfair developed digital tools and consultancy services to help companies implement their climate policies, with a specific emphasis on business travel (Grassl et al., 2007).

Theoretical Methodology.

Atmosfair developed its emissions calculator on the principles of:

1. **Freedom of data.**

   Atmosfair obtains its data solely from independent scientific research programs or private, professional data service providers (Grassl et al., 2007). Atmosfair does not use data generated by the airlines themselves under any circumstances.

2. **Annual Actualisations.**

   New types of aircraft that come onto the market are often up to 30 percent more competitive than their predecessors. AAI atmosfair updates its data annually for the flight carbon emission estimates (AAI atmosfair, 2013).

3. **Appropriate accuracy and displaying results.**

   The measurements are reliable and have a scientific significance. The emission calculator displays factors that can influence the passenger, as well as factors that have the most significant effect on the volume of pollution (Lee et al. 2010). The calculator relies on the average value for less important factors as well as factors beyond the passenger 's control sphere. If the user leaves one of the parameters (e.g., aircraft type), the calculator will show as many different results as possible.

4. **Validation.**

   The Umweltbundesamt (German Environment Agency) and several globally engaged scholars in the fields of physics and aeronautical engineering have acknowledged the pollution calculator's methods and data from Atmosfair (Lee et al. 2010).
   The Co2 emissions resulting from a flight are measured using the comprehensive Airline Index (AAI) formula in the atmosfair flight emission calculator.

   The index for airline services includes:
   • 32 Million flights (ICAO, 2018)
   • Over 200 of the world's most significant airlines (Grassl et al., 2007).
   • 22,300 pairs of cities around the world(Grassl et al., 2007).
   • 119 types of aircraft (97% coverage of the global market) (ICAO,2018)
   • 408 engines (96 percent penetration of the global market) (Grassl et al., 2007).

The index includes about 92 percent of global air traffic (as of 2016). The Co2 of the remaining flights is calculated in the corresponding world zone using weighted, standardized values from sources such as IATA and ICAO.

5. IATA (SABRE Holdings) – Co2 emissions measurement methodology.

This suggested practice provides a standard methodology for airlines and any third party to calculate at the level of shipments covered by a single air waybill. IATA Members' commitment to implement a harmonized and agreed industry-wide solution (Recommended Practice 1678, 2014).

Methodology:

The three-step method mentioned is discussed below:

Step 1: Define the different legs of the entire transport service.

The route to be taken into account when calculating the Co2 emissions at the shipping level is the transport service from Origin to Destination as per the route management.

The contracted transport service can comprise several segments that can be as follows:

1. The Airline Routes
2. Interline and codeshare airline routes
3. Road Transport Segment
4. Water Transport Segment
5. Rail Transport Segment

Step 2: Measure CO2 emissions for each leg

Calculation of the CO2 emissions at the shipping point is established after the transport service has taken place, as the routing is clearly established. The use of the accepted methodologies is recommended for non-air segments. For air segments, the measurement of the Co2 emissions assigned to a shipment is supported by two methods. These two methods are discussed below.

Method 1. Leg-Based:

Shipment weight (t) * Leg-based emission factor (kgCO2/t)

Where,

Shipment weight (t) is the freight mass borne in compliance with the shipment. It protects the influence of any packaging that the shipper offers.

Leg-based emission factor (kgCO2 / t) is the average CO2 emissions produced by one ton of cargo being transported on a given city-pair. The leg dependent emission factor is determined as follows for every given city-pair:

(Average total fuel burn for legx (t) * 1000 * 3.15)/(Average total payload for legx (t)) = Legx emission factor (kgCO2/t)

The average cumulative fuel burn calculation will be performed in accordance with the Fuel Calculation Protocol of IATA's. The global constant accepted is the number of tons of Co2 produced by one ton of burning aviation fuel (Recommended Practice 1678, 2014).
As the weight of passenger seats carried in full freighter aircraft is negligible for full freighter, the average total payload calculation shall be as follows:

Total payload (t) = total cargo weight (t) + total mail weight (t).

Method 2. Network-Based:

Shipment weight (t) * Distance (km) * Network-based emission factor (kgCO2/tkm)

Where,
Shipment weight (t) is the freight mass borne in conjunction with shipment. It includes the weight of any packaging given by the shipper but excludes Aircraft Unit Load System (ULD) weight. The Great Circle (GCD) is the distance to be considered for the calculation methodology. GCD is the practice recommended by IATA, according to the Fuel Calculation Protocol, to be used for all distance measurements to the aerodrome (Recommended Practice 1678, 2014). It does not, however, prohibit the use of other current and proven methods (e.g., for compulsory reporting requirements, such as an emissions trading system describing GCD+ set definition of maneuver terms).

The network-based emission factor (kgCO2 / tkm) is the average CO2 emissions generated for a given network by transporting one ton of cargo per kilometer.
The emission factor for each given network is calculated as:

(Average total fuel burn for networkx (t) * 1000 * 3.15)/(∑average total payload for flight*GCD Distance(kms)) = Networkx emission factor (kgCO2/tkm)

The estimation of the annual average fuel burn will be performed in compliance with the IATA Fuel Measurement Protocol. 3.15 is the globally accepted constant, which refers to the number of tons of CO2 generated by a ton of burning aviation fuel. The distance flew measured in accordance with the fuel calculation protocol of IATA (Recommended Practice 1678, 2014). Also, in accordance with the Carbon Emissions Calculator Methodology developed by IATA for passenger carbon offsetting programs, the calculation of the average cumulative payload for belly freight will be performed (Recommended Practice 1678, 2014). For full cargo, since the weight of passenger seats conveyed in full cargo aircraft is small, the maximum total payload shall be estimated as follows:

Total payload (t) = total cargo weight (t) + total mail weight (t)

If there are no historical company data (e.g., a new route or new aircraft), the airline shall use comparable data (for example, identical city-pair or aircraft), the fleet emission factor of the airline, or data available on the public domain.

Step 3: Summarize the results for all legs.

Airlines can publish shipment-level results or aggregate the results by shipper in support of all transport services within a given timeframe.

6. The Co2 emissions from New Zealand's international air freight.

In June 2007, airfreight accounted for just 0.56 percent and 0.45 percent of New Zealand mass imports and mass exports respectively. Air freight accounted for 21% and 15% of the same year's imports and exports by value (Statistics New Zealand, 2007a). Air freight trades high-value, low-mass goods internationally, with lower-value, heavy materials being shipped by ship. Air freight may be transported either in dedicated freighters or in lower holdings ("belly-hold") of passenger aircraft (Ministry of Economic Development, 2005; Air New Zealand, comm. pers., November 19, 2010).

Methodology.

This current methodology uses a general approach to multiply the mass-distance of goods carried by the international air freight with Co2 emission factors. The present work discusses another method of measuring the emission per distance by international air freight and air freight factors of goods being transported. Co2 emission factors have been extracted from commercially sensitive fuel-uplifting data from internationally bound aircraft exiting Auckland, the largest international airport in New Zealand. The following equation has been used to implement calculation methodology on city pairs that separately reflect short- and long-haul journeys. This also culminated in the estimation of an average short- and long-haul Co2 emission factor for each aircraft model. This also culminated in the estimation for each aircraft model of an average short and long haul Co2 emission factor.

$$EF_{(CO_2,uplift)_a} = \frac{\sum_{c=1}^{r}\left(\frac{m_{Fuel_c} \times EF_{CO_2,fule}}{d_c \times N_{maXa} \times LF \times (m_p + m_f)}\right)}{r}$$

Where:

A (subscript) refers to a specific model of an aircraft.
C (subscript) applies to a specific city pair of origin and destination airports.
R represents the total number of pairs Airports origin and destination.
$EF_{CO2uplift}$ is the emission factor for each of the fuel lifts (kg CO2 per t-km) concerned.
M_{fuel} is an uplift (kg) to fuel.
$EF_{CO2fuel}$ is the release of CO2 from the burning of mfuel (kg CO2 per kg of fuel).
DC is the distance flew (km) between the origin and destination airports.
N_{maxa} is the passenger capacity (passenger number) of an aircraft.
LF is the passenger load factor which is expressed as a fraction of the Nmaxa aircraft.mp is the average mass per passenger plus their luggage (t per passenger).
Mf is the total freight amount carried per plane (t per passenger).
Mp is the average passenger mass plus passenger baggage (t per passenger).

Mf is the total freight amount carried per plane (t per passenger).

3.2 Sample Calculations and Comparative Analysis of Different Methodologies.

A comparative analysis was carried out on the usage of relevant carbon emission methodologies based on various important parameters mentioned below. The Atmosfair emission calculator was not included in the comparison table as it just provides a conceptual background to the research and the algorithm and methodology in place was strictly confidential. Also, It is evident that the methodologies differ significantly from one another in terms of algorithms, usage of confidential and public data sources as well as country-specific requirements. Based on the review of the literature on antecedent research and the analysis of different carbon emissions calculation methodologies being used internationally in all the mentioned institutions, various methods for the calculation of Co2 emissions due to air freight were used to obtain some sample calculations which are placed in Appendix A5.

Parameters	DEFRA	ICAO	myClimate	Zurich Carbon	IATA	NZL Co2 Calc
GCD Correction	10 %	Upto 11 %	10 %	10 %	As per ICAO standards i.e 10 %	10 %
Fuel Burn Data	Extracted from Corinair- European Environment Agency (confidential)	Manages own data with the help of EU ETS small emitters tool and other airline's confidential sources	Uses linear interpolated function described earlier to measure fuel consumption	Uses confidential airline sources for fuel data. Also uses Corinair data.	Uses EU ETS small emitters tool.	Uses confidential airline sources for fuel data

Form of emission algorithms	Factors used as a multiplier for emission calculations; mostly linear, y=ax for the domestic, short and long haul	The emission algorithm is confidential. Mostly linear; y=ax+b	Non-linear; $Y=ax^2+bx+c$ The calculation methodology is described above.	Mostly linear; y=ax+b	Mostly linear; y=ax+b	Mostly linear; y=ax+b
Freight factor	<1% domestic and short-haul; 28.8% long haul.	47-88% depending on the route and wide/narrow-body planes divided into 34 classes.	20% long haul 0% short haul	Depending on the user load requirements and plane freight carrying capacity	20% wide body. 10% narrow	Depending on the user load requirements and plane freight carrying capacity
Passenger Load Factor	65.3 Domestic Haul 81.2 Short Haul 78.1% Long Haul	67-100 % depending on the region	n/a	World region-specific load factors used.	n/a	67-100 % depending on the region
Seating Configuration	Representative from the CAA Data	No. of economy seats fitted in the cabin	Uses average seat data for an aircraft	Uses average seat data for an aircraft	Representative from the CAA Data.	Uses average seat data for an aircraft
Radiative Forcing Multiplier	Not Considered	Not Considered	Yes	Not considered	Not Considered	Not considered

Table 4. Comparison table for different carbon emission calculation methodologies.

The abovementioned comparative analysis of various researched methodologies proves to be a good source in identifying the usage of relevant variables and datasets in the calculation of emission factors as well as marginal Co2 emissions due to cargo freight. Multiple data sources were used in the process, and these sample calculations lead to the selection of an appropriate methodology that would satisfy PostNL's requirements for the current research. The variables in the methodology are taken as such so that PostNL can modify, change, and add new routes whenever possible. The method selected for the development of the emission models and the implementation of the simulation and optimization models is discussed in the coming chapters.

Chapter 4. Data Overview and Preparation.

This section summarizes the datasets used in the study. Since it included information deemed relevant for this work, it presents an explanation of the preparation and selection procedures for the final data needed for the analysis, including the collection of additional data required.

4.1 Overview of the datasets.

4.1.1 PostNL's Route Management Datasheets (IPS Dataset).

PostNL Group Reporting has an annual obligation to report on Co2 emissions. They started reporting in 2010 with mostly manual effort to calculate the emission. Their first aim was to reduce the amount of manual labor by automating the report and secondly have a better insight of the subcontractor's influence on total Co2 emissions. Scope for the datasets has been set to all receptacles that are sent via a route on which PostNL has any influence. In IPS, this means only those routes are selected that are associated to the operator code "NLA" this means only exported consignments are included in the dataset, for imported consignment, the datasets do not have the information because they are owned by another postal operator. The dataset is also used and filtered by relevant stakeholders to accommodate their individual reporting needs.

Depending on the purpose, two datasets were defined.

Dataset 1: Direct transportation only .

In IPS, the reported datasets are registered as "Co2 direct routes". This dataset includes all transportation types and routes conducted in a particular month that composes one transportation segment.

Selection Criteria .

• The entered period in the IPS client interface (the parameter), will be used to select the required consignment information based on the capture date (the timestamp when an event was registered in the IPS database) of the "Actual Close Consignment" event date or the "Actual Close Depeche" event date in case of missing consignment information.
• In case of multiple capture dates associated with the event, the data related to the first capture date will be selected.
• Because the goal of the reports is to show only route information on which PostNL has any influence, only consignments with the operator code "NLA" (=PostNL) will be selected.
• Only closed receptacles are used (because they have been assigned to a consignment and Depeche).

Grouping.

The rows in the datasets are group by:

- Period
- Origin office
- Origin location

- Destination location
- Destination office
- Flight nr.
- Transport type

Selected columns.

The following columns of the report are populated based on information that's available in the IPS database.

Dataset Column name	Description
Period	The year and month in which a consignment was closed based on the "Close Consignment Date" or the "Close Depeche date" in case the first one is missing.
Origin office	The office of exchange associated with receptacle included in the consignment or depeche. Position 1-6 of the receptacle identifier.
Origin location	The physical starting point of the segment as registered in IPS as part of the route between offices of exchange.
Destination location	The physical end point of the segment as registered in IPS as part of the route between offices of exchange.
Destination office	The office of exchange associated with receptacle included in the consignment or depeche. Position 7-12 of the receptacle identifier.
Flight nr.	Is the identifier associated with the physical transport. Various formats exist for flight, truck and boat transportation.
Transport type	The type of transportation associated with the segment (plane, truck or ship).

Table 5. IPS Data sheet selected columns (direct transportation)

Calculated Columns/Data Preparation.

Dataset Column name	Description
Used kms/miles	For road and plane transportation, the distance is measured in kilometers (km). For the plane, the great circle method is used. For roads, the transportation table is used. For boat transportation, the distance is measured in nautical sea miles (1.6 km). With all transportation types, distance is measured between the segment's start and endpoints. These points are associate with the end's office location (associated with the offices of exchange) between origin and destination
Defra factor	It is the factor to convert kilometer distance weight into CO2 emissions based on the "freight" type DEFRA factor. See 'Completely Freight emission' for further information. The factor may change depending on the distance of the segment.
Parcel kg	The sum of the weight of transported PARCELS on that segment route within the selected period.
Parcel % weight	The percentage of PARCELS weight as part of the total weight transported on that segment, route, period combination.
EMS kg	The sum of the weight of all transported EMS items on that segment route within the selected period.
EMS % weight	The percentage of EMS weight as part of the total weight transported on that segment, route, period combination.
Empty bag kg	The sum of the weight of all transported EMPTY BAGS on that segment route within the selected period.
Empty bag % weight	The percentage of EMPTY BAGS weight as part of the total weight transported on that segment, route, period combination.
Letter kg	The sum of the weight of all transported LETTERS on that segment route within the selected period.
Letter % weight	The percentage of LETTERS weight as part of the total weight transported on that segment, route, period combination.
Number of Parcels	The total number of PARCELS items transported on that segment, the route, period combination.
Number of EMS	The total number of EMS items transported on that segment, route, period combination.
Number of Empty bags	The total number of EMPTY BAGS transported on that segment, route, period combination.

Number of Letters	The total number of LETTERS items transported on that segment, route, period combination.
Kg Co2 belasting CO2 emission (kg tonnage) Freight Method	= ((Directly flown kms * Defra factor) / 1000) * transported kilos on the route.
Euros	Contains the "Internal Carbon Pricing" per 50 euros per the whole kilogram the tonnage of emitted CO2 (3,6 will be rounded as 3).

Table 6. IPS Data sheet calculated columns (direct transportation)

Dataset 2: Indirect transportation.

This dataset includes all transportation types and routes conducted in a particular month that composes of more than one transportation segment. Because of performance optimization, the set has been split up between 2- 3 segments and 4-5 segments.

Selection Criteria.

- The entered period in the IPS client interface (the parameter), will be used to select the required consignment information based on the capture date (the timestamp when an event was registered in the IPS database) of the "Actual Close Consignment" event date or the "Actual Close Depeche" event date in case of missing consignment information.

- In the case of multiple capture dates associated with the event, the information associated with the first capture date will be selected.

- Because the goal of the reports is to show only route information on which PostNL has any influence, only consignments with the operator code "NLA" (=PostNL) will be selected.

- Only closed receptacles are used (because they have been assigned to a consignment and/or Depeche).

Grouping.

The rows in the datasets are group by:

- Period
- Origin office
- Origin location
- Destination location
- Destination office
- Flight nr.
- Transport type

Selected columns.

The following columns of the datasets are populated based on information that's available in the IPS database.

Dataset Column name	Description
Period	The year and month in which a consignment was closed based on the "Close Consignment Date" or the "Close Depeche date" in case the first one is missing.
Route Origin office	The office of exchange associated with receptacle included in the consignment or depeche. Position 1-6 of the receptacle identifier.
RouteDestination office	The office of exchange associated with receptacle included in the consignment or depeche. Position 7-12 of the receptacle identifier.
Sx - origin location	The physical starting point of the segment as registered in IPS as part of the route between offices of exchange.
Sx-destination location	The physical end point of the segment as registered in IPS as part of the route between offices of exchange.
Sx - flight nr	Is the identifier associated with the physical transport. Various formats exist for flight, truck, and boat transportation.
Sx - transport type	The type of transportation associated with the segment (can be plane, truck or ship).

Table 7. IPS Data sheet selected columns (indirect transportation)

Calculated Columns/Data Preparation.

Dataset Column name	Description
Sx - used kms	For road and plane transportation, the distance is measured in kilometers (km). For the plane, the great circle method is used. For road and boat transportation, the reference table (see chapter "Transportation reference table"). For boat transportation, the distance is first measured in nautical sea miles (1.6 kms) and later converted to kms to match column format.
	With all transportation types, distance is measured between the segment's start and endpoints. These points are associate with the end's office location (associated with the offices of exchange) between origin and destination
Sx - Defra factor	Is the factor to convert kilometer distance weight into CO2 emissions based on the "freight" type DEFRA factor.
Direct flight kms	The distance measured between the route's start and end point associated with the office location (related to the offices of exchange) between origin and destination. The calculation is based on the Great Circle Method.
Sum segment kms	Is sum of all distances in kms for all segments.
Parcel kg	The sum of the weight of transported PARCELS on that segment route within the selected period.
Parcel % weight	The percentage of PARCELS weight as part of the total weight transported on that segment, route, period combination.
EMS kg	The sum of the weight of all transported EMS items on that segment route within the selected period.
EMS % weight	The percentage of EMS weight as part of the total weight transported on that segment, route, period combination.
Empty bag kg	The sum of the weight of all transported EMPTY BAGS on that segment route within the selected period.

Empty bag % weight	The percentage of EMPTY BAGS weight as part of the total weight transported on that segment, route, period combination.
Letter kg	The sum of the weight of all transported LETTERS on that segment route within the selected period.
Letter % weight	The percentage of LETTERS weight as part of the total weight transported on that segment, route, period combination.
Number of Parcels	The total number of PARCELS items transported on that segment, the route, period combination.
Number of EMS	The total number of EMS items transported on that segment, route, period combination.
Number of Empty bags	The total number of EMPTY BAGS transported on that segment, route, period combination.
Number of Letters	The total number of LETTERS items transported on that segment, route, period combination.
Kg Co2 / km ton	= ((Sum of all segments in km * Defra factor) / 1000) * transported kilos on the route.
Euros	Contains the "Internal Carbon Pricing" per 50 euros per whole kilogram tonnage of emitted CO2 (3,6 will be rounded as 3).
Kg Co2 / km ton for direct flight	= ((Directly flown kms * Defra factor) / 1000) * transported kilos on the route.
Euros for direct flight	It contains the "Internal Carbon Pricing" per 50 euros per the whole kilogram tonnage of emitted CO2 for directly flown km.

Table 8. IPS Data sheet calculated columns (direct transportation)

4.1.2 PostNL's Business Data Management Datasheet (Tender Dataset).

Business Data Management (BDM) serves the International Relations & Development (IRD) team with their goal of Data-Driven Procurement in which CO2 emissions are a future negotiating factor in terms of their relationship with the airline companies. The department prepares an annual tender dataset involving different variables related to cost and lead time, which helps the company make appropriate shipping decisions.

Grouping.

The rows in the tender datasets are group by:

- Company Name
- Airline Code
- Origin
- Destination
- Via Routes
- Cost Priority
- Cost Non-Priority
- Pickup Time
- Handover Time
- Total Flight Time
- Cargo Weight Limit (per Day)

Selected Columns for Calculations.

The following columns of the datasets are populated and altered based on information that's available in the tender database. The origin and destination names are renamed to match the route management IPS datasets. This makes the data analysis easier by making the model more coherent.

Dataset Column name	Description
Company Name	The airline company providing air freight services to PostNL.
Airline Code	The identifier associated with the physical transport. Various formats exist for flight.
Origin	The physical starting point of the segment as registered in IPS as part of the route between offices of exchange.
Destination	The physical end point of the segment as registered in IPS as part of the route between offices of exchange.
Via Routes	The physical intermediate transfer point of the overall segment as registered in IPS as part of the route between offices of exchange.
Cost (Priority)	The priority cost associated with shipping one kg of cargo freight on a particular day.
Cost (Non-Priority)	The non-priority cost associated with shipping one kg of cargo freight on a particular day.
Total Lead Time	The total lead time = pickup time + handover time + total flight time
Cargo Weight Limit (per day)	For each specific day, the airline company restricts the amount of cargo freight to be loaded by PostNL.

Table 9. Tender Data sheet calculated columns

Chapter 5. Methodology

5.1 Identification of Variables and Proposed Methodology.

The following methodological approach was developed to find the respective carbon emission calculations for the specific and already defined aircraft routes that PostNL operates in. PostNL's confidential datasets are used for the inputs in the model. These include variables such as cost-lead time data (TENDER datasets) and route management data. These data are merged with the fuel consumption data and other relevant aircraft-specific data. Following this, the information is fed into the calculation methodology, which produces the result in the form of cargo Co2 emissions data and specific carbon emission factors. These resultant business datasets are again fed into the simulation model and optimization model and further analyzed.

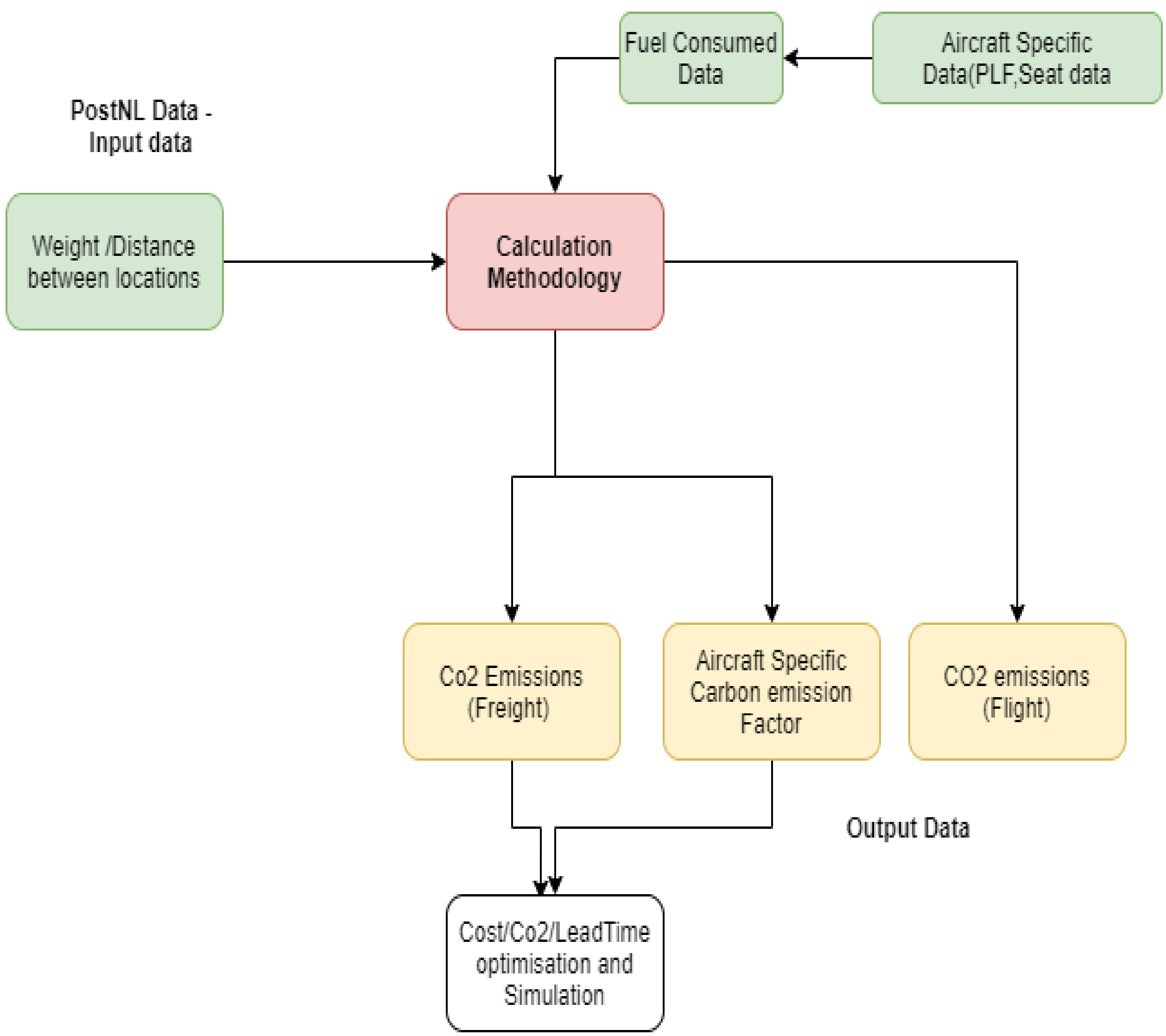

Fig 10. Proposed Methodology/Flowchart

Various variables for the calculation and usage in the carbon emission calculation model have been discussed below:

1. Great Circle Distance Method for Transportation Via Plane

The distance in the great circle is the shortest distance between two points on the surface of a sphere, measured along the surface. In Euclidean space, the distance is the length of a straight line connecting them, but the sphere does not have straight lines. Geodesics on the sphere are circles on the spheres whose poles correspond to the middle of the sphere. (Kifana & Abdurohman, 2012). The world is nearly spherical, and large-circle measurements include the right distance between points on the Earth's surface within approximately 0.5 percent (PostNL, 2019). The correction factor should include distance flew emissions above the GCD, piling, traffic, and weather-driven corrections. According to EIG, the actual distance flew in Europe is up to 11 percent different than GCD given in the scheduled flight schedule (*ICAO Carbon Emissions Calculator Methodology Version 10*, 2017).

GCD	Correction to GCD
Less than 550 Km	+50 Km
Between 550 Km and 5500Km	+100 Km
Above 5500 Km	+125 Km

Table 10. GCD correction factor used(*ICAO*, 2017)

The basis for the great circle distance is the receptacle identifier's first 11 locations. The path is extracted from receptacle marker positions 1-5, which are used as a guide to accessing the route's starting location (identifying the country of origin and airport) (PostNL, 2019). Positions 7-11 identifies the exchange office at the destination. Both are used as a key to obtain the related airport's latitude and longitude information. In the method that measures the great circle size, these coordinates are used.

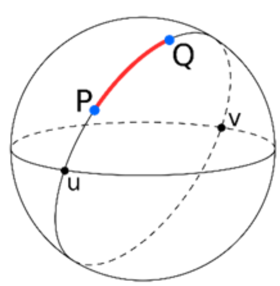

Fig 11. Pictorial Representation of The Great Circle Distance (PostNL, 2019).

2. Identifications of the Airplanes by Type

The data provided by PostNL's route management contained all route-specific information that involved a "Flight designated no." for every direct as well as connecting flights in all 16905 routes across the globe. After using ***Radarbox24.com***, each route was allocated a specific Airplane type (RadarBox LLC, 2020). This process is referred to as web scraping. Web scraping refers to extracting web data to a user-friendlier format. Many companies use web scraping to create vast databases and derive industry-specific insights from these. While web scraping can be performed manually, in most cases, you can be better off using an automated tool. These are usually quicker and less costly than scraping data manually, after all. The aspect, however, is beyond this study's scope. A manual process involving continuously monitoring the flights in designated routes was carried out for a duration of 12-15 days to confirm a list of 116 distinct airplane types. The procedure, as well as the extensive list of aircrafts used by different carriers, are mentioned below. The robustness of the model depends on the frequent examination of the consistency of the flight movements around the globe. With varying flight numbers, it is recommended to keep updating the aircraft information using the web scraping technique developed. Given current conditions of the global pandemic, multiple checks on the consistency of the movement of the flights could not be followed, which could lead to inconsistent results in the Co2 emission estimate.

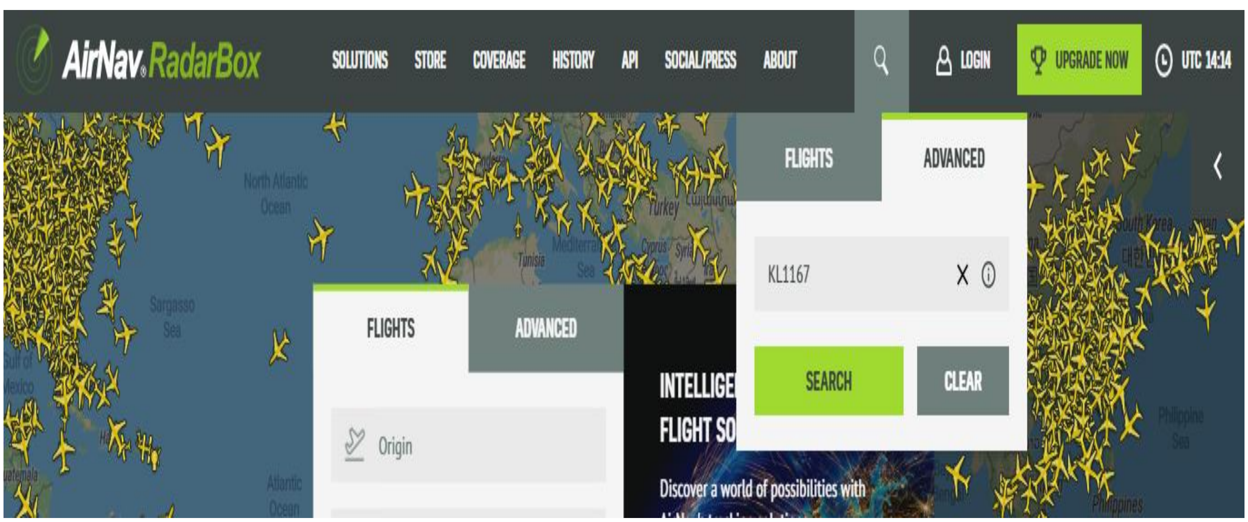

Fig 12. User Interface(1) for Radaxbox24.com

Step 1: Open Radarbox24.com. Go to "Search," then "Advance" and type in the designated flight no.

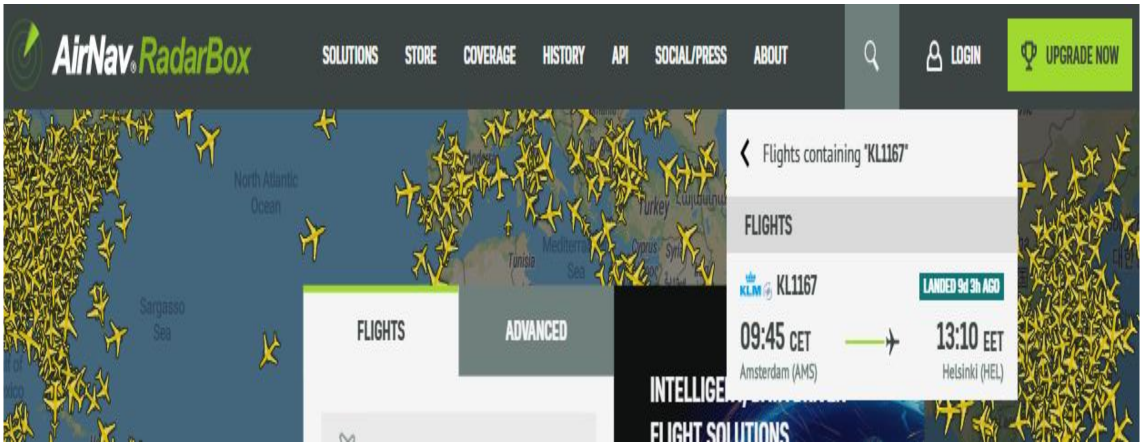

Fig 13. User Interface(2) for Radaxbox24.com

Step 2: Select the flight from a list of flights flying in the same direction.

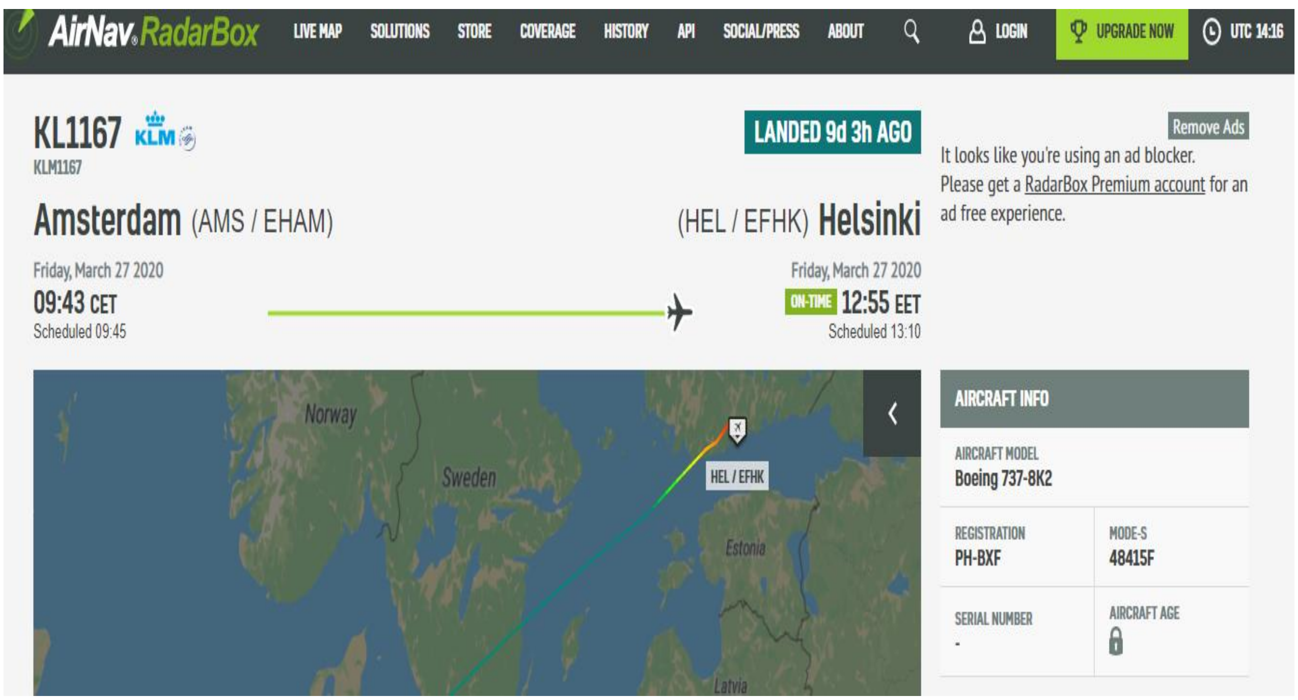

Fig 14. User Interface(3) for Radaxbox24.com

Step 3: Mark the Aircraft model and continuously monitor for 12-15 days to be certain of the aircraft model being used by the carrier in a particular direction.

The following pictures provide an extensive list of all aircraft being deployed by different carriers across all routes:

BOEING 787-8	AIRBUS A350-941	BOEING 757-223SF
BOEING 747-4H6F	AIRBUS 321-231	DHC-8- 400 DASH 8Q
BOEING 777-F6N	AIRBUS 321-251NX	AIRBUS A350-941
BOEING 777-367ER	AIRBUS 320-232	BOEING 777-300
BOEING 747-87UF	AIRBUS 320-233	AIRBUS A330-342
BOEING 777-F1B	AIRBUS A220-300	BOEING 787-9
BOEING 737-8JP	AIRBUS 350-941	AIRBUS A330-323
Boeing 757-308	AIRBUS A350-941	AIRBUS A330-302
BOEING 747-830	AIRBUS A330-343E	BOEING 777-31HER
Embraer 195	AIRBUS 319-112	AIRBUS A350-900
Embraer 190-200LR-195LR	AIRBUS A321-231	BOEING 787-8
BOEING 737-89P	AIRBUS A319-132	BOEING 737-860
BOEING 737-900	AIRBUS A320-251N	BOEING 777-200LR
BOEING 737-958ER	AIRBUS A320-21N	AIRBUS A330-200
BOEING 777-2J9ER	AIRBUS A320-211	AIRBUS A340-642
BOEING 767-3Z9ER	Airbus A330-243F	CR9
BOEING 777-240LR	Airbus A300B4-622R(F)	AIRBUS A319-115
BOEING 737-8Q8	Airbus A380-841	BOEING 747-830
BOEING 777-200	Airbus A350-941	AIRBUS A320-214
BOEING 777-300ER	Airbus A321	BOEING 777-300ER
BOEING 777-F	Airbus A330-223	BOEING 737-866
BOEING 777-FDZ	Airbus A321-271NX	AIRBUS A320-251N
Boeing 737-4Y0F	Airbus A319-111	AIRBUS A330-343E
Boeing 747-8HVF	Airbus A330-223	AIRBUS A330-300
Boeing 747-400	Airbus A350-1000	BOEING 767-3Z9ER
Boeing 747-8	Aerospatiale ATR 42-500	BOEING 737-8FZ
Boeing 747-46NERF	BOEING 737-86N	AIRBUS A300
Boeing 747-8F	BOEING 737-85R	AIRBUS A320-232
Boeing 747-8HVF	AIRBUS A330-203	BOEING 747-8HVF
Boeing 747-46NERF	BOEING 777-223ER	BOEING 777-312ER
Boeing 747-412F	BOEING 737-800	BOEING 777-2D7ER
Boeing 737-8F2	BOEING 737-823	BOEING 767-424ER
Boeing 767-322ER	EMBRAER 190-100AR	BOEING 777-200ER
Boeing 787-9	BOEING 767-323ER	BOEING 737-7M2
Bombardier BD-500-1A11-CS300	BOEING 777-333ER	AIRBUS A380-842
AIRBUS A321-232	BOEING 767-300	BOEING 747-8
AIRBUS A319-112	BOEING 737-8B6	
AIRBUS A319-111	BOEING 737-700	
AIRBUS 320-214	AIRBUS A330-204	
	BOEING 777-236ER	

Table 11. List of all aircrafts deployed by different carriers across all routes handled by PostNL.

3. Passenger Load Factors

Passenger load factor (PLF) is a metric in the aviation industry that measures how much passenger capacity an airline uses ("Air Emissions Calculations," 2019). PLF measures merely passenger performance, not to be confused with an aeronautical charging factor. PLF is one of the most important indicators, from a power management perspective. Airlines not only seek to optimize their PLF but also make decisions on pricing, availability, and flight frequency based on this primary performance measure. Passenger aircraft frequently carry substantial amounts of freight and mail, especially on long-haul flights with wide-body planes. Moreover, some of the aircraft's total emissions have to be allocated to the freight. To keep in compliance with the European standard (DIN EN 16258, 2012), air freight is now allocated by weight (mass approach). PLF trends provide a clear predictor for senior airline management as to whether their passengers are growing or rising as regards their capacity ratio. This also necessarily means that in terms of the number of kilometers flown, the airline's fleet is completely utilized.

Example:

XYZ Airlines operates one Boeing 767- aircraft between New York JFK and Chicago ORD with a capacity of 285 passengers, with revenue of 203 passengers per leg for the route ("Cargo Calculations," 2019). The distance between the two airports is 1.200 KM, which means the load factor will be as follows:

$$Load\ Factor = \frac{Number\ of\ carried\ passenger * distance}{Avalable\ seat * distance} * 100\%$$

$$Load\ Factor = \frac{203 * 1200}{285 * 1200} * 100\% = 71.22\%$$

The daily and annual PLF will be estimated accordingly based on the frequency of this path per day and per year (ICAO, 2018). Appendix 9.1 provides the following tables, which marks the average passenger load factor across different geographical regions around the world. For the calculations the PLF was taken as a variable ranging from 0.7 to 0.9. This estimation is taken by looking at the usual pattern of passenger flow through different regions where PostNL operates within Europe specifically. The PLF was locked to 0.9 for the calculations after discussions with different department representatives who anticipated the traffic among theses regions to be high. However, the model allows the user to make changes in the PLF across different regions to obtain a better estimate of the emissions.

4. Fuel Consumption Calculation.

ICAO has been conducting regional variations studies in international airline operating economies since the 1980s to measure and compare airline operating costs and revenues in different regions of the world, using a specialized database that includes fuel consumption (Burzlaff et al., 2017). The fuel-burning relation to flight distance is extrapolated from the ICAO Fuel Consumption Theory. Variables used are known as passenger load factor, flight duration, block time, the proportion of total payload given by passenger traffic, cabin flew class, and type of comparable aircraft flew (ICAO, 2017). The amount of fuel used on a route is the weighted average of the total fuel consumed, based on the aircraft type frequencies being flown. For each airline, on each sector of a scheduled flight, the fuel consumption in that database is calculated based on details provided by the airlines for their scheduled operations. With only the reference of the aircraft manufacturer's information, given within the airport planning documents, a method is established that allows computing values for the fuel consumption of every aircraft in question.
The aircraft's fuel consumption per passenger kilometers decreases rapidly with range until a near-constant level is reached around the aircraft's average range. At more extended range, where payload reduction becomes necessary, fuel consumption increases significantly. Numerical results are visualized, explained, and discussed in the further sections. With regard to today's increasing number of long-haul flights, the results are investigated in terms of efficiency and viability. The presented method allows calculating aircraft type-specific fuel consumption based on publicly available information. In this way, the fuel consumption of every aircraft can be investigated and can be discussed openly. The objectives of this calculation are to take a closer look on the calculation of the fuel consumption and the implementation on an Excel file, which enables the user to calculate the required fuel of any aircraft, based on the `Aircraft characteristics for Airport planning,' which are published by the respective aircraft manufacturer.

For the calculation of the fuel mass for a flight, several aspects have to be considered. Hereafter, these aspects will be closer annotated within this section.

4.1 Aircraft Weights.

Different aircraft weights for the consideration of the calculation of fuel mass consumption are summarized below:

1. The Manufacturers Empty Weight **(MEW)** is an airplane's structural weight like the necessary equipment, the engines, and all the systems needed (Burzlaff et al., 2017).
2. Operation Empty Weight **(OEW)** includes permanently fixed equipment, including MEW and even customer-specific equipment such as passenger seats or galleys.

3. The basic weight is the OEW and all the operational fluids required, including hydraulics, oils, and the remaining unusable fuel.
4. The Dry Operating Weight **(DOW)** includes the basic weight, plus crew weight, luggage, and water and passenger catering services (Burzlaff et al., 2017).
5. The Zero Fuel Weight **(ZFW)** contributes the aircraft's payload weight to DOW, including passengers, their freight, and their luggage.
7. Take-off weight **(TOW)** at take-off moment is specified as zero fuel weight plus available fuel quantity. The maximum fuel mass **(MFW)** is a definition of the maximum fuel mass that the planes can carry (Burzlaff et al., 2017). If the MFW is loaded, it is expected to reduce payload. Their respective Maximum Zero Fuel Weight **(MZFW)** and Maximum Take-off Weight (MTOW) derivatives are typically used for the Zero Fuel Weight and the Take-off Weight.
8. Their Maximum Zero Fuel Weight (MZFW) and Maximum Take-off Weight (MTOW) variants, respectively, are usually used for the Zero Fuel Weight and Take-off Weight (Burzlaff et al., 2017). This terminology helps in the calculation of the breuget factor, which eventually leads to the calculation of the fuel consumed over a definite range and with a specific payload.

4.2 Breguet Range Equation.

The total average fuel expended during a flight is determined on the basis of the so-called 'Breguet Range Equation,' stemming from the French aviation pioneer Louis Breguet (1880-1955) (Burzlaff et al., 2017). His calculation takes into account the magnitude of the mass change in an aircraft during its flight.

The fuel mass flow Q is defined as the change of fuel mass m_f per time t.

$$Q = \frac{mf_2 - mf_1}{t2 - t1} = -\frac{dm}{dt} \tag{1.1}$$

It is typically the only mass adjustment an airplane can make during a routine flight (Burzlaff et al., 2017). The fuel mass flow Q of a specific aircraft depends on its propulsion, the fuel mass flow Q_j is specified for engine-driven aircraft as

$$Q_j = c\frac{D}{L}w = \frac{c}{E}mg\ , \tag{1.2}$$

Where c is the thrust specific fuel consumption, D is the drag force, L represents the lift force, w is the instant weight of the aircraft.

To account a distance on the dependency of velocity V and time t, generally

$$R = V.t \tag{1.3}$$

Using Eq (1.1) the change of range dR is

$$dR = V.dt = -\frac{V}{Q}dm$$

(1.4)

The range R is calculated through the integration of the above equation

$$R = \int -\frac{V}{Q} dm$$

(1.5)

The following equations are based on the range equation of an engine-powered plane (Q = Qj) for simplification. Hence

$$R = \int -\frac{VE}{cg}\frac{dm}{m}$$

(1.6)

By integrating this term, The Breguet Equation is ascertained:

$$R = -\frac{VE}{cg}\int_{m1}^{m2}\frac{dm}{m} = \frac{VE}{cg} ln\frac{m_1}{m_2}$$

(1.7)

It is the Breguet Distance Equation, which can be used by its very own distance given to measure the aircraft mass shift during a flight.

The Breguet Range Equation can not be used in this form in order to calculate the weight change (the consumed fuel) of an aircraft for a flight using publicly accessible data, since data such as the specific fuel consumption or the glide ratio are not published by the aircraft manufacturer (Burzlaff et al., 2017). Hence, a particular method, based on an aircraft's payload-range model, is used for measuring the fuel mass.

4.2.1 Breguet Factor for Horizontal Flight.

Based on Eq (1.7), the Breguet Factor is written as:

$$B = \frac{VE}{cg}$$

(1.8)

This forms the Breguet Range Equation to :

$$R = B\ ln\frac{m_1}{m_2}$$

(1.9)

A re-positioning of the above equation leads to:

$$B = \frac{R}{ln\frac{m_1}{m_2}}$$

(1.10)

For this calculation of the Breguet Factor, every data can be obtained from the Payload Range diagram with m_1 being the maximum take-off weight and m_2 being the zero fuel weight. It is to be noted that this way of calculation is only valid for the horizontal flight. For the non-horizontal flight, we have a slightly modified equation.

$$B = \frac{R}{10.38 \, ln \frac{m_1}{m_2}}$$

(1.11)

The above equation is used for the fuel mass calculation.

4.2.2 Fuel Fractions.

Fuel fractions are applied to adapt to the calculation of the Breguet Factor not only to the horizontal flight (cruise) but also to the entire flight period including takeoff, climb, cruise, descent, loiter and landing (Burzlaff et al., 2017).

A Fuel Fraction M_{ff} is a relation between the mass m_2 at the end of a flight period and the mass m_1 at the start of the flight phase.

$$M_{ff} = \frac{m_2}{m_1}$$

(1.12)

4.2.3 Fuel Mass Calculation.

The range of an aircraft is given by,

$$R = B \, ln \frac{m_1}{m_2}$$

(1.13)

Where m_1 is the mass prior to the take-off, and m_2 is the aircraft mass after landing. The difference between m_1 and m_2 can be assumed as burned fuel mass m_f. Thus, the following equation applies

$$m_f = m_1 - m_2$$

(1.14)

Thus, the range equation becomes,

$$R = B \, ln \frac{m_2 + m_f}{m_2}$$

(1.15)

In order to calculate the estimated fuel mass m_f, the rearrangement results in:

$$m_f(R) = m_2 \left[\exp\left(\frac{R}{B}\right) - 1 \right]$$

(1.16)

4.2.4 Carbon Emission Calculation

As per the International Civil Aviation Organization (ICAO), the Co2 emission is calculated 3.16 times the total fuel burned.

$$m_{Co_2} = 3.16 * m_f$$

(1.17)

The marginal carbon emission from the cargo will be calculated as follows:

$$m_{Co_{2(cargo)}} = 3.16 * m_f \left(1 - \frac{MZFW}{MTOW}\right)$$

(1.18)

4.2.5 Fuel Mass Calculation for Different Modern Aircrafts

Each year several more long-haul routes are inaugurated in today 's aircraft service. Due of the introduction of new generation aircraft such as the Boeing 787 or the long-haul routes of the Airbus A350 it is becoming more feasible, as this aircraft is running very fuel-efficient relative to the aircraft of the last decade (Burzlaff et al., 2017). This section will take a closer look at the aircraft operated today and their fuel consumption compared to earlier-day aircraft such as the Airbus A320.

In order to demonstrate the growing efficiency of new aircrafts, a specifications comparison between the 2005 introduced Boeing 777-300ER, a 1984 introduced Airbus A320 and the 2007 introduced Airbus A330-200F is done (Burzlaff et al., 2017).

Data	**Boeing B777-300ER**	**Airbus A320**	**Airbus A330-200F**
MTOW (kg)	351535	78000	233000
MZFW (kg)	237683	61000	173000
OEW (kg)	167829	42000	106000
MFW (kg)	145538	23282	76561
Max. Payload (kg)	69853	19000	67000
Range at Point A (km)	10556	4100	6000
Payload at point B (kg)	38671	16300	42000
Range at point B (km)	14466	5300	10200
Range at point C (km)	15742	6900	13600
Seat capacity	370	180	277
CO2 emission fuel (kg)	459972	72863	248208
CO2 emission cargo (kg)	148972	15881	63917

Table 12. Aircraft Specifications.

We need the above data except for the Co2 emission from the aircraft's manufacturer in order to calculate the fuel consumption. The Co2 emission is then calculated by multiplying the fuel consumption by a factor of 3.16.

4.2.6 Payload range Chart

In this approach the data needed for the calculated measurement is derived from the Payload Range Diagrams published by the manufacturer. This type of diagram visualizes the behavior against the expected flight distance with the maximum possible take-off mass independence.

With the extended Payload Range Diagram given in Figure 15, the efficiency of each aircraft can be represented. Based on the size of the proposed path, the blue line represents the highest possible payload mass. The aircraft's total takeoff weight is indicated by the yellow line.

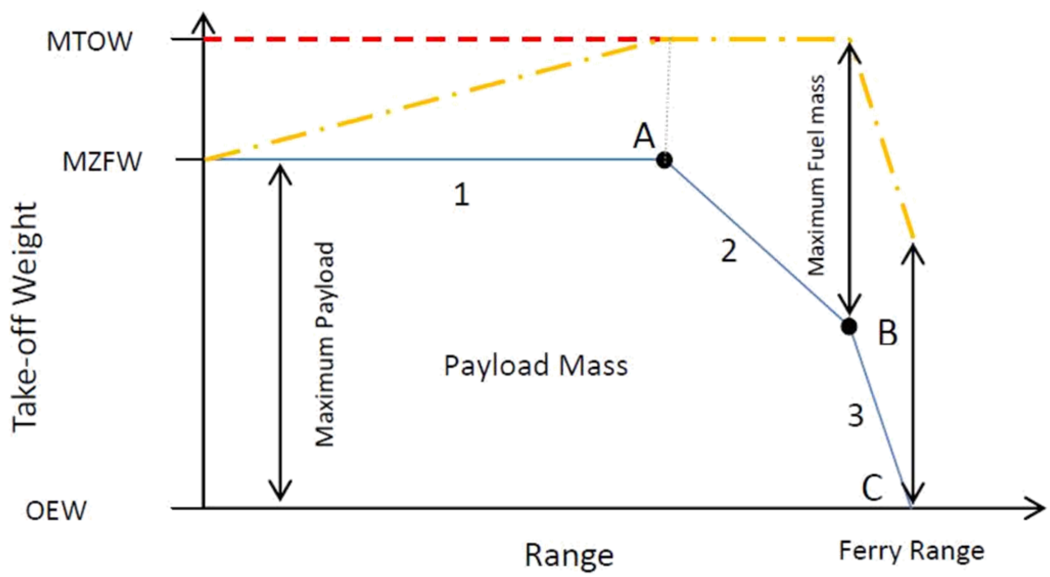

Fig 15. Extended Payload Range Chart.

Section 1 shows the maximum possible payload for an increasing volume of fuel that can be carried by aircraft up to the point A range which is known as an aircraft's design point. The maximum take-off weight is achieved at this stage but the fuel tanks can also hold more fuel.

A payload reduction, visualized in section 2, is necessary for achieving additional range. At the same time the amount of fuel for required for additional range increases. At point B the fuel tanks are fully filled for the first time. The fuel tanks remain fully filled from this point on. Every incremental expansion in the range includes a greater decrease of the weight, as illustrated in line 3, before the ferry range can be flew. No extra payload can be carried onboard the aircraft at this range (Burzlaff et al., 2017).

4.2.7 Different Fuel Consumption Visualizations

This section deals with the different ways of the representation of an aircraft’s fuel consumption. Three kinds of charts will be explained, which is based on the fundamentals discussed in the previous chapters.

a. Fuel vs. Range Chart

The fuel vs. range chart visualizes the amount of fuel that is needed to fly a specific range. An example is given in Fig 16, where the fuel load independence of the range of the reference aircraft, an A330-200F with 233000 kg MTOW, is demonstrated (Aircraft Characteristics - A330, 2020).

This illustration (see Fig 16) shows a linear development of the fuel curve with an rising slope at 4700 km. The slope stops at around 9000 km, and an almost constant amount of fuel is achieved, which is retained until the aircraft's ferry range. Here too , three parts listed in the payload range table can be noticed. Point A is at 4700 km, at the decline of the slope. At this point the first reduction in payload is needed (Burzlaff et al., 2017). At a slightly smaller slope the curve increases onwards. There, the decreased volume of payload is responsible for the smaller rise in the fuel required. If the curve reaches point B the fuel efficiency of the aircraft should be in full operation. So the fuel amount can no longer be raised and stays at a fixed level of approximation, f or this case, its 82000 Kg. Point C can be reached at the end of the curve at the ferry range of the plane, i.e. at 13600 km (Burzlaff et al., 2017).

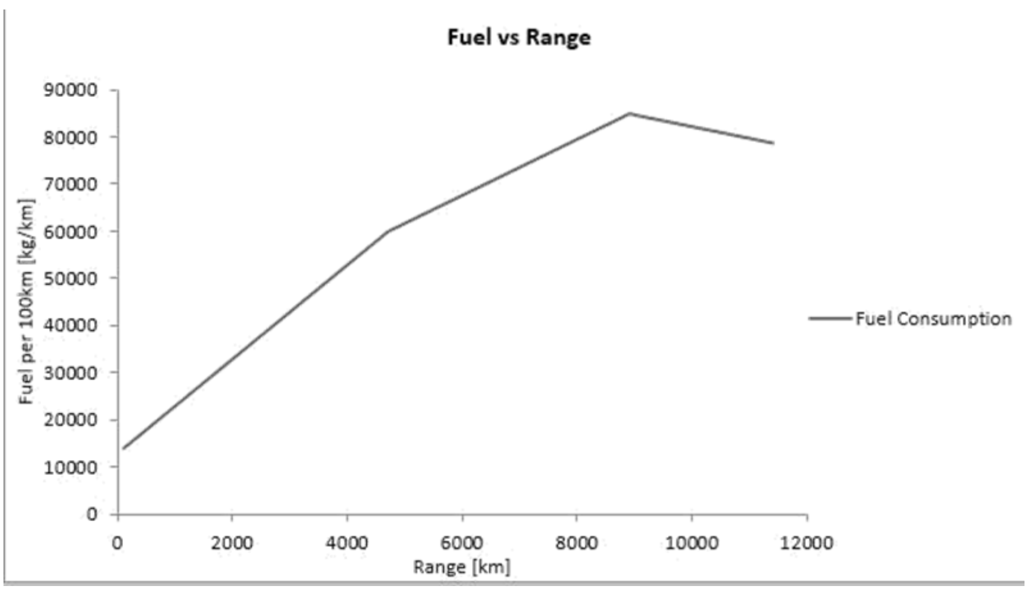

Fig 16. Fuel Consumption vs Range of an A330-200F

Sample Calculations:

Point	Range	Take-off weight	Landing weight
A	R_1 = 6000km	MTOW+Max.Payload = **301000*** kg	MZFW=**173000**kg
B	R_2 =10200km	MTOW=**233000** kg	MTOW-(MFW/R_3)*R_2 –$Payload_B$ =**132524** kg
C	R_3 = 13600km	OEM+MFW+(MFW-(MFW/13600) *11500)=**194429** kg	OEM+(MFW-(MFW/13600)*11500=**115882** kg

Table 13. Range and Mass of support points in Payload-Range Diagram
*factor of safety = 0.34%

Point A: $B_a = \frac{R_1}{10.38\ ln\frac{take-off}{landing}}$; $B_a = \frac{6000}{10.38\ ln\frac{301000}{173000}} = 1043.73km$

Hence, m_f/100km=(67000/100)(exp (4700/1043.73)-1) = 59000kg/km

b. Fuel/Range vs. Range Chart

A first glimpse into the fuel capacity of the aircraft is offered in the Fuel / Range vs. Range Graph. Based on the data, fuel consumption can be viewed on a certain range per kilometer on its own. The example given in Figure 17 indicates the amount of burning fuel across the spectrum of kilograms per kilometre. The curve is asymptotic, and reaches 7.4 kg / km. From this model it can be inferred that on short haul flights the fuel burning per kilometer is clearly higher than the fuel burning on a longer haul flight (Burzlaff et al., 2017). The short cruise flight on a medium haul range flight is triggering this behaviour. Compared with longer flights, the share of climb travel, where the increasing fuel consumption exists, is considerably higher in shorter flight periods. In comparison, the proportion of savings is often greater than on a longer flight. This form of visualization shows an increased efficiency at longer flight distances of its own. The lower fuel consumption is due to the declining share of fuel supplies on longer flights. For this form of example, the effect on longer ranges, where fuel has been transported to carry fuel and its resulting inefficiency is not noticeable, because only absolute values are used, which do not mean a decrease of the weight at longer distances (Burzlaff et al., 2017).

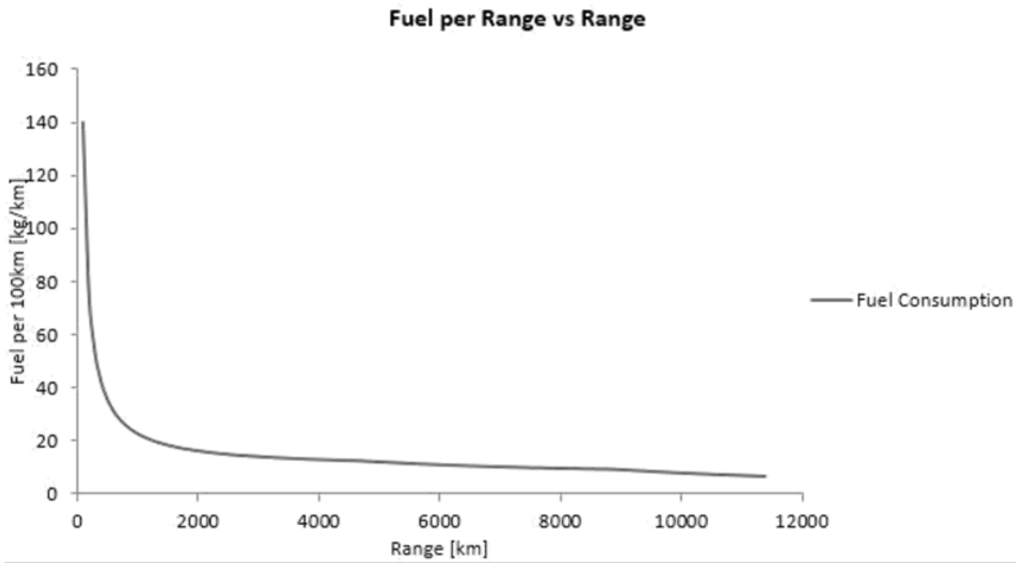

Fig 17. Fuel/Range vs. Range Chart of A330-200F

c. Fuel/Payload vs. Range Chart.

A large amount of fuel is required for the long-haul flights to cover the distance. The amount of fuel has a significant effect on the take-off weight of the aircraft. Due to the higher weight and the resulting higher required thrust, more fuel is needed to bear this mass of fuel on longer parts. The Fig 18 shows the connection, including the decrease in payload, between the fuel required per kilogram of payload across the period. The reference aircraft is an Airbus 330-200F, a traditional aircraft still used to support long-haul flights (Burzlaff et al., 2017). Figure 18. displays the amount of fuel needed to transport one kilogram of payload over a given range. The graph is easily visible, with an increasing slope. It is obvious in regards to a long-range flight that the longer a flight lasts, the more fuel for the payload needs to be transported. Unlike previous tables, the results of the rising inefficiency are detected. Whereas a flight of a distance of 5300 km requires about 1 kg of fuel for 1 kg of payload, the flight distance of 9100 km requires 2.14 kg of fuel for 1 kg of payload (Burzlaff et al., 2017). This impact is demonstrated at an area of 11400 km, where 7.1 kg of fuel is required for each kilogram of payload.

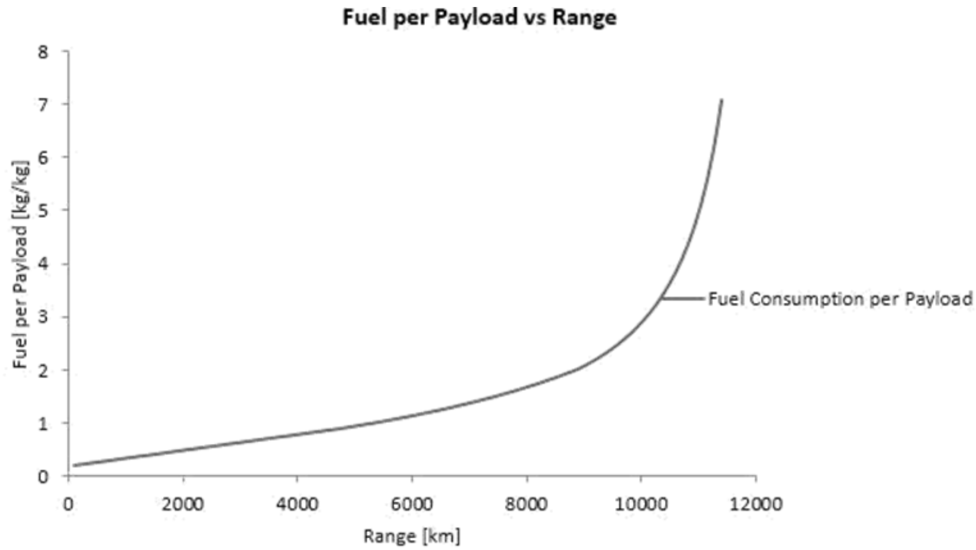

Fig 18. Fuel per Payload vs Range of A330-200F

4.3 Fuel Mass calculations and Visualizations using Excel

The Excel file consists of one sheet, divided into five parts. The first results analyzed payload range diagram data. Because the details given by the suppliers differ in terms of units, there is a specific conversion method for translating between pounds and kilograms as well as nautical miles and kilometres.

It should be noted that only the weights of payload in the first section are needed for calculation. Some manufacturers may add the weights of the payload to the Operating Empty Weight (OEW). In this case, the empty operating weight must be subtracted from the weight of the payload. To figure out if the data supplied is the payload weight including the empty operating weight or just the payload, the user has to make a comparison. Operating empty weight and full take-off weight (MTOW) are usually considerably greater than the payload weight (Burzlaff et al., 2017).

The second section includes the data on weights already presented in the documentation on 'Airplane characteristics for airport planning.' The Cumulative Fuel Weight Unit (MFW) is given in the same unit as the other details about the weights. In addition, this should mention a passenger's average weight. The third section deals with settings on estimation. As mentioned in the previous chapter, payload reduction can be achieved using two methods. First, when lowering payloads becomes required, the entire cargo becomes eliminated until the number of passengers starts to decline. The second form concurrently proposes reduction of the freight and passenger. There are three approaches which can be used for reserves (Burzlaff et al., 2017). The 'International' reserve contributes 10 percent to the distance from the route, additionally holdings for 30 minutes at a speed of 220 knots (which results in an overall additional fighting distance of 204 km) and the distance to alternate. The 'Domestic' reserve consists of a hold at a speed of 220 knots for 45 minutes (which results in an additional fighting distance of 306 km) and the distance to the alternate airport. In the field 'Alternate' at the right side, the distance to the

alternate can be specified for both methods (Burzlaff et al., 2017). The 'Custom' reservations can be specified by both 'Loiter' (Holding) and 'Alternate' fields.
The interval of plotting defines the range measures, where the amount of fuel is measured and ploted. A low amount will lead to longer calculation time. The user is asked to join the range by using the 'Calculate' button, before the fuel characteristics can be displayed. Once the ferry spectrum is reached, the estimate immediately halts. The size depends on how many stocks there are. The fourth section contains the estimation figures, provided that there are three separate diagrams as well as the amount of fuel required for this flight. In addition , the maximum flyable distance is given using all the reserves (Burzlaff et al., 2017). The data for the diagrams resulting from the calculation can be seen on the right hand side of the segment. The fifth section is given at the first section's right side. Each portion includes the calculation of all the petrol. The three sections are the areas of the payload distribution diagram from the above points A, B , and C. Of both ranges each segment measures the fuel weight (Burzlaff et al., 2017).
The 'Seat Parallel Interpolation' section provides the interpolated number of passengers in the payload range chart at point B. It is used to cut cargo and passengers in parallel.

4.4 Summary and Comparison of Different Aircrafts.

A preliminary insight into the fuel usage of commercial aviation can be done with the fuel estimation based on the weights derived from the payload range diagram. The figures demonstrate the evolution of the efficiency of the aircraft, especially on long-range freighter flights. It is possible to reduce fuel by 40 per cent on the same route with nearly the same passenger load with the use of a modern aircraft. This accomplishment is made possible by the use of lightweight materials such as carbon-fiber - reinforced polymer and the improved technological efficiency, which requires two engines to be used instead of three or four (Burzlaff et al., 2017). Furthermore, by saving fuel, air emissions and exhaust gas emission are also minimized. A comparison of three modern aircraft is also made, and fuel consumption is calculated from aircraft manufacturer data and Breguet range equation. The plots can be found in the excel sheet and Appendix 9.7 which is supplemented with this report.

4.5Simulations for Averaged Out Fuel consumption using PianoX.

PianoX is a unique professional instrument used to analyze commercial and freighter aircraft. It is used by airframe and engine suppliers, aviation research organizations, and governmental or decision-making agencies worldwide in preliminary design, competitor evaluation, performance reviews, environmental pollution assessments, and other development activities (*Piano-X*, 2020). PianoX takes into account the Breuget Factor and compares the fuel consumption of different aircraft over their entire range with the Original Equipment Weight plus the additional payload required for the cargo.

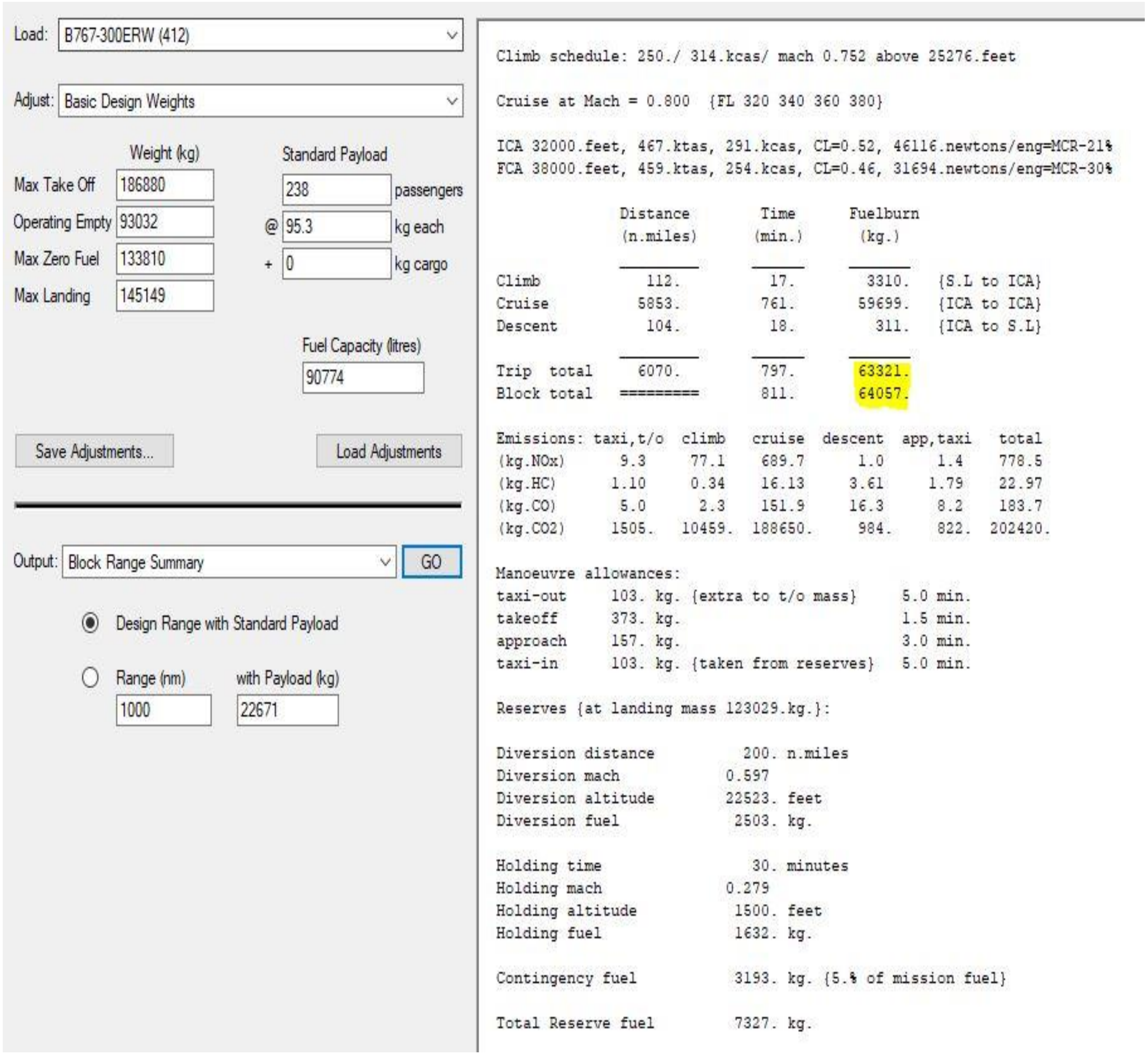

Fig 19. PianoX simulation for Boeing 767 (*Piano-X*, 2020).

The sample fuel consumption calculations using the PianoX Simulations is comparable to the calculations being used by the ICAO fuel consumption calculator and corresponds to the average weighted fuel consumption as depicted in the ICAO datasets for different set of aircrafts. Also, there is no availability of official confidential data by different aircraft about fuel consumption for different payloads and specific ranges, which can be found specifically using the Breguet range equation, as discussed in the previous sections of this chapter. Hence, the averaged out ICAO values are to be taken into account for the carbon emission model. These values correspond to an extensive list of 116 aircrafts that are operational for freight transportation for PostNL. This also helps the management team to figure out the exact fuel consumption values making the calculation at their part much easier. However, if the management decides to gain an even closer estimate to the real values, then it is recommended to follow the Breguet range equation calculation method for the same. The figures in Appendix A2 describes the fuel consumption pattern datasets for different aircraft over a designated distance scale.

	Fuel (in kg) for given Great Circle Distance (in km)																
Type Designator	0	500	1000	1500	2000	2500	3000	3500	4000	4500	5000	5500	6000	7000	8000	9000	10000
A20N	603	2,225	3,543	4,861	6,179	7,497	8,815	10,133	11,451	12,769	14,087	15,405	16,723				
A21N	839	2,081	3,497	5,102	6,707	8,312	9,917	11,522	13,127	14,732	16,337	17,942	19,547	22,757			
A306	2,718	5,586	8,454	11,322	14,190	17,057	19,925	22,793	25,661	28,529	31,396	34,264	37,132	42,868			
A310	1,579	4,434	7,289	10,145	13,000	15,855	18,710	21,565	24,420	27,276	30,131	32,986	35,841	41,552	47,262	52,972	
A318	1,052	2,462	3,849	5,233	6,617	8,000	9,384	10,767	12,151	13,535	14,918	16,302	17,685				
A319	865	2,628	4,064	5,393	6,854	8,315	9,776	11,237	12,698	14,159	15,620	17,081	18,542				
A320	975	2,698	4,211	5,725	7,238	8,751	10,496	12,241	13,986	15,731	17,476	19,221					
A321	688	2,965	4,767	6,569	8,371	10,173	11,975	13,777	15,579	17,381	19,183	20,985	22,787				
A332	2,045	5,252	8,018	10,784	13,550	16,843	20,261	23,679	27,096	30,514	33,932	37,350	40,768	47,603	54,439	61,275	68,110
A333	1,813	5,970	9,936	13,248	16,561	19,873	23,186	26,498	29,811	33,123	36,436	39,748	43,061	49,686	56,311	62,936	69,561
A343	2,789	6,689	10,589	14,200	17,811	21,422	25,033	28,644	32,255	35,866	39,479	43,756	48,032	56,585	65,138	73,691	82,244
A346	4,424	8,226	12,027	15,829	19,630	23,431	28,700	33,969	39,238	44,507	49,776	55,045	60,314	70,852	81,390	91,928	102,466
A359	3,416	6,572	9,727	12,883	16,038	19,194	22,349	25,505	28,689	32,324	35,960	39,595	43,231	50,502	57,773	65,044	72,315
A388	4,474	11,646	18,818	25,990	33,162	40,334	47,506	54,678	61,850	69,022	76,194	83,366	90,538	104,882	119,226	136,767	154,922
AN26	228	1,736	2,944	3,701	4,458	5,215											
AT43	99	718	1,267	1,816	2,365	2,913	3,462	4,011	4,560	5,109	5,658						
AT45	98	857	1,488	2,119	2,750	3,381	4,012										
AT46	199	863	1,527														
AT72	185	863	1,541	2,219	2,897												
AT75	202	875	1,588	2,301													
AT76	177	917	1,616														
B190	97	446	795	1,144	1,493	1,842											
B38M	750	2,079	3,409	4,739	6,069	7,399	8,728	10,058	11,388	12,718	14,048	15,377	16,707				
B462	746	2,400	4,053	5,706	7,360	9,013											
B463	667	2,543	4,420	6,296	8,172	10,048											
B722	975	4,337	7,049	9,760	12,472	15,183	17,895	20,606	23,318	26,029	28,741	31,452					
B733	1,119	2,500	3,984	5,547	7,111	8,674	10,238	11,801	13,365	14,928	16,492	18,055	19,619				
B734	704	2,797	4,525	6,177	7,830	9,483	11,136	12,789	14,442	16,095	17,748	19,401	21,054	24,359	27,665	30,971	34,277
B735	982	2,515	4,047	5,580	7,112	8,645	10,177	11,710	13,242	14,775	16,307	17,840	19,372	22,437	25,502	28,567	
B736	1,086	2,300	3,515	4,804	6,112	7,420	8,728	10,036	11,344	12,652	13,960	15,268	16,576	19,192			
B737	794	2,399	3,871	5,342	6,814	8,285	9,757	11,228	12,700	14,171	15,643	17,114	18,586				
B738	655	2,639	4,201	5,762	7,323	8,885	10,446	12,007	13,568	15,130	16,691	18,252					
B739	1,215	2,874	4,534	6,193	7,853	9,513	11,172	12,832	14,491	16,151	17,811						
B744	6,221	11,435	16,648	21,862	27,076	32,290	37,728	43,675	49,621	55,568	61,514	67,460	73,407	85,300	98,281	113,677	129,072
B748	6,391	11,634	16,878	22,121	27,365	32,608	37,852	43,095	48,339	53,582	58,826	64,069	69,574	82,354	95,134	107,914	120,694
B752	1,520	3,627	5,733	7,840	9,861	11,793	13,725	15,657	17,589	19,521	21,453	23,385	25,317	29,181	33,045		
B753	1,443	3,863	6,283	8,702	11,122	13,542	15,962	18,381	20,801	23,221	25,641	28,061	30,480	35,320	40,159		
B762	1,457	4,302	7,148	9,993	12,838	15,683	18,529	21,374	24,219	27,065	29,910	32,755	35,601	41,291	46,982	52,672	
B763	1,650	4,440	7,230	10,020	12,809	15,599	18,389	21,179	23,969	27,060	30,294	33,528	36,763	43,231	49,700	56,168	62,637
B764	1,883	4,889	7,895	10,901	13,907	16,913	19,919	22,925	25,930	28,936	31,942	34,948	37,954	43,966	49,977	55,989	62,001
B772	3,137	6,911	10,685	14,459	18,233	22,007	25,781	29,555	33,329	37,103	40,877	44,651	48,425	55,971	65,216	74,461	83,706
B773	3,765	8,064	12,363	16,662	20,961	25,260	29,844	34,463	39,082	43,701	48,320	52,939	57,558	66,796	76,034	85,272	94,510
B77L	3,309	7,275	11,240	15,206	19,171	23,137	27,102	31,068	35,034	40,416	45,797	51,179	56,560	67,323	78,089	86,071	94,053
B77W	4,807	8,738	12,670	16,601	20,533	24,464	28,396	32,328	37,385	42,443	47,500	52,558	57,615	67,730	77,850	86,991	96,132
B788	2,324	4,864	7,404	9,944	12,483	15,356	18,230	21,103	23,977	26,850	29,724	32,597	35,471	41,218	46,965	52,712	58,459
B789	2,235	5,163	8,091	11,019	13,947	16,875	19,803	22,731	25,660	28,896	32,132	35,368	38,604	45,076	51,548	58,020	64,492
C550	190	617	945	1,270	1,596	1,921	2,246	2,571									
C56X	207	758	1,103	1,447	1,792	2,136	2,481	2,826									
C68A	385	970	1,429	1,866	2,304	2,742	3,179	3,617	4,055	4,493	4,930	5,368	5,806				
CL30	336	980	1,579	2,050	2,521	2,992	3,463	3,934	4,405	4,876	5,347	5,818					
CL35	288	1,020	1,476	1,932	2,397	2,898	3,399	3,900	4,401	4,902	5,403	5,904					
CL60	347	1,084	1,677	2,270	2,862	3,455	4,047	4,640	5,232	5,825	6,417	7,010	7,602	8,788			
CRJ1	459	1,224	1,980	2,659	3,338	4,017	4,696	5,375	6,054	6,733	7,412	8,091	8,770				
CRJ2	247	1,201	2,037	2,872	3,708	4,544	5,379	6,215	7,050	7,886	8,721	9,557	10,393				
CRJ7	499	1,670	2,652	3,634	4,616	5,598											
CRJ9	545	1,745	2,779	3,801	4,822	5,843											
CRJX	517	1,853	2,905	3,956	5,006												
D328	141	674	1,208	1,741													
DH8D	303	1,117	1,931	2,746	3,560												
E135	388	1,219	1,893	2,567	3,241	3,915	4,591	5,103	5,615								

Table 14. Fuel Consumption Dataset (ICAO, 2018)

9. Average Seating Capacity

Aircraft also have a different seating capacity, and each seating capacity takes up a distinct amount of room in the plane. This leads to a differentiated value of payload on different aircraft resulting in different fuel mass consumption for various aircraft. Aircraft passenger capacity is often restricted because first, and business class seats take up more space. In other words, if the cabin space was minimized, the same aircraft could carry more passengers. However, If an aircraft had more seating space, more people would fit into the plane, and there would be fewer emissions per passenger. This seating weighting factor is used for each distinctive type of aircraft in the model. Seat Guru is used to producing a valid and extensive list of average seating capacity of different flights flying in a different direction all over the world (Seat guru, 2020). The ICAO dataset mentioning average seating capacity is also considered for obtaining the required data for flights flying over the European region. These datasets are provided in the Appendix 9.5.

The following table illustrates the seating capacity of different planes PostNL uses in its routes.

Flight Type	No. of Seats		Flight Type	No. of Seats
BOEING 787-8	293		BOEING 737-823	189
BOEING 747-4H6F	344		EMBRAER 190-100AR	98
BOEING 777-F6N	220		BOEING 767-323ER	220
BOEING 777-367ER	357		BOEING 777-333ER	357
BOEING 747-87UF	344		BOEING 767-300	220
BOEING 777-F1B	20		BOEING 737-8B6	189
BOEING 737-8JP	189		BOEING 737-700	135
Boeing 757-308	152		AIRBUS A330-204	281
BOEING 747-830	344		BOEING 777-236ER	246
Embraer 195	120		BOEING 757-223SF	170
Embraer 190-200LR-195LR	98		DHC-8- 400 DASH 8Q	60
BOEING 737-89P	189		AIRBUS A350-941	291
BOEING 737-900	176		BOEING 777-300	340
BOEING 737-958ER	176		AIRBUS A330-342	278
BOEING 777-2J9ER	220		BOEING 787-9	263
BOEING 767-3Z9ER	220		AIRBUS A330-323	278
BOEING 777-240LR	220		AIRBUS A330-302	278
BOEING 737-8Q8	189		BOEING 777-31HER	164
BOEING 777-200	223		AIRBUS A350-900	291
BOEING 777-300ER	300		BOEING 787-8	293
BOEING 777-F	220		BOEING 737-860	189
BOEING 777-FDZ	220		BOEING 777-200LR	223
Boeing 737-4Y0F	85		AIRBUS A330-200	352
Boeing 747-8HVF	344		AIRBUS A340-642	307
Boeing 747-400	344		CR9	88
Boeing 747-8	344		AIRBUS A319-115	152
Boeing 747-46NERF	344		BOEING 747-830	189
Boeing 747-8F	344		AIRBUS A320-214	175
Boeing 747-8HVF	344		BOEING 777-300ER	300
Boeing 747-46NERF	344		BOEING 737-866	189
Boeing 747-412F	344		AIRBUS A320-251N	175
Boeing 737-8F2	189		AIRBUS A330-343E	298
Boeing 767-322ER	220		AIRBUS A330-300	298
Boeing 787-9	293		BOEING 767-3Z9ER	220
Bombardier BD-500-1A11-CS300	78		BOEING 737-8FZ	189
AIRBUS A321-232	198		AIRBUS A300	247
AIRBUS A319-112	152		AIRBUS A320-232	175
AIRBUS A319-111	152		BOEING 747-8HVF	344
AIRBUS 320-214	175		BOEING 777-312ER	357
AIRBUS A350-941	298		BOEING 777-2D7ER	220
AIRBUS 321-231	215		BOEING 767-424ER	220
AIRBUS 321-251NX	215		BOEING 777-200ER	220
AIRBUS 320-232	175		BOEING 737-7M2	135
AIRBUS 320-233	175		AIRBUS A380-842	499
AIRBUS A220-300	140		BOEING 747-8	344
AIRBUS 350-941	298		Airbus A380-841	868
AIRBUS A350-941	298		Airbus A350-941	298
AIRBUS A330-343E	298		Airbus A321	215
AIRBUS 319-112	152		Airbus A330-223	352
AIRBUS A321-231	215		Airbus A321-271NX	215
AIRBUS A319-132	152		Airbus A319-111	152
AIRBUS A320-251N	175		Airbus A330-223	352
AIRBUS A320-21N	175		Airbus A350-1000	298
AIRBUS A320-211	175		Aerospatiale ATR 42-50	45
Airbus A330-243F	352		BOEING 737-86N	189
Airbus A300B4-622R(F)	323		BOEING 737-85R	189
BOEING 777-223ER	223		AIRBUS A330-203	352
BOEING 737-800	189			

Table 15. Average seating capacity for the different aircrafts (Seat guru, 2020).

10. Total Payload Calculations

Passenger aircraft frequently carry substantial amounts of freight and mail, especially on long-haul flights with wide-body planes. Moreover, some of the aircraft's total emissions have to be allocated to the freight. To keep in compliance with the European standard (DIN EN 16258, 2012), air freight is now allocated by weight (mass approach). The weight for each passenger air carrier and freighter is determined by the number of aircraft seats, the passenger load factor, and the passenger to freight ratio. , Passenger-to-freight ratio is the amount of passenger aircraft cargo. Passenger payload is therefore determined by multiplying the number of passenger seats and the industry average of 100 kg for passenger weight and baggage allowance for check-in (ICAODATA, 2019). By default, the model used ICAO passenger load and passenger-to-freight factors for each route(ICAO, 2018).
Total payload calculation for belly and cargo flights can be as follows.

Total Passenger Fuel Usage = [(Total Passenger Weight / Total Weight)] x Total Fuel Used
Where, Total Weight = Total Passenger Weight + Total Freight Weight

Total Passenger Weight (kg) = (Number of Seats* 50kg) + (Number of Passengers* 100kg)

11. Radiative Forcing

Aviation has climatic impacts beyond those that result from its Co2 emissions, including impacts of its NOx emissions on tropospheric ozone and methane, water vapor, particulate emissions, and contrails / enhanced cirrus cloudiness formation. Aviation has also been shown to have an IPCC (1999) 2.7-fold cumulative radiative forcing of its Co2 radiative forcing onto a 1992 fleet (the so-called Radiative Forcing Index or RFI), excluding any impact of enhanced cirrus cloudiness that was too vague to have a 'best guess.'
More recently, (Sausen et al. , 2005) measured the fleet's radiative force for the year 2000, which implies an RFI of 1.9 based on improved scientific understanding. Some studies omit the impact of enhanced cirrus cloudiness compared to IPCC (1999), while others (e.g., Stordal et al., 2005) reiterated IPCC (1999) figures. Although multiplying Co2 emissions by the RFI is wrong, from the preceding, it is clear that the effects of aviation are higher than those of Co2. There is currently no efficient climate metric for communicating the relationship between aviation emissions and radiative effects. Aviation has specific climatic effects that are greater than those implied by considering only its own Co2 emissions.

5.2 Assumptions taken in the selection of variables for carbon emission calculation.

The selection of non-time dependent linear variables was an essential step in the calculation methodology. This would help PostNL in modifying, deleting, and adding new routes seamlessly in the current model itself. The acquired datasheets and aircraft specifications used in the model would help PostNL to continually monitor and modify the model without any discrepancies in the data. The smallest of changes to the state of an aircraft causes a change in its fuel consumption, which might not be immediately noticeable because of averaged out factors, but over a period, it is. Some of the assumptions made in the model has been discussed below:

1. **Weight of the Aircraft** - A heavier aircraft will consume more fuel compared to a lighter aircraft.
2. **Age of the Aircraft** - A newer aircraft will typically consume lesser fuel compared to an older aircraft.
3. **Flight Altitude** - Every flight has an optimum altitude that gives the best fuel economy. Flying above or below that optimum altitude (lower being the case mostly) will cause an increase in fuel consumption.
4. **Flight Speed**- Similar to the optimum altitude, every flight has an optimum speed as well, which will provide the best fuel economy. Flying faster or slower (faster being the case mostly) will cause an increase in fuel consumption.
5. **Aerodynamic factors** - Factors such as the CG (Center of Gravity) position, aircraft configuration (Flaps, landing gear, spoiler, trim, etc.) all-cause changes to fuel consumption.
6. **Radiative Forcing -** Aviation has impacts on climate beyond those arising from its CO2 emissions. These include impacts on tropospheric ozone and methane from its NOx emissions, water vapor, particulate pollution, and contrails / enhanced cirrus cloudiness formation.

5.3 Procurement Decision Making Simulation Model along with Optimization model to tradeoff between *Cost*, *Lead-time,* and *Co2*.

5.3.1 Procurement Decision Making and Simulation.

The optimization of supply chains gains more significance, driven by the high complexities of the markets. In industrial practice, various procurement methods and the effects of different sustainability criteria are difficult to achieve because of the increasing need to reduce annual carbon emissions. Simulations of supply chains are thus used to strengthen the processes of negotiation and air transportation procurement. Recent developments in the acquisition include the implementation of the ideals of sustainability in the way the entire procurement process is carried out. The need to enhance operational performance, minimize waste, resolve the risk of the supply chain, and attain a competitive position has made businesses start to understand environmental issues. A simulation is a model in the real world that imitates a process or a network. Decision-makers are concerned with the operational characteristics of a program. One way of assessing a system's operating characteristics is by witnessing the system in actual operation. From a theoretical standpoint, using computers to perform simulations is not necessary. Most simulations from a functional perspective are sufficiently complex to require the use of computer programs to run them.

5.3.2 Optimization Model for Cost-Lead time relative.

In order to achieve the objective of developing a model for optimizing costs and related lead time (KPIs) in PostNL, a logistics structure was evaluated and, as a result, significant subsystems, logistics processes, and most essential logistics costs and related lead time for air freight transport were identified. Using VBA in Excel, the results of the analysis were used to elaborate a conceptual optimization model. Strategic targets were decomposed into the priorities of the individual divisions at PostNL, articulated with the target values of the lead time and cargo cost performance indicators.

5.3.3 Building the models.

The first general move to research a system is to create a model. For most purposes of simulation, this will be a statistically-based model based where appropriate on empirical evidence. Such a model would be an abstraction of mathematics and a calculation methodology which approximates the reality of the situation under study. It is a constant problem to balance the need for detail with the need for a model that suits reasonable techniques of solution. Unfortunately, there is no guarantee that a model can be built successfully to accurately reflect the real-world relationships at play.

Built on Microsoft Excel, the simulation model allows the total cost of the system to be derived under the two scenarios, thus helping PostNL select the most appropriate (i.e., Cost-Leadtime Relative) transportation strategy. Another move is to take into account various linear variables (already discovered) to measure the emission factor per tonne-km for all aircraft operating on different routes under PostNL with the ultimate aim of minimizing annual carbon emissions within PostNL and achieving the sustainability targets of the organization.

Similarly, In businesses and organizations, the scope of logistics optimization has grown to tackle strategic, tactical, organizational, and collective decision-making. An estimation of the overall cost compared to the lead time is a widely used metric. This relative is chosen in the optimization model as the primary performance indicator(KPIs), which includes pickup time, handover time, total flight time, and overall transportation costs. This estimation is quantified into a process that identifies the optimum relative cost-lead time and determines the weight allocation in accordance with the user's requirements, subject to a number of constraints relating to cargo weight limits, source, destination and day of operation.

Chapter 6. Results

6.1 Analysis of Results

6.1.1 Carbon Emission Calculation.

There are currently no error-proof internationally accepted methodologies for allocating emissions from international aviation freight (Wood et al., 2010). The main concern surrounding the effective quantification of international aircraft emissions lies in the commercially sensitive existence of reliable, activity-based data on aircraft fuel consumption. The methodology, which is being used in the model developed for the calculation of marginal carbon emission due to freight and the total carbon emission by the aircraft, has been recognized to suit the requirements of the current research. The Zurich carbon emission calculator provides relevant results with the help of linear variables that are already obtained through this research and the sources of these varibales have already been discussed in the previous chapter. These linear variables are taken as such PostNL can modify, change, and add new routes whenever possible. Other calculators were also used to make sample emission calculations; however, due to the unavailability of some of the privately owned confidential data, the Zurich carbon emission formula was decided as the optimal solution for the problem.

The following equation has been applied for the estimation of the standard aircraft emission factor:

$$\boldsymbol{EF_{Region} = \frac{FB_{Flightblock} * EI_{CO2}}{Distance_{Flightblock/Region} * Payload}}$$

Where:

EF_{Region} = Emission factor [kg CO2 / t*km] per world region

FB $_{Flightblock}$ = Total Fuel Burn of aircraft [kg fuel] to that region

EI_{CO2} = CO2 [kg / kg fuel] emissions index

DistanceFlightblock /Area = Flight block distance [km] per particular region of the world

Payload = Passenger number (=Average no. of seats*Passenger load factor) *100 kg + Cargo Freight by PostNL(kg)

The resultant emission factor obtained by using this formula is further put into use to find the marginal emissions of the cargo freight in all the aircraft routes.

The emissions for an aircraft cargo shipment to a particular region are calculated using the equation:

CO_2 [kg] = EFRegion [kg CO_2/t*km] * Flight distance (GCD + correction factor) [km] * cargo mass [t]

However, It should also be noted that the belowmentioned picture depicts, that from Jan 2019 to December 2019, the KLM flight flying from NLAMS to AEAUH with flight no. KL0451 ships an average of 2710 kgs of freight dedicated to PostNL monthly and produces an average of 6732 kgs Co2 monthly calculated as per the current methodology.

Year/Month	Source	Destination	Flight No	PostNL Freight(in kgs)	Co2(Freight)
201901	NLAMSA	AEAUHA	KL0451	3181.26	7827.852126
201902	NLAMSA	AEAUHA	KL0451	2745.81	6841.838882
201903	NLAMSA	AEAUHA	KL0451	3088.41	7619.678504
201904	NLAMSA	AEAUHA	KL0451	2442	6139.001068
201905	NLAMSA	AEAUHA	KL0451	3318.21	8132.88372
201906	NLAMSA	AEAUHA	KL0451	2892.67	7177.157862
201907	NLAMSA	AEAUHA	KL0451	3030.51	7489.300466
201908	NLAMSA	AEAUHA	KL0451	2796.63	6958.197187
201909	NLAMSA	AEAUHA	KL0451	2917.67	7233.955717
201910	NLAMSA	AEAUHA	KL0451	3379.88	8269.464438
201911	NLAMSA	AEAUHA	KL0451	1352.35	3511.851649
201912	NLAMSA	AEAUHA	KL0451	1384.79	3592.565358

Average:	**2710 kgs**	**6732 kgs Co2**

Table 16. Route Based Information for NLAMSA-AEAUHA.

Company name	**Origin**	**Destination**	**Lead Time(hrs)**	**M Limit (KG)**	**T Limit (KG)**	**W Limit (KG)**	**Thu Limit (KG)**	**F Limit (KG)**	**Sat Limit (KG)**	**Sun Limit (KG)**
KLM	NLAMS	AEAUH	14	150	150	150	150	150	150	150

Table 17. Maximum Cargo Limit Data for NLAMS-AEAUH route.

It can be clearly noticed that if the aircraft operated seven days a week as per the cost-lead time datasets, there would be a maximum of 1050 kgs of registered freight load as per the mass. The maximum limit for the aircraft given the cargo limits would be 4200 kgs (1050*4) in a month. However, it is clear that the monthly upper limit for this dedicated route in the year 2019 was 3318.21 kgs, which is significantly less than the speculated maximum monthly cargo limit of 4200 kgs. This shows that the flight does not operate everyday in the specific route from NLAMS to AEAUH. However, without the specifications of how often a route was flown (every day/ weekday/once a week). It can also be seen that the maximum limit for a three week cargo flow within the dedicated route is 3150kgs(1050*3 weeks). This no. compares with the maximum cargo weight shipped in a month, as shown in the Table 16. Now , when we compare the average flown kgs monthly over the year 2019, it can be easily calculated as 2710 kgs of cargo. Now while comparing the three week cargo limit of 3150kgs to the average flow of 2710kgs i.e. (2710/3150=0.866), we get a factor of 0.86 which can be rounded off to 0.8. Similar sample calculations were done with different individual routes, and the factor of 0.8 was chosen to be a constant for the normalized calculation of the cargo weights. This factor is used in the model and calculations for the weighted average loss due to the actually flown kgs to the estimated kgs flown within the dedicated routes within PostNL. This factor also takes into account the comparable weighted average volumetric losses due to the usage of different parcel dimensions with different weights associated with them, which indirectly affects the capacity utilization factor of an aircraft in operation.

6.1.2 Emission Calculation Results.

All required data was extracted and linked in Excel for the emission calculations. A VBA interface was created and the methodology was put into action for the calculation of carbon emissions from air freight. The figure below shows two conditional drop-down boxes along with a cargo weight input box, which links different aircraft routes in which PostNL operates from the route management dataset. The user inputs the required value to get a list of aircraft types flying in the same direction with respective flight no's, emission factors, and marginal and overall Co2 consumptions in the specific route. Adjacent to the data table, a visual interpretation of the results is generated along with the data labels of "Aircraft name" and "Co2 emissions" generated (in kgs). This helps the user to quantify simulations and figure out which airline is the least polluting in the operational process. This tool can be vital in carrying out procurement and negotiation decision making with the aviation companies regarding the availability and use of specific aircraft.

Origin: NLAMS

Destination: PTLIS

Weight: 100

Aircraft Type	Flight Number	Distance (kms)	Emission Factor	Co2 (kg)-Freight	Co2 (kg)-Total
Airbus A319-111	TP0669	1877	0.75	125.74	21658.64
BOEING 737-4Y0F	KL1695	1877	1.22	205.31	19889.04
AIRBUS A330-300	TP0671	1877	0.76	127.25	42818.00
BOEING 737-4Y0F	KL1697	1877	1.22	205.31	19889.04
Airbus A319-111	TP1002	1877	0.75	125.74	21658.64

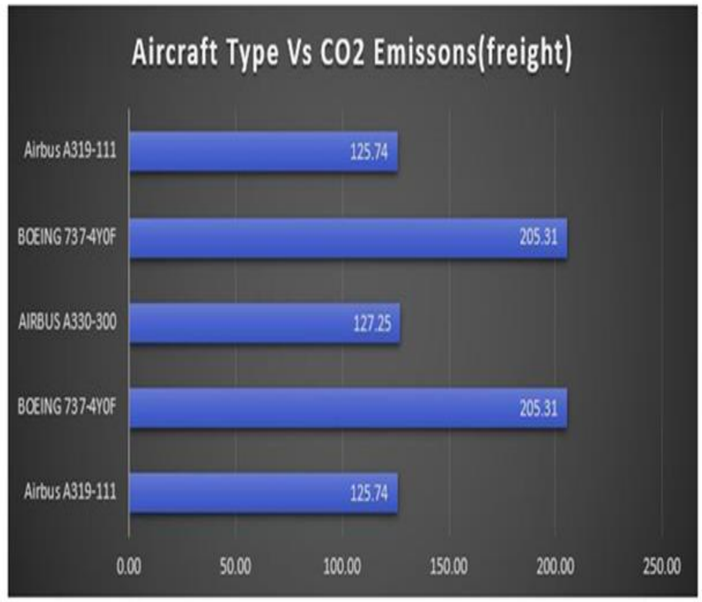

Fig 20. Emission Calculator and Data Visualization in Excel

6.2 Interpretation Of Results.

6.2.1 Comparison with the EU ETS Data.

Taking into account the characteristics of air traffic protected by the EU Emissions Trading Scheme (EU ETS), the Small Emitters (SET) calculator makes it possible to measure the fuel burned and related Co2 emissions for an entire flight. The EU SET internal aircraft type fuel burning, and emission models are based on a statistical method based on fuel-burning samples from operations on real-life flights. As a result, although the tool can measure estimated values (fuel and Co2) that may vary in real life from those of one single flight (with its unique PAX, wind conditions, ATC delays, cost index, aircraft sub-type variant,etc.), it still provides a very reliable estimated total fuel and associated Co2 emissions for a set of flights with one or more aircraft type (mixed fleet).

The following graphs show a comparison between the EU ETS calculations and the current calculations for four different flights, namely Airbus A319-112, Airbus A320-214, and Boeing 737-800. The graphs show almost similar trends to the current model and thus can provide some authenticity to the practical use of the model in organizations such as PostNL. It should be noted that while considering the calculation using the ICAO datasets, the distance used is taken as in the range of 500kms to 10,000 kms. However, in many situations, the distances recorded by a flight operating for PostNL has distance values which are not exact to the values represented by

ICAO. In such situations, the nearest rounded off values of distance is considered for the calculation and used for the determination of
the below-mentioned line graphs.

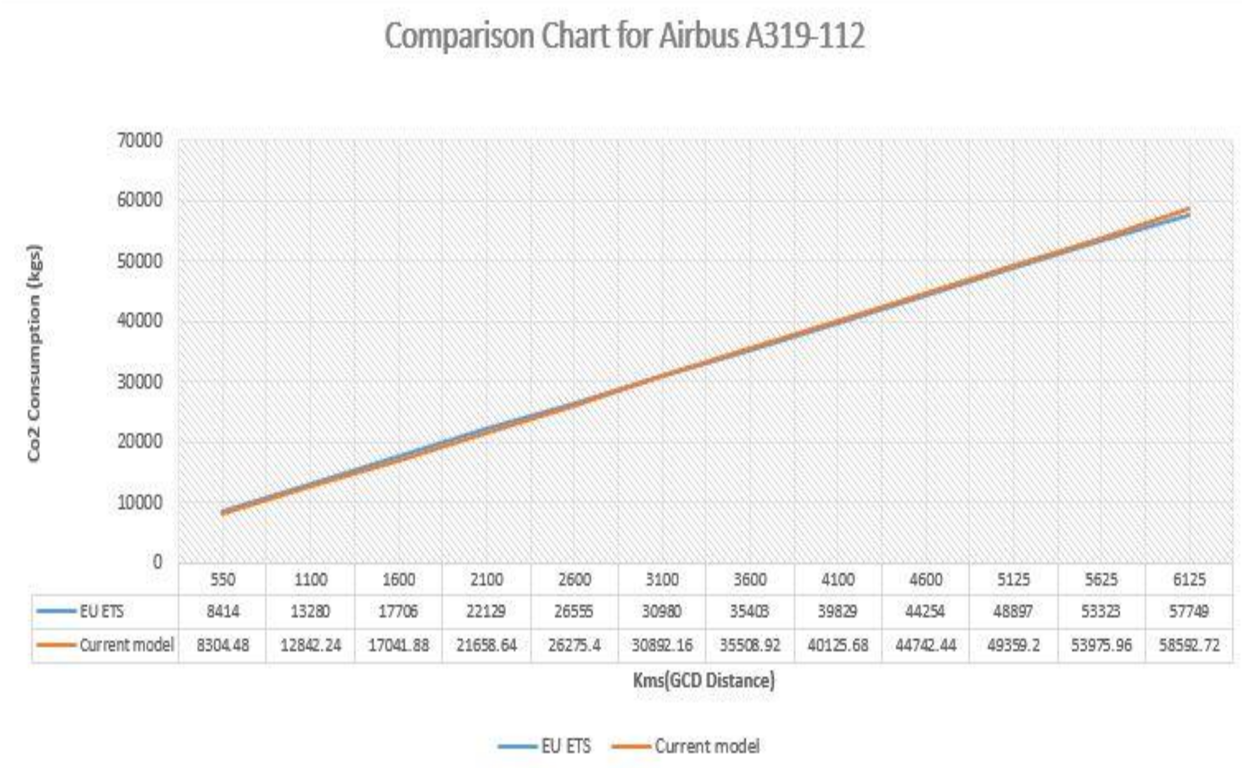

Fig 21. Co2 Emissions Comparison Chart for Airbus A319-112

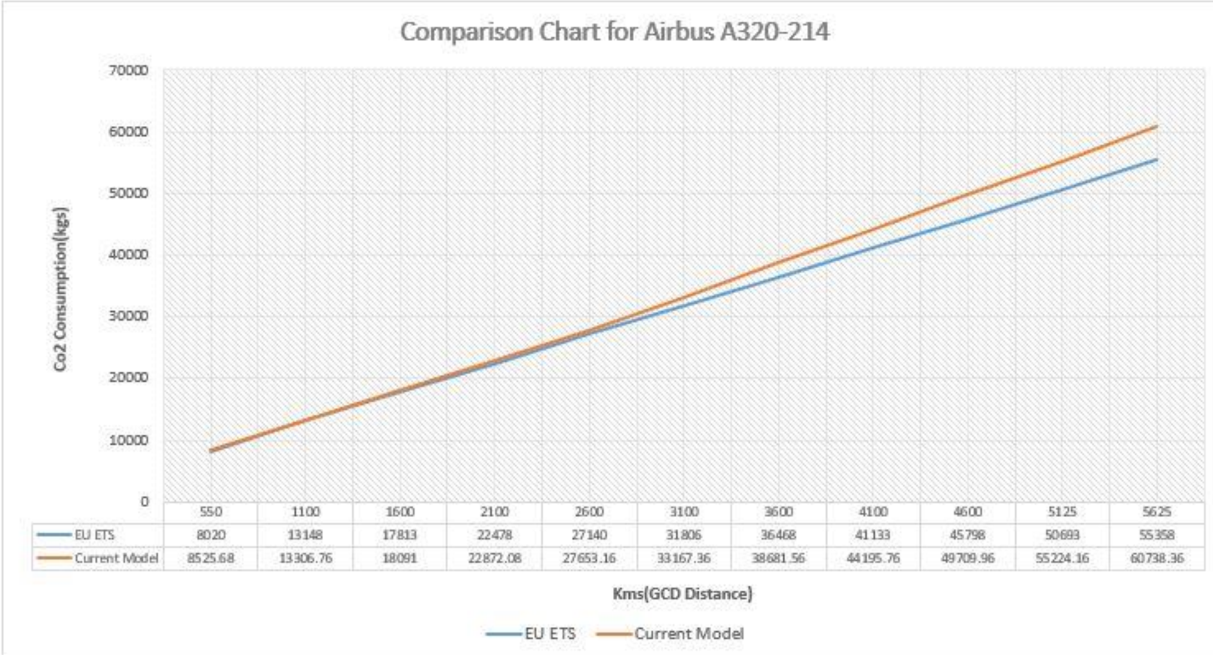

Fig 22. Co2 Emissions Comparison Chart for Airbus A320-214

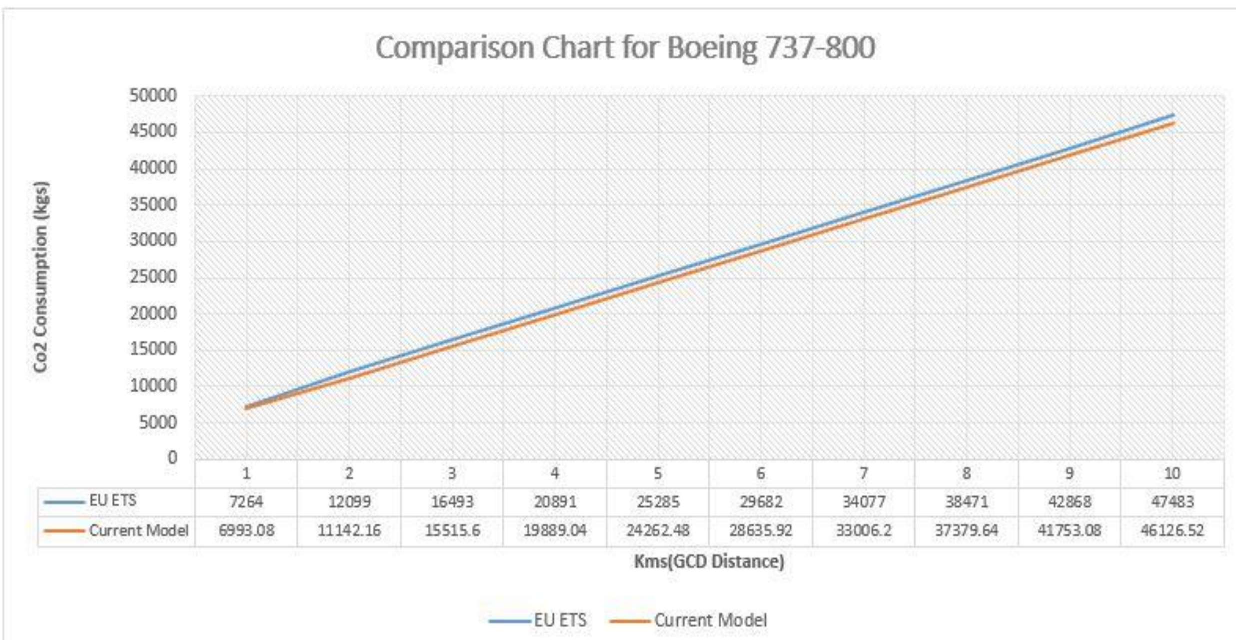

Fig 23. Co2 Emissions Comparison Chart for Boeing 737-800

6.2.2 Visual Interpretation and Comparison of Carbon Emissions by the Defra model and Current Model.

A statistical analysis was carried out using the model developed along different routes within PostNL and reported in the route management's IPS sheet. As explained in the previous chapter, PostNL continues to use the DEFRA method for the calculation of carbon emissions by their air freight. Comparing these emission values with the values obtained by the current methodology helps the company to evaluate the variations in their total yearly emissions and lets the top management take critical procurement and strategic decisions to minimize the same.

The graph mentioned below shows the deviation and comparison between the Co2 emissions between the Defra model and the current model. The first graph shows a three-legged route from BEBRU to LSMSU via ETADD and ZAJNB. The second graph shows a deviation chart from BEBRU to LSMSU, and it focusses on the emissions values comparison between the two models over the entire leg.

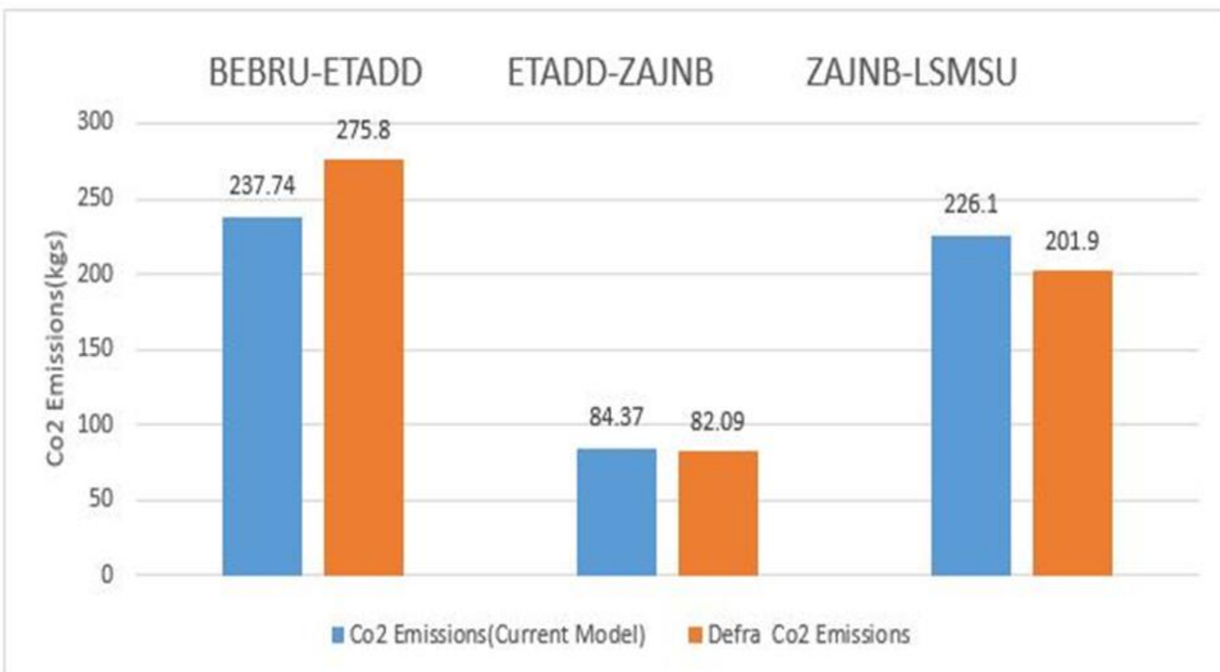

Fig 24. Co2 Emission comparison for a 3-legged route from BEBRU-LSMSU

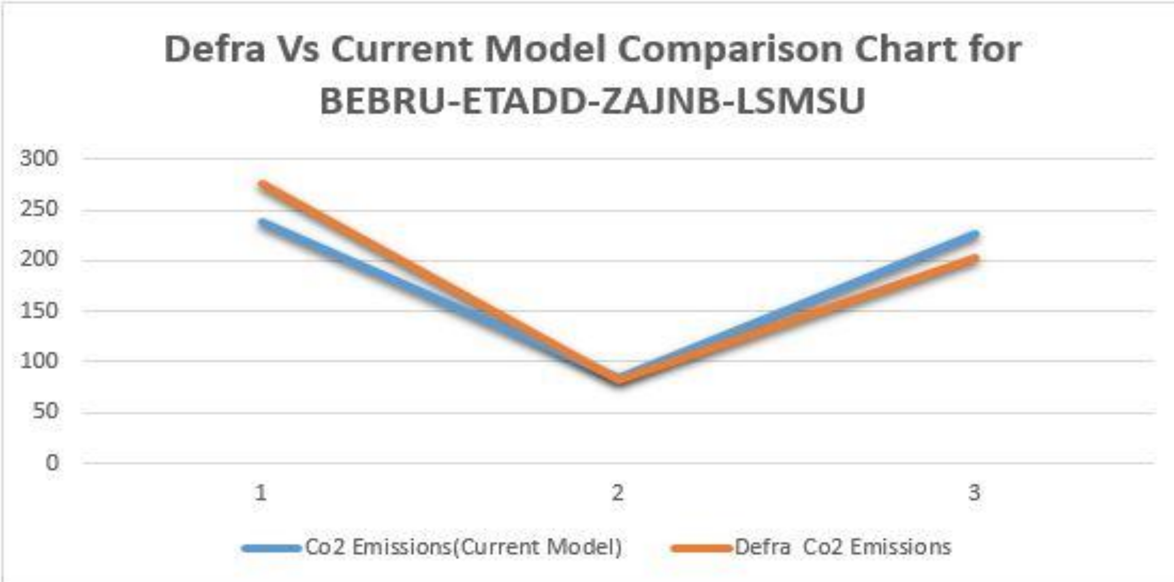

Fig 25. A line graph comparing Defra and Current model over the three-legged route from BEBRU-LSMSU

A deviation analysis was followed to compare the trends of the two models over the three-legged process from BEBRU-LSMSU. This explains how the current model shows an overall deviation of -2.05 percent in marginal emissions due to cargo freight put by PostNL. This has been visualized below in the form of a table.

Route	Route Type	Defra Model	Current Model	Deviation (%)
Leg 1 BEBRU-ETADD	Plane	275.78	237.74	-13.79
Leg 2 ETADD-ZAJNB	Plane	82.09	84.37	2.77
Leg 3 ZAJNB-LSMSU	Plane	201.9	226.19	12.03
Total BEBRU-LSMSU		559.7	548.3	-2.05

Table 18. Percentage deviation in the carbon emission values over the entire three-legged process.

A further trend analysis was carried out over 50 different routes from PostNL's route file, and a graph was plotted for the same. This graph showed a similar trend over multiple routes and can help in interpreting the comparison between the Defra model and the current model emissions. It can be easily seen from the graph that the emission values are consistent over a small range carrying the specific cargo weight. However, the emissions from the two models show considerable variation when the calculation is done over a greater range. This accounts for the variation in the values of the two-line graphs plotted. The overall yearly deviation in the carbon emissions due to air freight couldn't be successfully interpreted because of the involvement of multiple route segments (truck, ship, etc.) in the route management file. However, a detailed analysis of the carbon emissions involving air freight was carried out using the same route management IPS sheet.

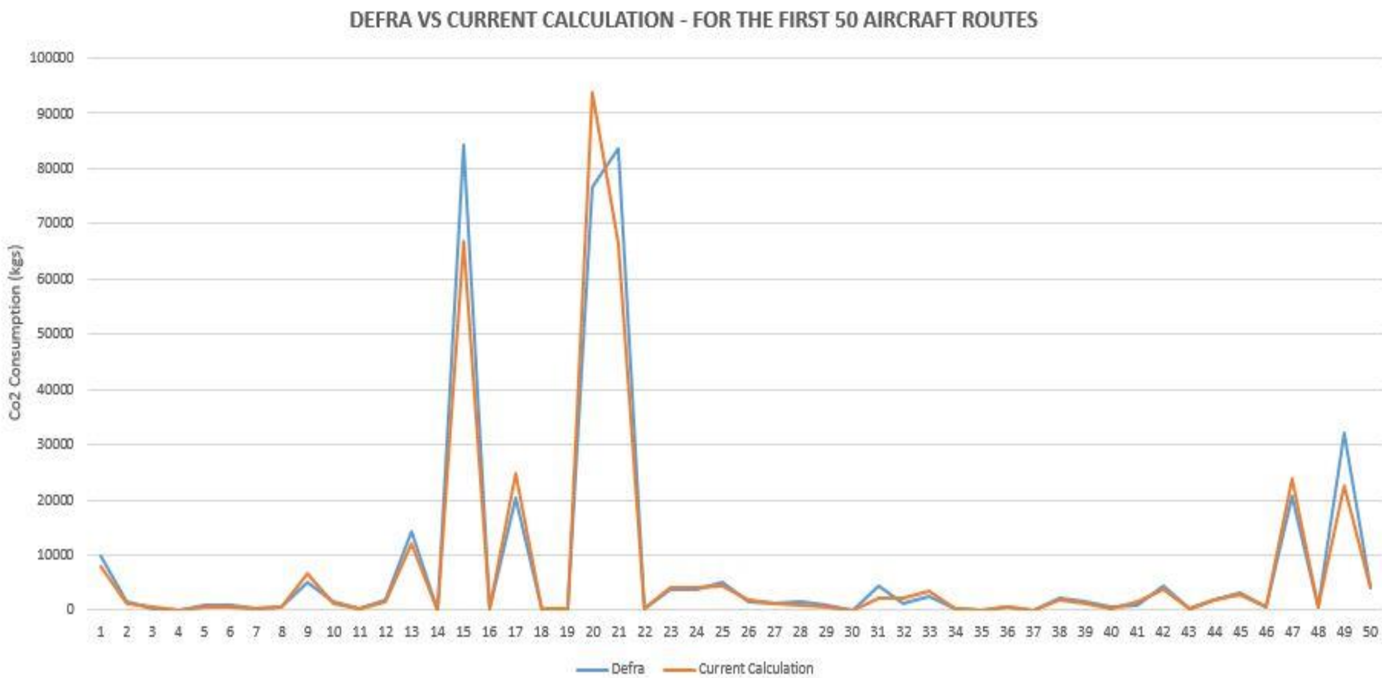

Fig 26. Comparison Chart for the first 50 aircraft routes from the route management file.

6.2.3 Simulation/Data Analysis and Optimization Model using VBA in Excel.

VBA is used as a primary simulation/data analysis method in the model development for PostNL. VBA is a programming language that Microsoft creates to apply for the Microsoft office kit, such as Word, Access, Excel, and others. It is used to configure the software to suit business needs. This is an effective and secure method to help in the data analysis repeatedly and continuously. It also allows users to customize beyond what is usually available with MS Office host applications by controlling graphical-user interfaces (GUI) elements such as toolbars and menus, dialog boxes, and forms. VBA can also be used to build user-defined functions (UDFs), access Windows application programming interfaces (APIs), and automate processes and calculations unique to your computer. VBA was chosen because most of the business-related activities such as route management, accounting, and finances are carried out in Excel, and VBA helps the user to control most of the excel operations smoothly and accurately. Using VBA Macros, financial reporting and review are carried out securely and accurately and can also help PostNL in their accounting purposes as per the management needs.

1. Simulation/Data Analysis.

Data Cleaning and Data Preparation.

Data cleansing or data cleaning is the method of identifying and correcting (or removing) defective or inaccurate records from a record collection, table or database and refers to the detection of missing, wrong, incorrect or irrelevant parts of the data and the substitution, alteration or deletion of dirty or coarse information. Data cleaning can be achieved by manual processing, scripting, either interactively with data wrangling software, or as batch processing. For the development of the current model, manual processing of data was carried out to remove detectable discrepancies in the data. The data in the "Cost-Lead-Time" was altered to match with the data in the "Aircraft Routes" file. This was an extensive process that reduces the processing time of the VBA code and results in quicker results. The preparation of the datasets is explained in Chapter 4.

Data Input.

Followed by this process, a "Userform" was developed, which is a custom dialog box that makes the entry of user data more controllable and more manageable for the user to use. Firstly, it allows the user to put in the "Origin" and "Destination" of the entire route. A conditional drop-down dependent list is created to link one "From" to "To" locations, which exists in the "Cost-Lead-Time" sheet. The user also has the option to put in the "Via" option on a dedicated route. This has been depicted in the below-mentioned snapshot of the UserForm.

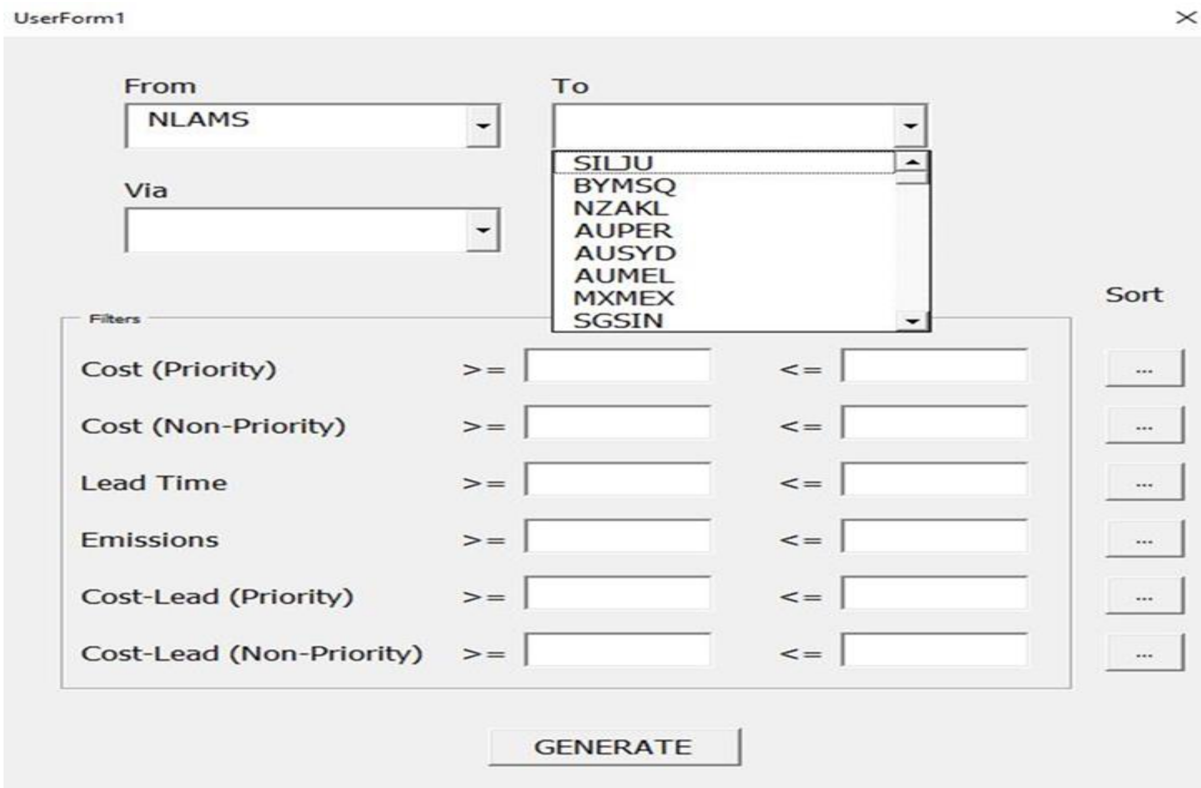

Fig 27. UserForm to Input Data

After putting in the routes, the user has the option to put in the “Day” from a drop-down validation list. This is an essential step in the process because each different day corresponds to a different set of data for the “cargo weight limit” to be carried by aircraft, lead-time, and cost (priority) and cost (non-priority). This data is being managed by the Tender Datasets discussed in Chapter 4. Followed by this, the user chooses the day out of the list containing days from “Monday” to “Sunday,” respectively. Finally, the user can opt to press the “GENERATE” button to generate a list of dedicated results. The user also has the option to put in the following constraints such as “Cost (Priority),” Cost (Non-Priority),” Lead Time,” Emissions,” Cost-Lead (Priority) and Cost-Lead (Non-Priority) to filter the results as per specific company requirements. This enables different department representatives at PostNL to be facilitated in having decision-making abilities to strengthen both their negotiation powers with their suppliers and having to enhance their business processes and supply chain processes with their customers as per their specific needs and requirements.

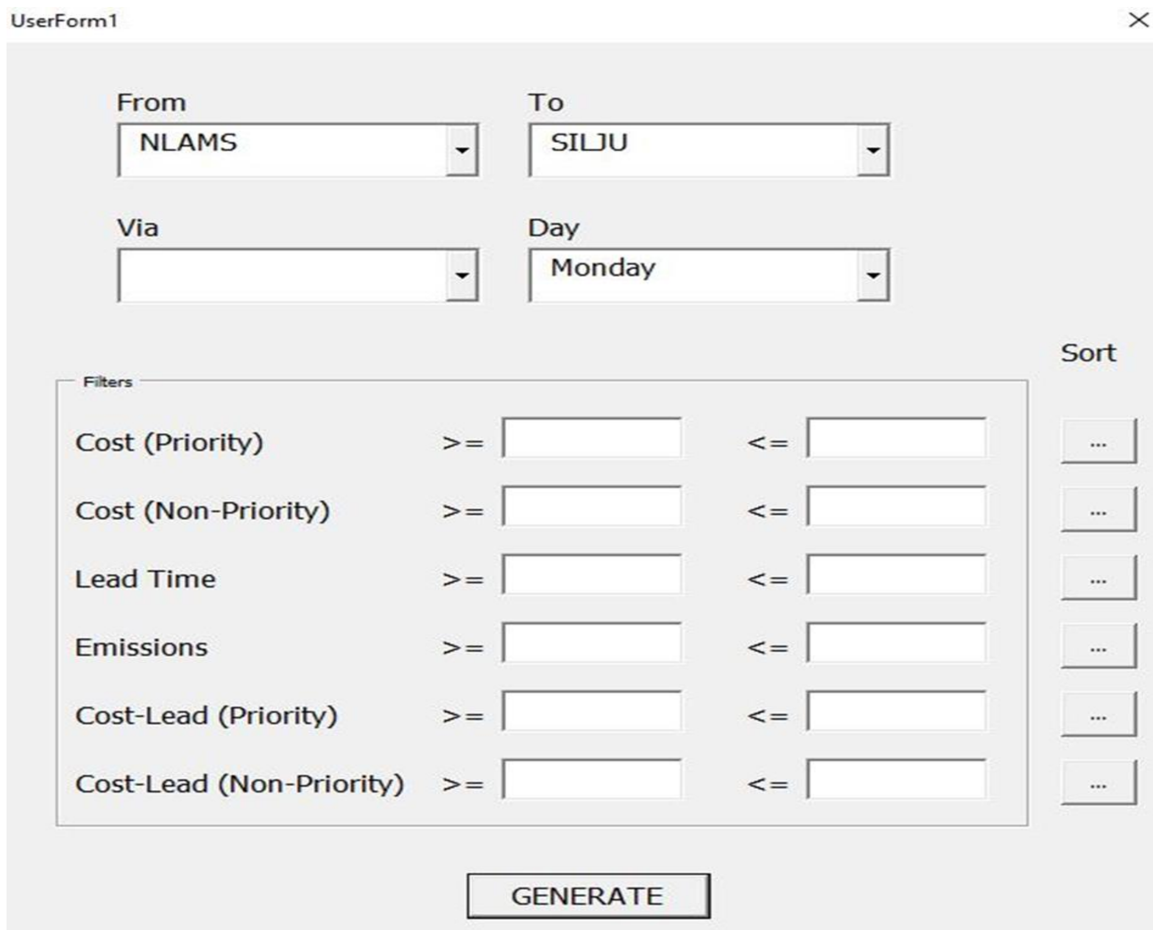

Fig 28. UserForm to Input Data

This also allows the user to make the best decisions for procurement and negotiations with the airline companies and other related clients. Cost-Lead (Priority) and Cost-Lead (Non-Priority) are two different performance indicators (KPIs) used to evaluate the cost of the shipment relative to the lead-time of the shipment. This relative is a measurable value that demonstrates how effectively a company is achieving key business objectives. It also helps in selecting the best aircraft option in terms of cost and lead time performance.

Simulation Results.

The pictures mentioned below show the results of the input entries in the “UserForm.” The result explicitly displays the “Route,” Distance,” Flight Number,” Aircraft Type,” “Cargo Weight Limit,” “Cargo Weight,” “Lead Time,” “Cost(Priority),” Cost(Non Priority),” Co2 Emissions”, “Cost-Lead (Priority), ”Cost-Lead (Non-Priority), ”Co2 Emissions/km”. The results also display a dynamically varying graph, which shows the amount of Co2 consumed for each input. The result allows the user to put in cargo weight within the restricted cargo limit displayed. The cargo weight cannot be set as a negative value. After the user places in the cargo weight, the model shows the marginal consumption for that specific amount of cargo weight. The model also depicts the aircraft specific emission factor for each resultant aircraft carrying a particular cargo weight. The dynamic graphs also change per the new allotted cargo weight and shows simulated results which can be interpreted easily by the user to figure out the best suited optimal results as per his/her business requirements. The UserForm can be used again to put more restrictions in the model itself and show filtered results. The UserForm also allows the user to put sorting options in the results, which penetrates the filters in the ascending order of their precedence value. This helps in selecting the least polluting and most polluting aircraft given the specific constraints from the whole lot.

						TOTAL	6554	1250				
Route	Distance	Flight Number	Aircraft Type	Cargo Weight Limit	Cargo Weig	Lead Time	Cost (Priorit	Cost (Non Priorit	CO2 Emissio	Cost-Lead (Priority	Cost-Lead (Non-Priority)	CO2 Emission s / K
NLAMS-SILIJU	966	JP0435	AIRBUS A330-343E	300	300	8	2997	345	224.22	23976	2760	0.7474
NLAMS-SILIJU	966	JP0499	AIRBUS A220-300	300	300	8	2997	345	208.30	23976	2760	0.69432
NLAMS-SILIJU	966	JP0435	AIRBUS A330-343E	400	400	9	280	280	297.86	2520	2520	0.74465
NLAMS-SILIJU	966	JP0499	AIRBUS A220-300	400	400	9	280	280	275.59	2520	2520	0.68898

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Fig 29. Excel VBA Output with Data Visualization for Carbon Emissions

2. **Optimization by allotting weights as per precedence.**

This is an additional part of my ongoing research at PostNL and uses the quick sort algorithm for its functioning. The quicksort algorithm is used in the code to "divide and conquer" the array around a pivot element. First, it defines a pivot value within your array, which is nothing more than a random component of the array. The macro definition assumes the element of the very center, but it could be any element. After that, it divides the array to one side of your array by moving elements greater than your pivot value and moving elements smaller than your pivot to the other side. This is the "divide and conquer" part of the algorithm. Further, the quicksort algorithm conquers after dividing and partitioning around the pivot, by recursively calling itself to process the two halves, or subarrays, of the original array. This process is used to sort the arrays in order to allot the cargo weights keeping into mind the "Cost-Lead Time" relative. The lowest Cost-Lead Time relative is used to fill up the cargo weights first and so on.

Data Input.

The "UserForm" mentioned below lets the user put the country name in the "From" and "To" input boxes. Each and every route in the aircrafts routes file has been assigned a specific country accordingly, and all the routes within the mentioned countries are taken into consideration while computing the results from this model. The "From" and "To" dropdown boxes are conditional drop-down lists and dependent on each other.

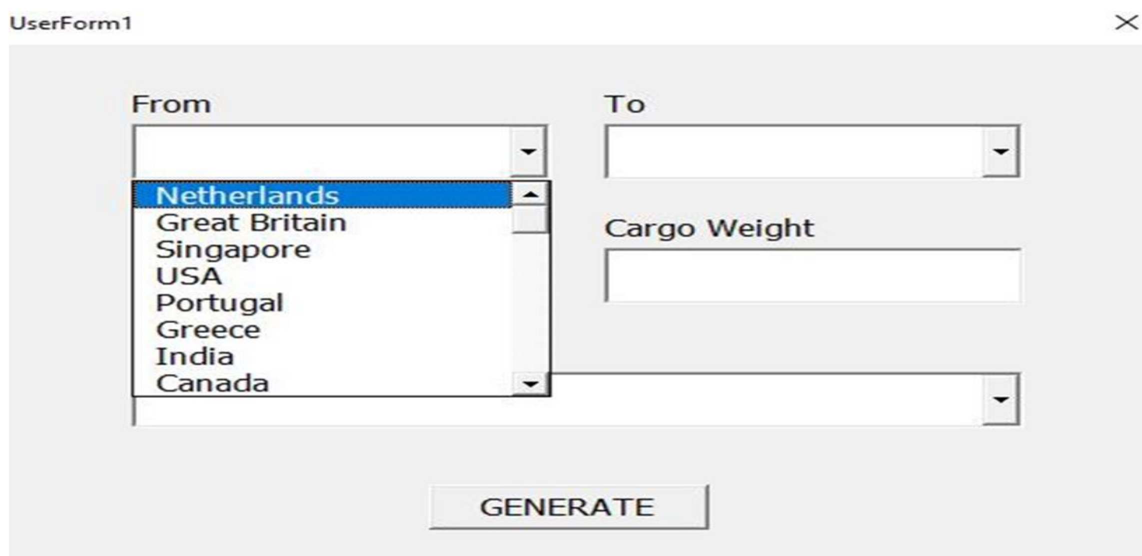

Fig 30. UserForm to Input Data

Further, the user has the option to select a particular day from a dropdown list. This is an essential step in the process because each different day corresponds to a different set of data for the "cargo weight limit" to be carried by aircraft, lead-time, and cost (priority) and cost (non-priority). The user chooses the day out of the list containing days from "Monday" to "Sunday," respectively. This corresponds to the value obtained from the Tender sheet and the IPS sheet datasets discussed in Chapter 4. This process helps in speeding up the computation process in VBA.

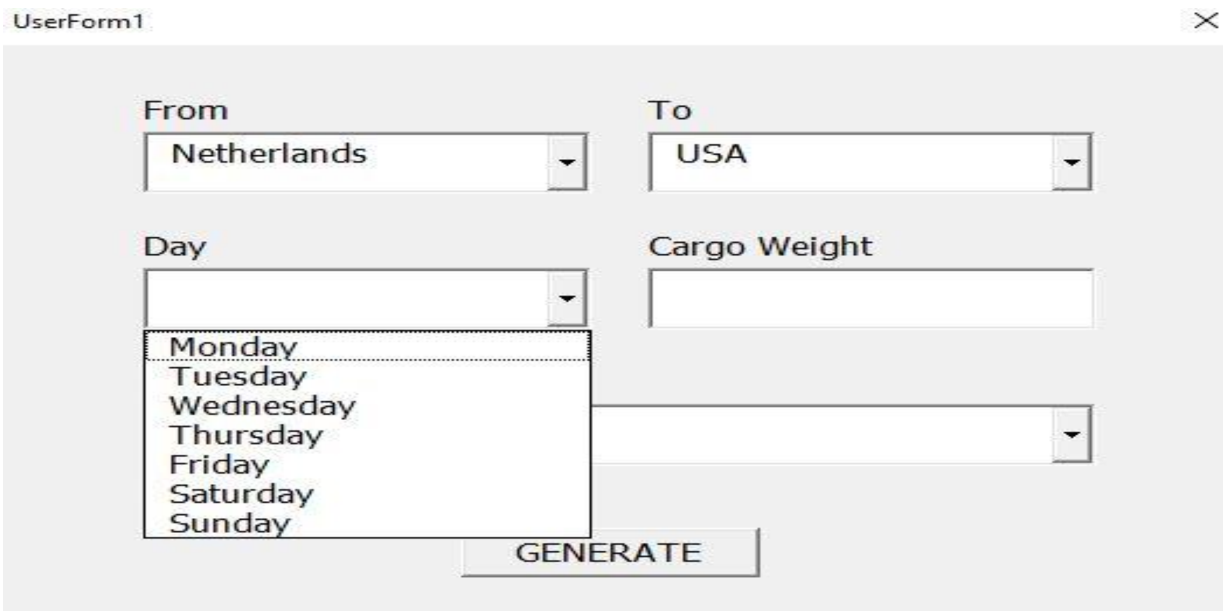

Fig 31. UserForm to Input Data

Further, the user is supposed to enter a cargo weight to be transported to a specific country from a particular country. This is followed by the user having to select an optimizing relative. As per the requirements of PostNL, the user has the option to choose either of the two business performance indicator relative (KPIs). This relative is a measurable value that demonstrates how effectively a company is achieving key business objectives. This measure also helps in selecting the best aircraft option in terms of cost and lead-time performance.

This process is initialized by combining the three variables to choose transport options in one KPI. Price relative to volume and lead time are taken as "price per kilo/ 1/L" and named as Cost-Lead Time (Priority) and Cost-Lead Time (Non-Priority). We now have a variable indicating the price relative to what you get for that price, namely associated lead time and quality. Here all variables are equally important in an easy to understand the formula. Next, we optimize our choice of transport options by choosing the option lowest on this KPI, where we pay the least amount of money for the given amount of cargo weight, which is equivalent to minimizing the value on our single KPI. And constraints that can change the relative value we account to lead time, cost, or Co2. For example, you can have a constraint that sets a target on the average cost, lead time, or Co2 of all your transport options to a certain destination, or across all destinations, thus influencing your total cost, Co2 or average lead time relative to other variables. Minimizing the value of our KPI within these constraints gives a certain total price, total Co2, and lead time of all your chosen options. By changing the value, you give to certain constraints, you can see the trade-offs between different variables. After entering the input values, the user is requested to press the “GENERATE” button, which helps in retrieving the output data.

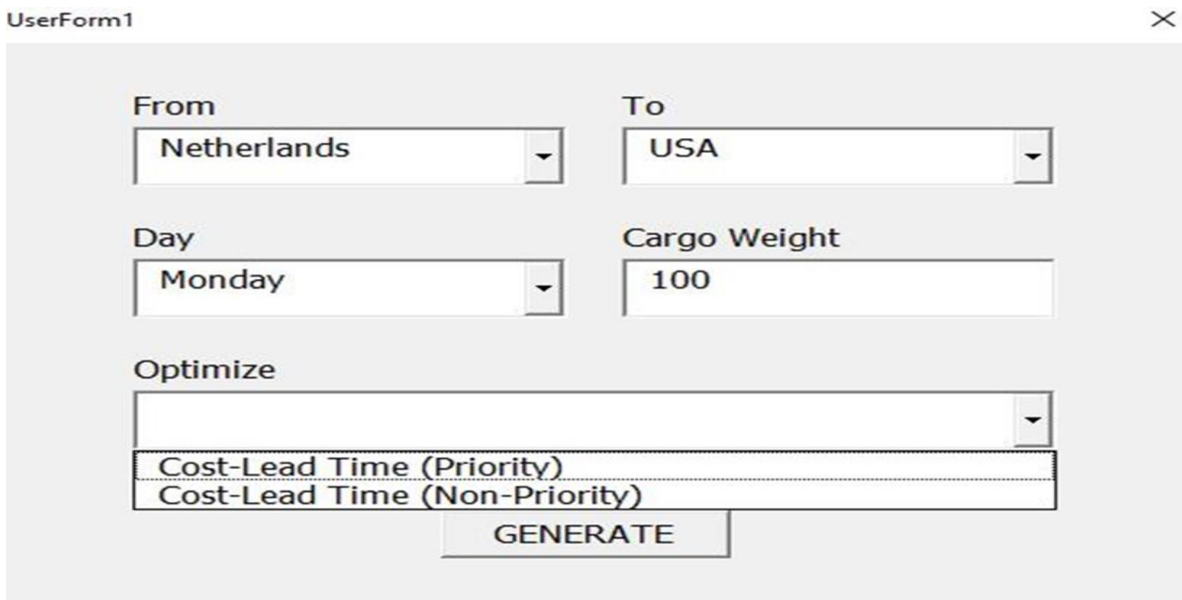

Fig 32. UserForm to Input Data

Results of Optimization.

The picture mentioned below shows the results of the input entries in the "UserForm." The result explicitly displays the "Route," Distance," Flight Number," Aircraft Type," "Cargo Weight Limit," "Cargo Weight," "Lead Time," "Cost(Priority)," Cost(Non Priority)," Co2 Emissions", "Cost-Lead (Priority), "Cost-Lead (Non-Priority), "Co2 Emissions/km". This result is quite similar to the previous model developed; however, these results are already sorted to account for the business performance relative (KPIs). This model does not take into account the "Via" option and considers only the direct route options between two different countries, respectively. The output also displays optimized results displaying specific aircraft types on a particular route carrying a designated amount of cargo weight put up by the user in the input box. This additional model is helpful in a situation where the user wants to ship certain kilograms of cargo freight by air freight transportation to a specific country to another.

						TOTAL	106.5	96.8				
Route	Distance	Flight Number	Aircraft Type	Cargo Weight Limit	Cargo Weigh	Lead Time	Cost (Priorit	Cost (Non Priorit	CO2 Emission	Cost-Lead (Priority)	Cost-Lead (Non-Priority)	CO2 Emission s / K
NLAMS-USORD	6586	QR8101	BOEING 777-F	1	1	11	1.55	1.55	7.35	17.05	17.05	7.348448
NLAMS-USORD	6586	KL0611	BOEING 747-8HV	1	1	11	1.55	1.55	6.08	17.05	17.05	6.084151
NLAMS-USORD	6586	UA0908	Boeing 767-322E	1	1	11	1.55	1.55	4.55	17.05	17.05	4.547872
NLAMS-USSFO	8735	UA0969	Boeing 787-9	400	97	18	101.85	92.15	542.24	1833.3	1658.7	5.590121

SHOW FORM

Fig 33. Excel VBA Output for Optimized Weighted Results.

6.3 Strategic Business Advantage in terms of Co2 reduction.

When people are more mindful of the need for a sustainable world in the future, more and more businesses are seeking to follow a sustainability policy. A convergence between cultural, social, and environmental dimensions is noted to be of great significance. Aside from the fiscal, social, and environmental advantages, the advantages of a plan to become more sustainable are claimed to provide sustainable competitive advantage and stakeholder satisfaction (Lash & Wellington, 2007). Many companies are facing increased costs of the supply chain, and carbon prices as policymakers across the globe are gradually implementing policies that put a premium on pollution. Consumers take into consideration the environmental performance of a corporation in making buying choices, so there is a burgeoning rise of greenhouse gas pollution allowances (the so-called carbon market), with annual trade estimated at tens of billions of dollars of such resources (Lash & Wellington, 2007). In a carbon-constrained future, businesses that control and reduce their vulnerability to climate-change threats while looking for new prospects for profit would create a strategic edge over rivals.

PostNL set itself new ambitious long-term goals for further rising Co2 emissions in 2018. The business wants all package and postal delivery inside the Benelux by 2030 at the latest to be emission-free in the last mile (PostNL, 2019). It aims to make deliveries emission-free in 25 city centers by 2025, as an intermediate move. The organization is also on the lookout for strategies to reduce their carbon impact and is committed to reducing the volume of Co2, NOx and particulate matter emitted into the atmosphere. People have, of course, carried mail on foot and by bicycle for several years now (PostNL, 2019). PostNL is gradually using safer modes of transport for the remaining deliveries, allowing drivers to develop reliable driving patterns and selecting routes that would minimize the number of kilometers traveled. PostNL has set a goal of reducing Co2 pollution from all activities (including outsourced road and air transport) by 18 per cent by 2030, relative to 2017 (PostNL, 2019). This goal requires a decrease in Co2 in our own activities (scope 1 and 2): an actual decrease of 60 percent and a reduction of 80 percent compared to kilometers powered (PostNL, 2019). After all, the business claims that sustainability is a guarantee for future activities. The tasks, despite themselves, are not targets. They are our way to ensure PostNL treats the environment we inhabit as respectfully as possible. Only then PostNL will we become a profitable mail and parcel business that can have a positive effect on individuals, the environment, and the community.

Executives usually treat environmental risk as a triple regulatory enforcement issue, possible industrial accident responsibility, and prevention of pollutant releases. However, climate change poses specific market challenges in general, as the effect is worldwide, the problem is long-term, and the damage is ultimately permanent (Lash & Wellington, 2007). Additionally, federal regulations have given businesses no direction about how to change environmental regulation in the future. Ignoring the financial and competitive impacts of climate change may result in an organization formulating an incorrect risk profile.

Policy authorities are not the only ones tracking ineffective climatic policies by private firms. Big investors are beginning to demand more information from the firms. For example, the Carbon Transparency Initiative, a consortium of institutional investors with more than $31 trillion in assets, demands information on their climate-risk positions from major global corporations annually. His latest study, released in 2006, found a substantial rise not only in respondents' understanding of climate change but also in the best practices being implemented to handle climate risk exposure. Likewise, activist coalitions are filing shareholder motions urging corporations to report more climate risk (Lash & Wellington, 2007). Throughout the period 2004 to 2005, more than two dozen climate-related proposals were filed with corporations, tripling the total from 2000 to 2001.

Regulatory risk.

This is the most evident region of effect if it takes the form of controlling supply chain pollution that you are working in. Most of the companies are now subject to the Kyoto Protocol, which seeks to minimize carbon dioxide and other greenhouse gases by forcing developing countries – and, by extension, businesses working within those countries – to curb greenhouse gas emissions. For example, the European Union’s Emissions Trade System gives permits to businesses to release specific quantities of specified greenhouse gases in order to achieve Kyoto's goals. If the emissions of a company are higher than their allotted permits, it must purchase extra permits from other businesses (Lash & Wellington, 2007). If its emissions are below its quota, it will sell its unused allowances on the market. By participating in pollution control programs outside their own organizations and nations, PostNL may earn credits that also grant the investor the ability to release certain quantities of gases. These credits can either be used to offset the emissions of own businesses, or they can be sold on the market.

Supply chain risk.

If customers evaluate their sensitivity to future legislation, PostNL will also evaluate their suppliers' vulnerability, which may lead to higher transportation costs and energy prices if suppliers pass on to their customers rising carbon-related costs. PostNL should also recognize the regional scope of its network of suppliers. Executives should be aware of how many of their vendors work in, for example, the European Union, where there are already regulatory mechanisms. Furthermore, executives have to be mindful that the other climate-related threats addressed here could impact not just their own businesses but also their suppliers.

Product and technology risk.

In a energy-constrained future, some businesses would do better than others, based on their ability to find ways to tap emerging business possibilities for eco-friendly offerings such as PostNL's "Green Post," which helps to reduce the carbon footprint through renewable innovation, meaning that your mail is distributed in a purely environmentally neutral fashion.

Litigation risk.

Companies that generate major carbon emissions face the threat of related litigation in the logistics and transport industries. Companies who don't handle climate change sufficiently can also build financial obligations for directors and officers who are liable to shareholder lawsuits. This can be avoided by making Co2 reduction an essential part of the operating cycle for the organization.

Reputational risk.

Customer or shareholder retaliation risk is especially high in environmentally sensitive markets or in dynamic industries where brand loyalty is a significant corporate value attribute. It is important for logistics companies like PostNL to create customized climate-risk profiles and strategies to minimize the risk (Lash & Wellington, 2007). Organizations in a particular industry would, of course, be equally vulnerable to those threats. Regulatory risks, for example, are more relevant in the power sector, while supply chain risks are crucial in the shipping and logistics sectors. But there are also variations across sectors — different reputational risk rates, for example.

Improving the company's strategic business advantage.

Working with organizations such as PostNL as they evaluate their vulnerability to climate change and begin implementing climate policies, it was found that the most successful initiatives entail two main phases, one of which includes clear leadership at the top and entails extensive learning around the organization.

1. Quantify your carbon footprint.

Since you can only handle what you calculate, companies need to consider the nature and extent of their own greenhouse gas emissions first to start monitoring and measuring those emissions accurately over time. This quantitative exercise will result in a company's expanded knowledge of climate change issues and set the stage for a wider look at the competitive challenges and opportunities they present (Lash & Wellington, 2007).

Companies need to build an exact inventory of their greenhouse gas emissions by quantifying their carbon footprint. They can differentiate between direct and indirect emissions — that is, emissions from their scope 3 emissions and pollution arising from their energy use, transportation, and other activities (Lash & Wellington, 2007). They should also set and change baselines for pollution and assess best practices in reporting the information. The goal is to identify and prioritize incentives for reducing emissions and to develop strategies for engaging in greenhouse gas trade markets.

With the use of the current method and quantifying Co2 emissions over the first 100 routes and later over the 8892 distinct routes, which contains multiple intermediate routes, it can be seen that the overall reduction in the emission is quite significant. This calculation is done using the IPS 2019 datasheet, and respecting cargo mail weights is considered for the calculation. The data is also visually interpreted and compared with the "DEFRA method" of accounting for carbon emissions.

Source	Destination	Defra Method(kgs)	Current Method(kgs)
NLAMSA	AEAUHA	9784	7827.852126
NLAMSA	AFKBLA	1477	1105.254015
NLAMSA	AGANUA	391	559.5272827
NLAMSA	AIAXAA	21	32.23398149
NLAMSA	ALTIAA	814	655.4198084
NLAMSA	ALTIAA	851	676.402664
NLAMSA	ALTIAA	169	116.2278855
NLAMSA	ALTIAA	733	475.6832395
NLAMSA	AMEVNA	5036	6748.440533
NLAMSA	AOLADA	1603	1181.063683
NLAMSA	AOLADF	259	192.8029931
NLAMSA	ARBUEA	1864	1691.839092
NLAMSA	ARBUEB	14308	12153.56708
NLAMSA	AUMELA	93	95.35088712
NLAMSA	AUMELA	84369	66702.53905
NLAMSA	AUMELB	241	252.9780388
NLAMSA	AUPERA	20402	24804.92405
NLAMSA	AUPERB	138	181.0576399
NLAMSA	AUPERD	144	188.7958548
NLAMSA	AUSYDA	76532	93729.95259
NLAMSA	AUSYDA	83689	66391.58179
NLAMSA	AUSYDD	153	279.1904583
NLAMSA	AUSYDD	3850	3998.643771
NLAMSA	AWAUAA	3725	3962.581942
NLAMSA	AWAUAA	4893	4392.447022
NLAMSA	AWMEAA	1590	1719.653569
NLAMSA	AWMEAA	1302	1196.819081
NLAMSA	AZBAKA	1432	1064.898049
NLAMSA	AZBAKB	898	674.2608247

NLAMSA	AZBAKC	2	1.448734113
NLAMSA	BASJJA	4505	2230.686691
NLAMSA	BBBGIA	1325	2112.687037
NLAMSA	BDDACA	2525	3314.794107
NLAMSA	BFOUAA	416	304.6047201
NLAMSA	BFOUAC	6	4.152165262
NLAMSA	BGSOFD	547	502.0293313
NLAMSA	BGSOFE	0	0.099659388
NLAMSA	BGSOFG	2099	1744.358407
NLAMSA	BHBAHA	1416	1198.63189
NLAMSA	BJCOOA	549	398.4647656
NLAMSA	BMSGEA	1025	1537.417457
NLAMSA	BOLPBA	4316	3692.750312
NLAMSA	BOLPBB	161	140.8242148
NLAMSA	BQBONB	1749	1907.688921
NLAMSA	BQBONB	3033	2782.882704
NLAMSA	BQLDJF	648	713.2313236
NLAMSA	BRCWBA	20527	23687.44484
NLAMSA	BRCWBA	676	524.2981721
NLAMSA	BRCWBA	32057	22655.76026
NLAMSA	BRCWBA	4217	4205.72862
NLAMSA	BRRIOE	29205	44494.96081
NLAMSA	BRSAOD	2595	3278.319433
NLAMSA	BRSAOD	6025	4696.991589
NLAMSA	BRSAOD	1821	1842.857161
NLAMSA	BSNASA	683	1060.601242
NLAMSA	BTTHIA	822	988.0270256
NLAMSA	BYMSQA	6	2.848054034
NLAMSA	BYMSQD	1010	477.2697951
NLAMSA	BYMSQF	1750	808.0098846
NLAMSA	CAYMQA	3586	3701.918905
NLAMSA	CAYMQA	17337	13513.81591
NLAMSA	CAYTOA	33612	43953.04336
NLAMSA	CAYVRA	15964	13631.0731
NLAMSA	CFBGFA	119	89.41987701
NLAMSA	CGBZVA	322	252.6695458
NLAMSA	CIABJC	1051	815.5724106
NLAMSA	CLSCLA	38903	28208.76119
NLAMSA	CMDLAA	857	652.5137366
NLAMSA	CMDLAB	457	348.7959453
NLAMSA	CMDLAE	5	3.454694327
NLAMSA	CNBJSA	71726	50137.70874
NLAMSA	CNBJSA	5343	8718.655671

NLAMSA	CNBJSA	5292	8638.23047
NLAMSA	CNBJSA	100	155.023172
NLAMSA	CNBJSB	52586	40717.12331
NLAMSA	CNBJSB	2840	4712.321173
NLAMSA	CNBJSB	2334	3886.196447
NLAMSA	COBOGC	22066	20247.34568
NLAMSA	CRSJOA	3842	6139.39563
NLAMSA	CUHAVA	2158	2509.407433
NLAMSA	CUHAVE	45	53.33389463
NLAMSA	CVVXEA	1459	1442.79788
NLAMSA	CWCURA	597	653.0274394
NLAMSA	CWCURA	18739	28192.08236
NLAMSA	CWMEAB	847	1431.667729
NLAMSA	CWMEAE	4689	7718.952279
NLAMSA	CYLCAA	997	717.9036312
NLAMSA	CYLCAA	675	488.9576026
NLAMSA	CYLCAA	232	229.0769909
NLAMSA	CYLMSB	182	132.9722254
NLAMSA	DMDOMB	222	235.4356368
NLAMSA	DOSDQA	3334	2453.703489
NLAMSA	DZALGB	1413	630.9663834
NLAMSA	DZALGD	2190	967.1065476
NLAMSA	ECUIOA	4215	7771.369716
NLAMSA	EETLLA	2395	1178.061796
NLAMSA	EGCAIB	1208	667.881476
NLAMSA	EGCAID	738	510.902072
NLAMSA	EGCAIF	129	89.52222317
NLAMSA	ETADDA	11887	14399.54264
Total	**Total**	**783170**	**755360**

Table 19. First 100 routes and their respective carbon calculations as per the DEFRA method and the current method.

Defra Method(kgs)	Current Method(kgs)
46429916	41414180

Table 20. Carbon emission calculations for 8892 distinct routes and intermediate routes .

It can be easily seen that there is no significant difference when it comes to individual flight routes, but the difference is quite significant when all the 8892 distinct routes linking multiple intermediary routes(including truck routes, ship routes) is considered. This can be helpful in being a starting point in quantifying route based carbon emissions.

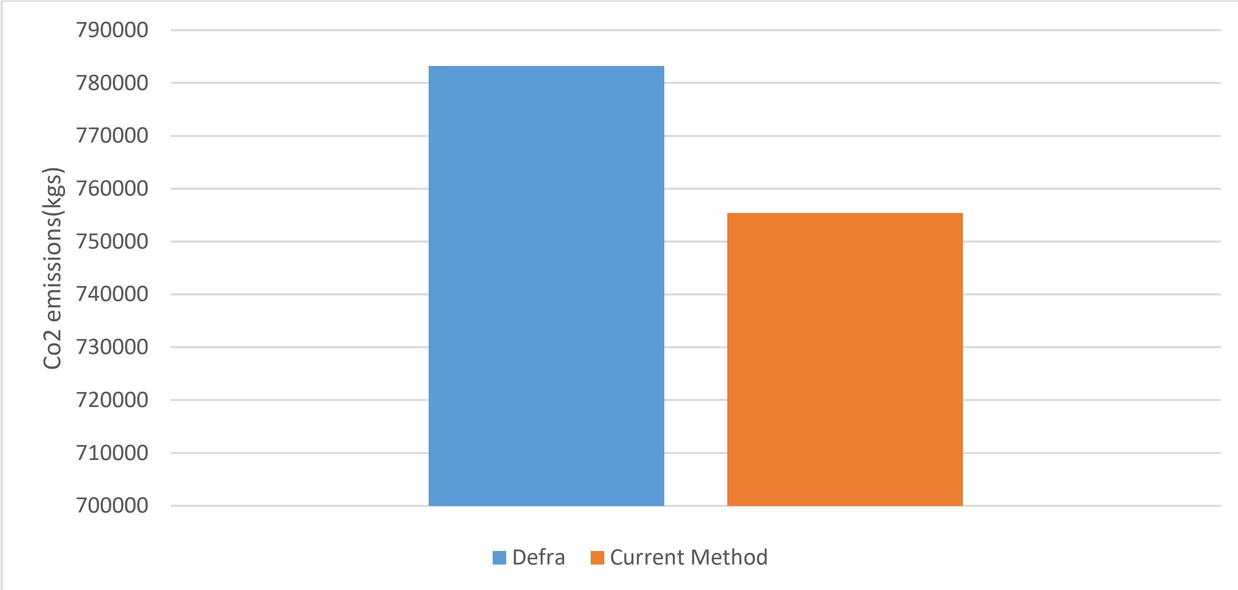

Fig 34. Carbon emissions due to 100 different routes at PostNL

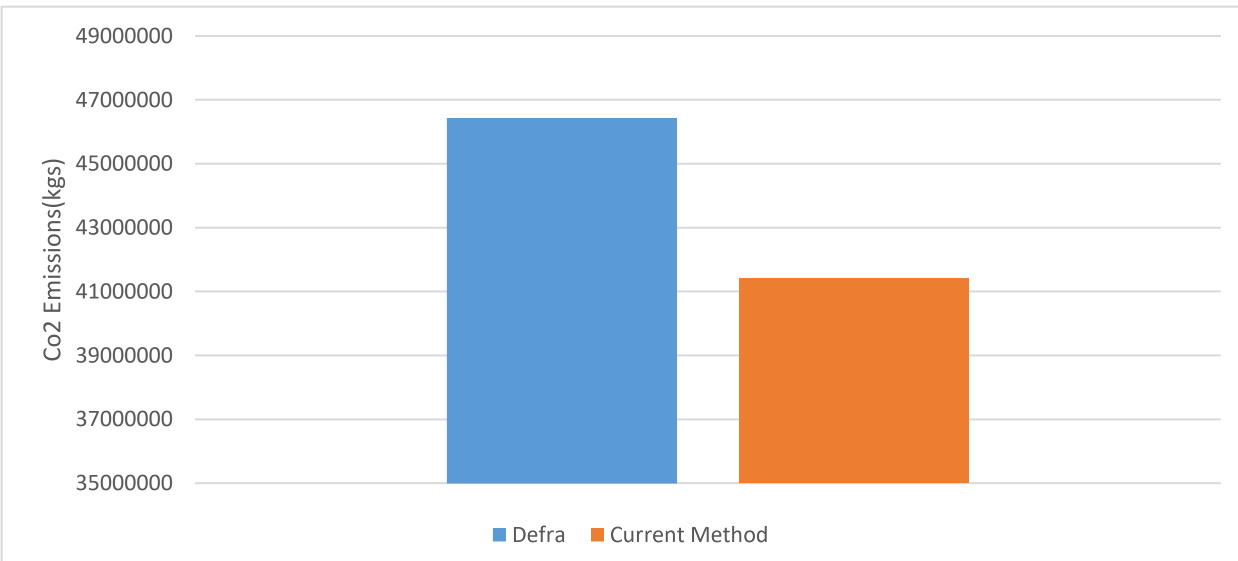

Fig 35. Carbon emissions due to 8892 distinct routes, which contain multiple intermediates at PostNL

Companies quantifying their emissions are putting out a clear warning acknowledging the value of climate change as a market challenge and opportunity. It is reported that businesses who started to perform a carbon audit to expose inefficient and wasteful energy activities and then went on to find prospects for brand improvement around climate change issues (Lash & Wellington, 2007). These firms, as we will see, ultimately leveraged their understanding of climate-related problems to build innovative and efficient supply chains.

2. Assess the carbon-related risks and opportunities.

The footprint for pollution just tells a portion of the story. After assessing the company's direct and indirect effect on the environment, PostNL has to extend its research and strategically learn about how the threats that might harm or give incentives to best position their companies.

Another way to determine the effect that climate factors would have on the company is to understand the direct and indirect financial effects. PostNL should look at the "energy level intensity" of its profits — that is, what amount is generated from high carbon dioxide-emitting services or can look at ways that climate change will impact their services and related costs (Lash & Wellington, 2007).

The interplay between the various elements of climate-related risk influences the capital expense of a business, and consequently, its value. Investors must incorporate the climatic performance of a business into forecasts of its potential cash flows (Lash & Wellington, 2007). The degree to which cash flow is climate risk-prone would also influence how much cash is available for interest costs and amortization of a company's debt, eventually impacting its bond and bank debt scores.

Chapter 7. Conclusion

7.1 Discussion/ Concluding Remarks on the Research Questions

Airline companies, governments, and other related stakeholders are beginning to take note, but current policies such as the ICAO Co2 requirement for new aircraft and its International Aviation Carbon Offsetting and Mitigation Scheme are not expected to substantially reduce aircraft emissions (Graver & Rutherford, 2018c; Pavlenko, 2018). This quantitative exercise results in a company's expanded knowledge of climate change issues, and set the stage for a wider look at the competitive challenges and opportunities they present (Lash & Wellington, 2007). This leads us to the main research question.

RQ:

"How can PostNL be facilitated in calculating aircraft specific carbon emission factors, which can be used for accounting purposes, to promote sustainable purchasing and green market positioning?"

This research provided PostNL with an up-to-date and precise Co2 emission calculation methodology. Multiple public data sources were collected, combined, and estimated using an aircraft performance and design program, i.e., PianoX, to simulate and compare the amount of fuel consumed with the ICAO datasets, and thus evaluating marginal Co2 emissions and relevant emission factors for specific aircraft carrying a definite cargo freight used by PostNL. This collection of data is presented at a time when air transport 's climate effect is increasingly under scrutiny. The research helps PostNL to build an exact inventory of their carbon emissions by quantifying their carbon footprint into their current accounting system, and the proposed methodology proves effective in solving the purpose. This can help in differentiating between direct and indirect emissions — that is, emissions from their scope 3 emissions and pollution arising from their energy use, transportation, and other activities (Lash & Wellington, 2007). Setting and changing baselines for pollution and assessing best practices in reporting the information can also help in identifying and prioritizing incentives for reducing emissions and to develop strategies for engaging in greenhouse gas trade markets. PostNL quantifying their emissions is putting out a clear warning acknowledging the value of climate change as a market challenge and opportunity. It was reported that businesses who started to perform a carbon audit to expose inefficient and wasteful energy activities and then went on to find prospects for brand improvement around climate change issues (Lash & Wellington, 2007). These firms, as we will see, ultimately leveraged their understanding of climate-related problems to build innovative and efficient supply chains.

To answer the main research mentioned above, the following secondary research questions were formulated and reasoned, respectively.

Sub questions:

1. Which variables are relevant in calculating an aircraft-specific carbon emission factor for airfreight transportation?

The research began with the estimation and study of the currently used Defra methodology and its implementation within the current supply chain accounting purposes. The problems with the Defra methodology were accounted for, and multiple carbon emission calculation methodologies were studied in the research process for the calculation and quantification of marginal carbon emission along with the estimation of the specific emission factors for a specific aircraft with dedicated cargo freight allotted to PostNL. After the successful background research, a comparative analysis of all the different methodologies was tabulated and examined. Followed by the sample calculations using these methods, the appropriate method was deduced. The methodology, which is being used for the calculation of marginal carbon emission due to freight and the total carbon emission by the aircraft, has been recognized to suit the requirements of the current research. The Zurich carbon emission calculator provides relevant results with the help of linear variables that are already obtained through this research. These variables are primarily found as "Passenger load factor," Fuel consumption," GCD Distance," Average seating capacity," Total Payload Calculations," and "Radiative Forcing." These linear variables are taken as such PostNL can modify, change, and add new routes whenever possible.

2. ***How can PostNL be facilitated in making data-driven air transport procurement decisions taking into account trade-offs between carbon emission, lead time, and cost to gain a strategic business advantage?***

The research facilitated PostNL in providing the data required for top management strategy makers and also helped in developing simulation and an optimization model along with calculating aircraft specific emission factors that would help in minimizing yearly carbon emissions while still meeting potential customer demand. However, this data model envisages several avenues for refinement. One, we should find better sources of data to enhance air freight research, in particular, to help the allocation of air freight to regions and countries. Secondly, we should undertake extensive research on model validation, particularly for domestic operations, using data at the regional, national, and airline levels. Three, data on the expected emissions over time can be incorporated into future reports based on regular, revised inventories.

Also, logistics companies should bear in mind that logistics networks will change, sometimes dramatically. New ways to do business like co-opetition and better modeling will help improve efficiency. Scenario planning and strategic approaches will have an advantage in holding the supply chain as a whole, yet another step forward and help the shipping and logistics sector face the demands of the future and become ever more competitive. Different risks and coping strategies were also discussed in the previous chapters to leverage and acquire a strategic business advantage among current and emerging markets with respect to tradeoffs between emissions, lead time, and costs.

3. How can PostNL drive business sustainability in their partnerships while maintaining their flexibility and bargaining power with suppliers?

PostNL has set itself new ambitious long-term goals for further rising Co2 emissions in 2018. The business wants all package and postal delivery inside the Benelux by 2030 at the latest to be emission-free in the last mile. It aims to make deliveries emission-free in 25 city centers by 2025, as an intermediate move. The organization is also on the lookout for strategies to reduce their carbon impact and is committed to reducing the volume of Co2, NOx, and particulate matter emitted into the atmosphere. The undergone research helped in quantifying the extend of carbon emissions due to one of the significant contributors, ie. Air freight transportation and helped PostNL in setting itself new ambitious long-term goals for further rising Co2 emissions issues in 2018. Customer or shareholder retaliation risk is exceptionally high in environmentally sensitive markets or in dynamic industries where brand loyalty is a significant corporate value attribute. The research explains how it is important for logistics companies like PostNL to create customized climate-risk profiles and strategies to minimize the risk and create a sustainable competitive advantage while maintaining the company's business flexibility and bargaining power with the current suppliers. It was evident from the research that PostNL should also focus at the "energy level intensity" of its profits — that is, what amount is generated from high carbon dioxide-emitting services or can look at ways that climate change will impact their services and related costs (Lash & Wellington, 2007). The interplay between the various elements of climate-related risk influences the capital expense of the undergoing business, and consequently, its value. Investors must incorporate the climatic performance of a business into forecasts of its potential cash flows (Lash & Wellington, 2007). The degree to which cash flow is climate risk-prone would also influence how much cash is available for interest costs and amortization of a company's debt, eventually impacting its bond and bank debt scores, which is discussed in the previous chapters of the research.

7.2 Limitations and Errors in the model

The model gives the best estimate possible with the use of the available non-confidential data and the use of linear variables. The model is made as per the given requirements of PostNL, and all required changes were added to the model to make it cohesive and robust. The model also allows the PostNL to add new routes, modify existing routes, and changes various other aircraft related datasets as per the user's requirements.

Nonetheless, there are three significant areas of uncertainty in the model due to the use of publically available information and not the inclusion of dynamic time-dependent variables, including privately owned airline data:

- Distance, load factors, vehicle usage, and speed operation data
- Performance-based modeling, for aircraft in particular (LTO and cruise)
- Destination facilities and local factors (power supply, aircraft handling, heating/cooling).

All future uncertainties can be reduced by more advanced modeling and input data improvement.

7.3 Recommendations For Further Research

The logistics companies often have a dominant position in the overall market chains, so they are partly designated to initiate changes at first glance. As customers/suppliers, they will make the difference, as well as providing the services, business extension, and chain partnership and participation. Many similar players, including the governments, are interested in raising Co2 emissions issues from transportation, and all of them have their own agenda. Some of the recommendations which can enable lesser yearly carbon emissions and can cause greener logistics are discussed below:

1. **A cleaner and low emitting cargo fleet.**

   There is no question that air-polluting emissions per kilometer of air travel will decrease in the future. The European Union has set the target of achieving a 10 percent share of total fuel consumption for the transport sector. However, given the current recession, freight transport demand projections still indicate estimated increases of up to 40 percent over the next ten years. A cleaner and low emitting cargo fleet definitely solve the purpose of lower emissions in the future.

2. **Transfer from the airways to roadways, waterways, and railways (modal shift).**

   A comparison of transport modes is made dependent on Co2 emissions. Air transport is seen as the least sustainable alternative to rail or waterway transport. The size and loading rate of transportation flows should also be considered while minimizing the total yearly emissions. A modal change from airways to the road, train, or waterways would seem suitable for making a sustainable modal shift.

3. **Optimization of your logistics network.**

   Distribution centers have a direct effect on the number of warehouse locations. The concept of one European Distribution Centre (EDC) is efficient for warehouse costs and inbounds transport. The EDC is efficiently distributed to the local warehouses, which are then consolidated on a weekly basis. This occurs since more customers mean more transport kilometers and higher costs. All uncertainties in the future can be reduced by more advanced modeling and improvement of input data, which can help in better simulations and optimization, resulting in better decision making in the supply chain and procurement divisions.

4. **Improved Sales & Operations Planning (S&OP).**

   A backorder delivery to a customer results in at least one additional movement of transport for one and the same order of sale. It needs to be noted that this is inefficient, from both a cost and a CO_2 emission reduction perspective.

5. **Logistics chain cooperatives.**

   Collaboration between shippers can lead to more efficient transport flows. Examples such as Kimberly-Clark & Lever-Fabergé and ELUPEG, which is a European collaboration of shippers and carriers with the sole objective of realizing logistics partnerships, joined forces to create a logistics hub in the Netherlands which could help in the cooperation of different logistics companies. These cooperations help in the overall optimization of chain and maintaining sustainability.

6. **Creation of shipments coming out.**

   Forty percent of all transport movements are carried out empty. These empty trips can be mostly concerned with return packages. These empty trips can be reduced by combining the loading and unloading locations in different collection warehouses.

7. **A wider Customer Service understanding.**

   Very often, the businesses think their customers want delivery spanning 24 hours. However, often consumers are more interested in service reliability than the speed of delivery. One could extend the delivery lead time to 48/72 hours, or add fixed delivery days per area. The additional versatility is not by definition to the detriment of consumer loyalty. However, it is a significant factor in restricting the number of trips and eventually minimizing CO_2 emissions.

8. **National and local laws and regulations.**

   The government has a vital position in reducing logistics pollution. Different rules and regulations may help boost transport's sustainability and quality, such as:

   1. Allowing road-trains in downtime periods causes an estimated 3-6 percent reduction in CO_2 emissions and helps in the overall emission reduction.
   2. Target lanes on the motorway for lorries. Enlargement of distribution periods for urbanized areas.
   3. Restriction in the movement of aircraft in certain areas with a sustainability perspective in mind would help in educating different stakeholders to make essential decisions in minimizing yearly CO_2 emissions.

7.4 Reflection

After grabbing a graduation project opportunity at PostNL, I was highly motivated to work on transport and logistics sustainability in the Netherlands, and this master thesis research helped me to focus on it. Soon, I identified several appropriate sources specifically to find the information and address the research question. Subsequently, I also succeeded in reviewing various online repositories and databases and restricted my scope to using recognized academic directories focused on the quality of publicly published articles and links to peer-reviewed journals. This research provides a unique view of the business sustainability aspect within the Cross Border Solutions (CBS) and the close working proximity of the accounting and the transport procurement departments. Arguably, the literature review, along with the data analysis was the most challenging phase to research. This was followed by the literature search involving numerous carbon emission calculation methodologies. The methodologies were duly studied, and a comparative analysis was carried out to point out the best applicable method considering the use of variables which would lead to a near true estimate of carbon emissions for PostNL and which can help in the annual Co2 emissions accounting purposes dues to the air freight transportation along multiple routes all over the world. Further, the difficulty was to follow the methodological way of doing respective calculations and analysis of the data to be considered. Different data cleaning and web scraping techniques were used to remove the discrepancies in the confidential company datasets and the publicly available datasets. After spending the first three months in setting up the datasets, a conceptual model was developed for the simulation model using Excel VBA and integrated GUI tools. Therefore, It can be rightly said that this research has been largely based on conceptual models, with the analytical, methodological, and accuracy constrictions inherent to this. This action design research followed the commercial development and evolution of the simulation model lead to the selection of specific business KPIs leading to the development of the optimization model, which could contribute to the best estimate of tradeoffs between lead time, cost and carbon emissions.

Secondly, this research has contributed to the further understanding and interlinkage of several research areas towards a more end-to-end overview of marginal fuel consumption of an aircraft leading to the specific emission factors and marginal carbon emissions due to cargo freight put up by PostNL.

It has also highlighted that there are significant knowledge gaps and potential improvements in the current formulation of the theories and proposed improvements based on this study. These limitations are duly noted, and the need for more advanced modeling is considered to be the next step to the current research. Follow-up research is needed to confirm the impact of time-dependent variables and through the usage of the highly confidential aircraft data to further refine their form and presentation, and study cases in other platform types and industries to uncover new design principles for the models discussed.

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9.Appendix.

9.1 Load factors by Route Group as prepared by the ICAO.

#	Route Group	Passenger Load Factor
1	Africa - Asia/Pacific	72.90%
2	Africa - Middle East	71.10%
3	Africa - North America	77.28%
4	Africa & Middle East - Central America/Caribbean	79.21%
5	Africa & Middle East - South America	60.20%
6	Central America/Caribbean - Europe	83.00%
7	Central America/Caribbean - North America	81.05%
8	Central America/Caribbean - South America	77.10%
9	Central Asia - Europe	82.08%
10	Central Asia - Middle East	76.40%
11	Central Asia - North America	82.85%
12	Central Asia & South West Asia - North Asia	73.50%
13	Central Asia & South West Asia - Pacific South East Asia	76.69%
14	Europe - Middle East	74.38%
15	Europe - North Africa	75.08%
16	Europe - North America	82.16%
17	Europe - North Asia	80.50%
18	Europe - Pacific South East Asia	79.50%
19	Europe - South America	82.20%
20	Europe - South West Asia	81.10%
21	Europe - Sub Saharan Africa	76.00%
22	Intra Africa	60.35%
23	Intra Central America/Caribbean	66.92%
24	Intra Central Asia & South West Asia	75.60%
25	Intra Europe	80.89%
26	Intra Middle East	71.13%
27	Intra North America	81.78%
28	Intra North Asia	76.50%
29	Intra Pacific South East Asia	76.05%

30	Intra South America	77.40%
31	Latin America/Caribbean - Central Asia	76.10%
32	Latin America/Caribbean - North Asia & Pacific South East Asia	72.50%
33	Middle East - North America	77.91%
34	Middle East - North Asia & Pacific South East Asia	77.50%
35	Middle East - South West Asia	77.90%
36	North America - North Asia	80.44%
37	North America - Pacific South East Asia	77.50%
38	North America - South America	79.66%
39	North America - South West Asia	80.61%
40	North Asia - Pacific South East Asia	77.58%

Table 21. Route group data for load factors

9.2 Table format of ICAO CO2 Estimation Models (CEMs) based on Great Circle Distance (GCD)

Table 22.a. Aircraft types (by ICAO type designator) modelled with ICAO CEM based on airplane operators data

	Fuel (in kg) for given Great Circle Distance (in km)																
Type Designator	0	500	1000	1500	2000	2500	3000	3500	4000	4500	5000	5500	6000	7000	8000	9000	10000
A20N	603	2,225	3,543	4,861	6,179	7,497	8,815	10,133	11,451	12,769	14,087	15,405	16,723				
A21N	839	2,081	3,497	5,102	6,707	8,312	9,917	11,522	13,127	14,732	16,337	17,942	19,547	22,757			
A306	2,718	5,586	8,454	11,322	14,190	17,057	19,925	22,793	25,661	28,529	31,396	34,264	37,132	42,868			
A310	1,579	4,434	7,289	10,145	13,000	15,855	18,710	21,565	24,420	27,276	30,131	32,986	35,841	41,552	47,262	52,972	
A318	1,052	2,462	3,849	5,233	6,617	8,000	9,384	10,767	12,151	13,535	14,918	16,302	17,685				
A319	865	2,628	4,064	5,393	6,854	8,315	9,776	11,237	12,698	14,159	15,620	17,081	18,542				
A320	975	2,698	4,211	5,725	7,238	8,751	10,496	12,241	13,986	15,731	17,476	19,221					
A321	688	2,965	4,767	6,569	8,371	10,173	11,975	13,777	15,579	17,381	19,183	20,985	22,787				
A332	2,045	5,252	8,018	10,784	13,550	16,843	20,261	23,679	27,096	30,514	33,932	37,350	40,768	47,603	54,439	61,275	68,110
A333	1,813	5,970	9,936	13,248	16,561	19,873	23,186	26,498	29,811	33,123	36,436	39,748	43,061	49,686	56,311	62,936	69,561
A343	2,789	6,689	10,589	14,200	17,811	21,422	25,033	28,644	32,255	35,866	39,479	43,756	48,032	56,585	65,138	73,691	82,244
A346	4,424	8,226	12,027	15,829	19,630	23,431	28,700	33,969	39,238	44,507	49,776	55,045	60,314	70,852	81,390	91,928	102,466
A359	3,416	6,572	9,727	12,883	16,038	19,194	22,349	25,505	28,689	32,324	35,960	39,595	43,231	50,502	57,773	65,044	72,315
A388	4,474	11,646	18,818	25,990	33,162	40,334	47,506	54,678	61,850	69,022	76,194	83,366	90,538	104,882	119,226	136,767	154,922
AN26	228	1,736	2,944	3,701	4,458	5,215											
AT43	99	718	1,267	1,816	2,365	2,913	3,462	4,011	4,560	5,109	5,658						
AT45	98	857	1,488	2,119	2,750	3,381	4,012										
AT46	199	863	1,527														
AT72	185	863	1,541	2,219	2,897												
AT75	202	875	1,588	2,301													
AT76	177	917	1,616														
B190	97	446	795	1,144	1,493	1,842											
B38M	750	2,079	3,409	4,739	6,069	7,399	8,728	10,058	11,388	12,718	14,048	15,377	16,707				
B462	746	2,400	4,053	5,706	7,360	9,013											
B463	667	2,543	4,420	6,296	8,172	10,048											
B722	975	4,337	7,049	9,760	12,472	15,183	17,895	20,606	23,318	26,029	28,741	31,452					
B733	1,119	2,500	3,984	5,547	7,111	8,674	10,238	11,801	13,365	14,928	16,492	18,055	19,619				
B734	704	2,797	4,525	6,177	7,830	9,483	11,136	12,789	14,442	16,095	17,748	19,401	21,054	24,359	27,665	30,971	34,277
B735	982	2,515	4,047	5,580	7,112	8,645	10,177	11,710	13,242	14,775	16,307	17,840	19,372	22,437	25,502	28,567	
B736	1,086	2,300	3,515	4,804	6,112	7,420	8,728	10,036	11,344	12,652	13,960	15,268	16,576	19,192			
B737	794	2,399	3,871	5,342	6,814	8,285	9,757	11,228	12,700	14,171	15,643	17,114	18,586				
B738	655	2,639	4,201	5,762	7,323	8,885	10,446	12,007	13,568	15,130	16,691	18,252					
B739	1,215	2,874	4,534	6,193	7,853	9,513	11,172	12,832	14,491	16,151	17,811						
B744	6,221	11,435	16,648	21,862	27,076	32,290	37,728	43,675	49,621	55,568	61,514	67,460	73,407	85,300	98,281	113,677	129,072
B748	6,391	11,634	16,878	22,121	27,365	32,608	37,852	43,095	48,339	53,582	58,826	64,069	69,574	82,354	95,134	107,914	120,694
B752	1,520	3,627	5,733	7,840	9,861	11,793	13,725	15,657	17,589	19,521	21,453	23,385	25,317	29,181	33,045		
B753	1,443	3,863	6,283	8,702	11,122	13,542	15,962	18,381	20,801	23,221	25,641	28,061	30,480	35,320	40,159		
B762	1,457	4,302	7,148	9,993	12,838	15,683	18,529	21,374	24,219	27,065	29,910	32,755	35,601	41,291	46,982	52,672	
B763	1,650	4,440	7,230	10,020	12,809	15,599	18,389	21,179	23,969	27,060	30,294	33,528	36,763	43,231	49,700	56,168	62,637
B764	1,883	4,889	7,895	10,901	13,907	16,913	19,919	22,925	25,930	28,936	31,942	34,948	37,954	43,966	49,977	55,989	62,001
B772	3,137	6,911	10,685	14,459	18,233	22,007	25,781	29,555	33,329	37,103	40,877	44,651	48,425	55,971	65,216	74,461	83,706
B773	3,765	8,064	12,363	16,662	20,961	25,260	29,844	34,463	39,082	43,701	48,320	52,939	57,558	66,796	76,034	85,272	94,510
B77L	3,309	7,275	11,240	15,206	19,171	23,137	27,102	31,068	35,034	40,416	45,797	51,179	56,560	67,323	78,089	86,071	94,053
B77W	4,807	8,738	12,670	16,601	20,533	24,464	28,396	32,328	37,385	42,443	47,500	52,558	57,615	67,730	77,850	86,991	96,132
B788	2,324	4,864	7,404	9,944	12,483	15,356	18,230	21,103	23,977	26,850	29,724	32,597	35,471	41,218	46,965	52,712	58,459
B789	2,235	5,163	8,091	11,019	13,947	16,875	19,803	22,731	25,660	28,896	32,132	35,368	38,604	45,076	51,548	58,020	64,492
C550	190	617	945	1,270	1,596	1,921	2,246	2,571									
C56X	207	758	1,103	1,447	1,792	2,136	2,481	2,826									
C68A	385	970	1,429	1,866	2,304	2,742	3,179	3,617	4,055	4,493	4,930	5,368	5,806				
CL30	336	980	1,579	2,050	2,521	2,992	3,463	3,934	4,405	4,876	5,347	5,818					
CL35	288	1,020	1,476	1,932	2,397	2,898	3,399	3,900	4,401	4,902	5,403	5,904					
CL60	347	1,084	1,677	2,270	2,862	3,455	4,047	4,640	5,232	5,825	6,417	7,010	7,602	8,788			
CRJ1	459	1,224	1,980	2,659	3,338	4,017	4,696	5,375	6,054	6,733	7,412	8,091	8,770				
CRJ2	247	1,201	2,037	2,872	3,708	4,544	5,379	6,215	7,050	7,886	8,721	9,557	10,393				
CRJ7	499	1,670	2,652	3,634	4,616	5,598											
CRJ9	545	1,745	2,779	3,801	4,822	5,843											
CRJX	517	1,853	2,905	3,956	5,006												
D328	141	674	1,208	1,741													
DH8D	303	1,117	1,931	2,746	3,560												
E135	388	1,219	1,893	2,567	3,241	3,915	4,591	5,103	5,615								

Table 22.b (cont.). Aircraft types (by ICAO type designator) modelled with ICAO CEM based on airplane operators data

	Fuel (in kg) for given Great Circle Distance (in km)																
Type Designator	0	500	1000	1500	2000	2500	3000	3500	4000	4500	5000	5500	6000	7000	8000	9000	10000
E145	257	1,248	1,934	2,620	3,306	3,992	4,678	5,364	6,050								
E170	467	1,714	2,743	3,904	5,085	6,266	7,446										
E190	510	2,100	3,335	4,586	5,957	7,327	8,698	10,069	11,439	12,810	14,180	15,551	16,922	19,663	22,404		
E195	541	2,129	3,466	4,803	6,140	7,477	8,814	10,151	11,488	12,825	14,162	15,499	16,836	19,510	22,184		
E35L	379	1,286	1,908	2,529	3,151	3,772	4,394	5,015	5,637	6,258	6,880	7,501	8,123	9,366			
E55P	205	668	934	1,200	1,466	1,732	1,998	2,264									
F100	539	2,178	3,526	4,874	6,222	7,570	8,918	10,266	11,615								
F2TH	329	1,012	1,528	2,044	2,560	3,076	3,592	4,109	4,589	5,070	5,550	6,031	6,511	7,472			
F50	123	865	1,487	2,108	2,730	3,351	3,972	4,594	5,215	5,837	6,458	7,080	7,701				
F70	642	1,962	3,106	4,250	5,394	6,538	7,682										
F900	338	1,050	1,659	2,269	2,878	3,488	4,097	4,707	5,316	5,926	6,535	7,145	7,754	8,973	10,192		
FA50	313	1,061	1,641	2,147	2,652	3,158	3,663	4,169	4,674	5,180	5,685	6,191	6,696				
FA7X	378	1,313	1,975	2,636	3,298	3,959	4,620	5,282	5,943	6,604	7,266	7,927	8,588	9,911	11,234	12,556	13,879
G280	326	862	1,397	1,933	2,469	3,005	3,398	3,732	4,066	4,400	4,735	5,069	5,403				
GL5T	751	1,812	2,679	3,546	4,413	5,280	6,147	7,014	7,881	8,748	9,615	10,483	11,350	13,084	14,818	16,552	
GLEX	659	1,863	2,733	3,602	4,472	5,341	6,211	7,080	7,950	8,820	9,689	10,559	11,428	13,167	14,906	16,645	18,385
GLF4	508	1,832	2,519	3,207	4,020	4,841	5,663	6,484	7,306	8,127	8,949	9,770	10,592	12,235			
GLF5	690	1,673	2,488	3,304	4,119	4,935	5,750	6,566	7,381	8,196	9,012	9,827	10,611	12,109	13,608	15,107	16,605
GLF6	528	1,774	2,568	3,362	4,156	4,950	5,744	6,538	7,332	8,126	8,920	9,714	10,508	12,096	13,683	15,271	16,859
H25B	236	803	1,233	1,664	2,094	2,525	2,955	3,386	3,816	4,247							
LJ31	118	595	889	1,183	1,477	1,771											
LJ40	126	610	993	1,377	1,760	2,144	2,527										
LJ45	76	657	1,010	1,364	1,717	2,071	2,424	2,778	3,131								
LJ60	209	648	1,026	1,404	1,782	2,160	2,538	2,916	3,294	3,672	4,050						
MD11	2,169	6,837	11,505	16,174	20,842	25,510	30,179	34,847	39,515	44,184	48,852	53,521	58,189	67,526	76,862	86,199	95,536
MD82	820	2,867	4,915	6,962	9,010	11,057	13,105	15,152	17,200	19,247							
MD88	1,756	3,691	5,625	7,560	9,782	12,146	14,510	16,874									
MD90	688	3,115	5,099	6,835	8,571	10,308	12,044	13,780									
RJ85	551	2,365	4,180	5,995	7,810	9,625	11,440	13,255									
SF34	154	612	1,069	1,527	1,984	2,442											

Table 22.c. Aircraft types (by ICAO type designator) modelled with equivalent aircraft types

	Fuel (in kg) for given Great Circle Distance (in km)																
Type Designator	0	500	1000	1500	2000	2500	3000	3500	4000	4500	5000	5500	6000	7000	8000	9000	10000
A30B	2,628	5,400	8,172	10,945	13,717	16,489	19,262	22,034	24,806	27,578	30,351	33,123	35,895	41,440	46,984		
A342	2,736	6,562	10,388	13,931	17,473	21,016	24,558	28,101	31,643	35,186	38,730	42,926	47,121	55,512	63,903	72,293	80,684
A345	4,480	8,329	12,179	16,029	19,878	23,728	29,062	34,398	39,733	45,069	50,405	55,740	61,076	71,747	82,418	93,089	103,760
A35K	3,912	7,525	11,138	14,751	18,364	21,978	25,591	29,204	32,817	36,431	41,176	45,339	49,501	57,827	66,153	74,478	82,804
AN30	218	1,664	2,821	3,547	4,272	4,998											
AN32	256	1,953	3,312	4,164	5,015	5,867	6,719										
AT73	190	887	1,584	2,281	2,978												
B37M	701	1,945	3,189	4,432	5,676	6,920	8,164	9,407	10,651	11,895	13,139	14,383	15,626	18,114			
B39M	804	2,230	3,656	5,081	6,507	7,933	9,359	10,785	12,211	13,637	15,063	16,489	17,915				
B461	674	2,167	3,660	5,153													
B712	1,386	2,912	4,439	5,854	7,719	9,585	11,450	13,316									
B732	991	2,213	3,526	4,910	6,294	7,678	9,062	10,445	11,829	13,213	14,597						
B741	5,370	9,870	14,371	18,871	23,372	27,434	32,566	37,699	42,832	47,965	53,098	58,231	63,364	71,546	84,835		
B742	5,853	10,757	15,662	20,567	25,472	30,377	35,493	41,087	46,682	52,276	57,870	63,464	69,058	80,247	92,459	106,942	121,426
B743	5,861	10,773	15,685	20,597	25,509	30,421	35,545	41,148	46,750	52,352	57,955	63,557	69,159	80,364	92,595	107,099	121,603
B74R	5,117	9,406	13,695	17,983	22,272	26,143	31,035	35,926	40,818	45,709	50,600	55,492	60,383	68,181	80,845	93,509	106,172
B74S	5,003	9,196	13,389	17,581	21,774	25,559	30,341	35,123	39,905	44,687	49,469	54,251	59,033	66,656	79,037	91,418	103,798
B78X	2,254	5,208	8,161	11,115	14,068	17,022	19,975	22,929	25,882	29,148	32,412	35,676	38,941	45,469	51,997	58,526	65,054
C25C	235	763	1,170	1,573	1,976	2,378	2,781	3,184	3,587								
C525	173	566	863	1,160	1,458	1,755											
C55B	205	667	1,022	1,373	1,725	2,077	2,428	2,780									
C560	224	727	1,114	1,497	1,881	2,264	2,648	3,031									
DH8A	165	611	1,056	1,501	1,946												
DH8B	171	631	1,091	1,550													
DH8C	201	743	1,285	1,827	2,369												
DHC7	208	769	1,330														
E75L	492	1,807	2,893	4,117	5,362	6,607	7,852										
E75S	477	1,752	2,805	3,992	5,200	6,407	7,614										
FA8X	395	1,370	2,059	2,749	3,439	4,128	4,818	5,508	6,198	6,887	7,577	8,267	8,956	10,336	11,715	13,094	14,474
H25A	217	738	1,134	1,530	1,926	2,322	2,718	3,114	3,509	3,905	4,301						
H25C	261	890	1,367	1,844	2,322	2,799											
LJ25	90	436	710	985	1,259	1,533	1,807										
LJ35	110	532	867	1,201	1,536	1,870	2,205	2,539	2,874	3,208							
LJ55	74	645	992	1,339	1,687	2,034	2,381										
LJ70	76	658	1,012	1,367	1,721	2,075	2,429	2,783									
LJ75	78	674	1,036	1,399	1,762	2,124	2,487	2,849									
MD81	784	2,742	4,699	6,657	8,614	10,572	12,530	14,487	16,445	18,402	20,360						
MD83	892	3,118	5,345	7,572	9,799	12,025	14,252	16,479	18,705	20,932	23,159	25,385	27,612	32,066			
MD87	1,597	3,356	5,115	6,874	8,896	11,045	13,195	15,345	17,495	19,644	21,794	23,944	26,094				
RJ1H	693	2,642	4,592	6,541	8,490	10,440	12,389	14,338	16,288								
RJ70	556	2,388	4,221	6,054	7,886												

Table 22.d. Aircraft types (by ICAO type designator) modelled with an ICAO Fuel Formula

	Fuel (in kg) for given Great Circle Distance (in km)																
Type Designator	0	500	1000	1500	2000	2500	3000	3500	4000	4500	5000	5500	6000	7000	8000	9000	10000
A124	9,659	18,979	28,299	37,619	46,939	56,259	65,579	74,899	84,219	93,539	102,859						
A140	314	963	1,612	2,261	2,909	3,558	4,207										
A148	783	1,732	2,681	3,630	4,579	5,528	6,477	7,427									
A748	321	982	1,644	2,306													
AN12	1,262	3,335	5,408	7,482	9,555	11,629	13,702	15,776	17,849	19,923	21,996	24,069					
AN24	433	1,135	1,837	2,539	3,241												
AN28	157	482	806														
AN72	783	1,732	2,681	3,630	4,579	5,528	6,477	7,427	8,376								
ATP	282	865	1,447	2,029	2,612	3,194	3,777	4,359	4,942								
B701	2,632	6,027	9,421	12,816	16,210	19,605	22,999	26,394	29,594	32,680	35,766	38,852	41,938	48,110	54,282	60,454	
B721	1,520	3,586	5,651	7,717	9,782	11,848	13,788	15,716	17,644	19,572							
BA11	558	2,209	3,861	5,512	7,164	8,815	10,467	12,118	13,770	15,421							
BE20	46	142	237	333	428	524	619	715									
BELF	397	3,910	6,502	9,094	11,686	14,278	16,870	19,462	22,054	24,646	27,238	29,830	32,422	37,606	42,790		
C130	869	2,664	4,459	6,254	8,049	9,844	11,639	13,434									
C212	138	423	707	992													
CN35	210	642	1,075	1,507	1,940	2,372	2,805	3,237	3,670								
CVLP	20	1,294															
D228	115	353	590	828	1,065	1,303											
DC10	3,297	7,887	12,476	17,066	21,655	26,245	31,309	36,660	42,010	47,361	52,711	58,062	63,412	74,113	85,021		
DC3	6	397	569	742	914												
DC6	22	1,412	2,026	2,639	3,253	3,866	4,480	5,093	5,707	6,320	6,934	7,547	8,161	9,388			
DC85	3,118	6,126	9,135	12,143	15,152	18,160	21,169	24,177	27,186	30,194	33,203	36,211	39,220	45,237	51,254	57,271	
DC86	3,118	6,126	9,135	12,143	15,152	18,160	21,169	24,177	27,186	30,194	33,203	36,211	39,220	45,237	51,254	57,271	
DC87	3,118	6,126	9,135	12,143	15,152	18,160	21,169	24,177	27,186	30,194	33,203	36,211	39,220	45,237	51,254	57,271	
DC91	685	2,234	3,784	5,333													
DC92	693	2,262	3,830	5,399	6,967	8,536											
DC93	741	2,418	4,095	5,772	7,449	9,126	10,803	12,480	14,157	15,834	17,511						
DC94	796	2,596	4,397	6,197	7,998	9,798	11,599										
DC95	821	2,680	4,538	6,397													
DHC6	26	366	608														
E110	35	342	569	796													
E120	169	539	909	1,279													
F27	48	1,048	1,743	2,438	3,133	3,828	4,523	5,218	5,913	6,608							
F28	419	2,221	3,404	4,588	5,771	6,955	8,138	9,322	10,505								
FA10	159	844	1,293	1,743	2,192	2,642	3,091										
G159	90	977	1,625	2,273	2,921	3,569	4,217	4,865	5,513								
I114	113	1,195	1,987														
IL18	890	2,729	4,567	6,405	8,243	10,082	11,920										
IL62	2,656	6,827	10,997	15,168	19,338	23,509	27,679	31,850	36,020	40,191	44,361	48,532	52,702	61,043	69,384		
IL76	7,415	11,716	16,018	20,749	25,845	30,941	36,037	41,133	46,229	51,325							
IL86	7,365	12,963	18,561	24,159	29,757	35,427	41,154	46,882	52,609	58,337							
IL96	2,477	7,237	11,998	16,758	21,519	26,279	31,040	35,800	40,561	45,321	50,082	54,842	59,603	69,124	78,645	88,166	97,492
J328	183	968	1,484	2,000													
JS31	120	369	618														
JS32	129	394	659														
JS41	177	544	910	1,276	1,642	2,008	2,375	2,741									
L101	2,733	7,649	12,566	17,482	22,399	27,315	32,232	37,148	42,065	46,981	51,898	57,340	63,066	74,518	85,970	97,422	108,874
L188	287	3,149	5,236	7,324	9,411	11,499	13,586	15,674									
L410	49	434	722	1,010													
N262	132	404	677														
S601	184	407	630	853	1,076	1,299											
SB20	829	1,391	1,954	2,517	3,080	3,643											
SC7	87	267	448														
SH33	166	508	850	1,193													
SH36	177	544	910	1,276													
SW2	124	380	636	892	1,148	1,403	1,659	1,915									
T134	2,065	3,584	5,104	6,623	8,142	9,662	11,181	12,701									
T154	2,805	5,809	8,813	11,817	14,821	17,825	20,734	23,594	26,453	29,313	32,172						
T204	2,801	5,806	8,812	11,817	14,823	17,828	20,734	23,594	26,453	29,313	32,172	35,032	37,891				
WW24	122	646	990	1,334	1,678	2,022	2,366	2,710	3,054								
YK40	171	906	1,389	1,872													
YK42	703	3,514	5,076	6,638	8,200	9,762	11,324	12,886	14,448								
YS11	87	958	1,593	2,228	2,863												

9.3 Aircraft types (by type designator) that will be the focus of further and targeted data collection towards the 2020 version on the ICAO CORSIA CERT

Type Designator	Manufacturer	Example of Model*
A124	ANTONOV	An-124 Ruslan
A140	ANTONOV	IRAN-140 Faraz
A148	ANTONOV	An-148
A158	ANTONOV	An-158
A20N	AIRBUS	A-320neo
A21N	AIRBUS	A-321neo
A225	ANTONOV	An-225 Mriya
A30B	AIRBUS	A-300B2
A342	AIRBUS	A-340-200
A345	AIRBUS	A-340-500
A359	AIRBUS	A-350-900 XWB
A35K	AIRBUS	A-350-1000 XWB
A3ST	AIRBUS	A-300ST Beluga
A743	ANTONOV	An-74-300
A748	AIL	748
AJET	AOI	Alpha Jet
AN12	ANTONOV	An-12
AN24	ANTONOV	An-24
AN26	ANTONOV	An-26
AN28	ANTONOV	An-28
AN30	ANTONOV	An-30
AN32	ANTONOV	An-32
AN38	ANTONOV	An-38
AN70	ANTONOV	An-70
AN72	ANTONOV	An-72
ASTR	GULFSTREAM AEROSPACE	1125 Astra
AT3	AIDC	AT-3 Tzu-Chung
AT43	ATR	ATR-42-300
AT44	ATR	ATR-42-400
AT73	ATR	ATR-72-211
AT75	ATR	ATR-72-500
ATP	BRITISH AEROSPACE	ATP
B350	BEECH	King Air 350
B38M	BOEING	737 MAX 8
B461	BRITISH AEROSPACE	BAe-146-100
B701	BOEING	707-100
B703	BOEING	707-300
B712	BOEING	717-200
B721	BOEING	727-100
B722	BOEING	727-200
B732	BOEING	737-200
B741	BOEING	747-100
B742	BOEING	747-200
B743	BOEING	747-300
B74D	BOEING	747-400 (domestic, no winglets)
B74R	BOEING	747SR
B74S	BOEING	747SP
B773	BOEING	777-300
B78X	BOEING	787-10 Dreamliner
BA11	BAC	BAC-111 One-Eleven
BCS1	BOMBARDIER	BD-500 CSeries CS100
BCS3	BOMBARDIER	BD-500 CSeries CS300
BE20	BEECH	Super King Air (200)
BE30	BEECH	300 Super King Air
BE40	BEECH	400 Beechjet
BELF	SHORT	SC-5 Belfast
BLCF	BOEING	747-400LCF Dreamlifter
C130	LOCKHEED	L-100 Hercules
C212	AIRBUS	C-212 Aviocar
C25B	CESSNA	525B Citation CJ3
C25C	CESSNA	525C Citation CJ4
C27J	ALENIA	Spartan (C-27J)
C295	AIRBUS	C-295
C525	CESSNA	525 Citation CJ1
C55B	CESSNA	550B Citation Bravo
C560	CESSNA	560 Citation 5
C650	CESSNA	650 Citation 3
C680	CESSNA	680 Citation Sovereign
C700	CESSNA	700 Citation Longitude
C750	CESSNA	750 Citation 10
CN35	AIRBUS	CN-235
CRJ2	CANADAIR	Challenger 800
CVLP	CONVAIR	Convairliner
CVLT	CANADAIR	Cosmopolitan
D228	DORNIER	Dornier 228
DC10	BOEING	DC-10
DC3	DOUGLAS	DC-3
DC6	DOUGLAS	DC-6
DC85	DOUGLAS	DC-8-50
DC87	DOUGLAS	DC-8-70
DC91	DOUGLAS	DC-9-10
DC92	DOUGLAS	DC-9-20
DC93	DOUGLAS	DC-9-30
DC94	DOUGLAS	DC-9-40
DC95	DOUGLAS	DC-9-50
DH8A	DE HAVILLAND CANADA	Dash 8 (100)
DH8B	DE HAVILLAND CANADA	Dash 8 (200)
DH8C	DE HAVILLAND CANADA	Dash 8 (300)
DHC6	DE HAVILLAND CANADA	DHC-6 Twin Otter
DHC7	DE HAVILLAND CANADA	DHC-7 Dash 7
E110	EMBRAER	EMB-110 Bandeirante
E120	EMBRAER	EMB-120 Brasilia
E195	EMBRAER	ERJ-190-200
E545	EMBRAER	EMB-545 Legacy 450
E550	EMBRAER	EMB-550 Legacy 500
E75L	EMBRAER	ERJ-170-200 (long wing)
E75S	EMBRAER	ERJ-170-200 (short wing)
F27	CONAIR	F-27
F28	FOKKER	F-28 Fellowship
FA10	DASSAULT	Falcon 10
FA20	DASSAULT	Falcon 20
FA8X	DASSAULT	Falcon 8X
G150	GULFSTREAM AEROSPACE	Gulfstream G150
G159	GRUMMAN	G-159 Gulfstream 1
GA5C	GULFSTREAM AEROSPACE	Gulfstream G500 (G-7)
GALX	GULFSTREAM AEROSPACE	Gulfstream G200
GLF2	GRUMMAN	Gulfstream 2
GLF3	GULFSTREAM AEROSPACE	Gulfstream 3
H25A	DE HAVILLAND	HS-125-1
H25C	BRITISH AEROSPACE	Hawker 1000
HA4T	HAWKER BEECHCRAFT	Hawker 4000
I114	ILYUSHIN	Il-114
IL18	ILYUSHIN	Il-18
IL62	ILYUSHIN	Il-62
IL76	ILYUSHIN	Il-76
IL86	ILYUSHIN	Il-86
IL96	ILYUSHIN	Il-96
J328	328 SUPPORT SERVICES	Dornier 328JET
JS31	BRITISH AEROSPACE	BAe-3100 Jetstream 31
JS32	BRITISH AEROSPACE	BAe-3200 Jetstream Super 31
JS41	AI(R)	BAe-4100 Jetstream 41
L101	LOCKHEED	L-1011 TriStar
L188	LOCKHEED	Electra (L-188)
L29B	LOCKHEED	L-1329 Jetstar 2
L410	AIRCRAFT INDUSTRIES	L-410 Turbolet
LJ24	GATES LEARJET	24
LJ25	GATES LEARJET	25
LJ35	GATES LEARJET	35
LJ55	GATES LEARJET	55
LJ70	LEARJET	70
LJ75	LEARJET	75
M28	PZL-MIELEC	M-28 Skytruck
MD81	BOEING	MD-81
MD82	BOEING	MD-82
MD83	BOEING	MD-83
MD87	BOEING	MD-87
MG15	AERO (2)	MiG-15
MRJ9	MITSUBISHI	MRJ-90
MU30	MITSUBISHI	MU-300 Diamond
N262	AEROSPATIALE	N-262 Frégate
PC24	PILATUS	PC-24
RJ1H	AI(R)	RJ-100 Avroliner
RJ70	AI(R)	RJ-70 Avroliner
S601	AEROSPATIALE	SN-601 Corvette
SB20	SAAB	2000
SBR1	NORTH AMERICAN	Sabreliner
SC7	SHORT	SC-7 Skyliner
SH33	SHORT	SD3-30
SH36	SHORT	360
SU95	SUKHOI	Superjet 100-95
SW2	SWEARINGEN	SA-26 Merlin 2
SW3	FAIRCHILD (1)	Merlin 3
SW4	FAIRCHILD (1)	Merlin 4
T134	TUPOLEV	Tu-134
T154	TUPOLEV	Tu-154
T204	TUPOLEV	Tu-204
T334	TUPOLEV	Tu-334
WW24	IAI	1124 Westwind
YK40	YAKOVLEV	Yak-40
YK42	YAKOVLEV	Yak-42
YS11	MITSUBISHI	YS-11

Fig 36. Aircraft type designator

9.4 PianoX Simulation for Airbus A340.

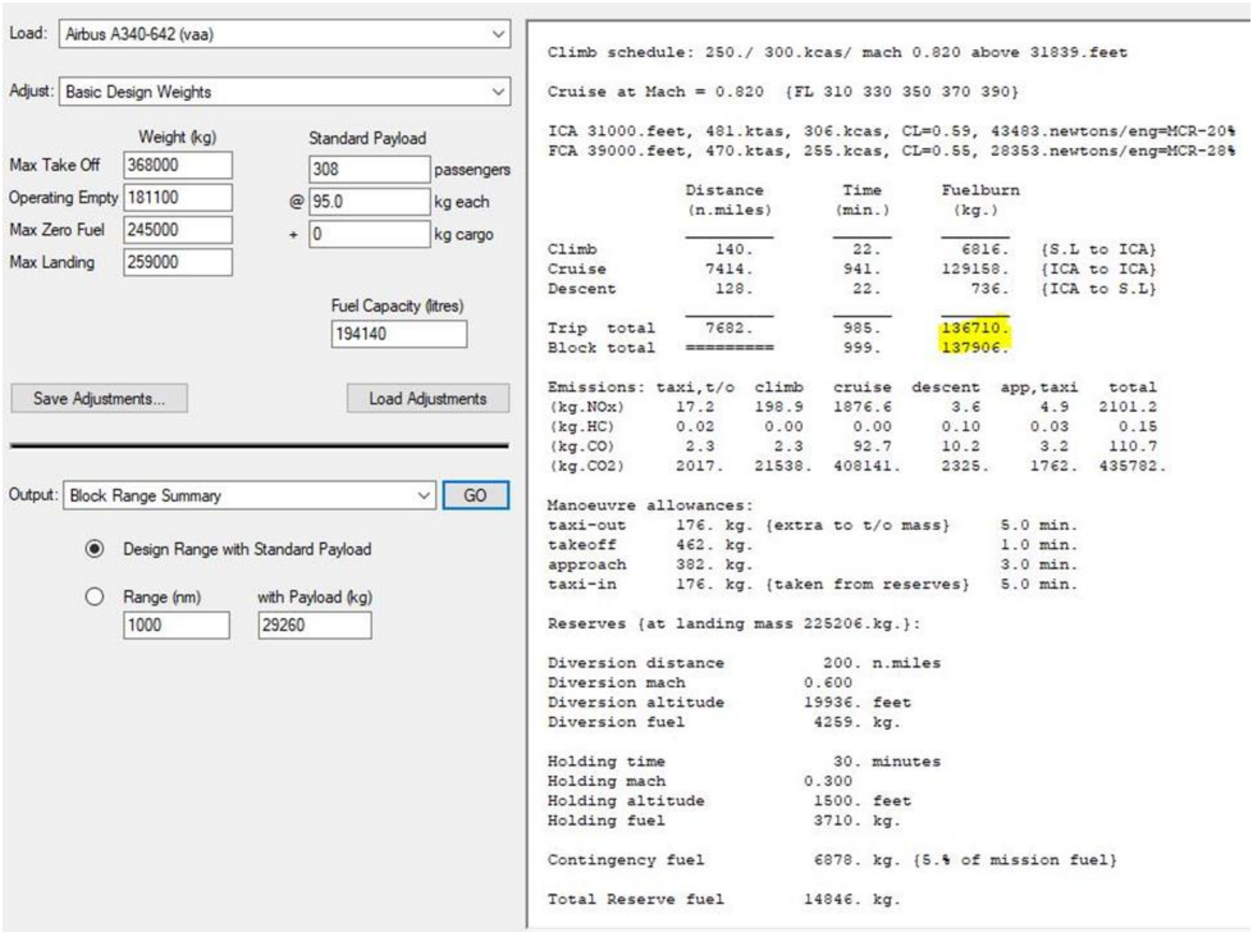

Fig 37. Simulation Screenshot of PianoX for Airbus A340

9.5 Aircraft Average Seat Dataset.

Aircrafts	Av. No. Seats
AIRBUS A319	152
AIRBUS A320-100/200	175
AIRBUS A321	198
ATR72 200/500/600	70
BOEING 737-800	190
BOEING 767-300ER/F	259
BOMBARDIER DASH 8 Q400	78
EMB ERJ170 (170-100)	83
EMBRAER ERJ190	106
SAAB 2000	35
SAAB FAIRCHILD 340	23
Short-haul Flights	
AIRBUS A319	153
AIRBUS A320-100/200	180
AIRBUS A321	215
AIRBUS A330-200	352
AIRBUS A330-300	298
AIRBUS A350-900	298
ATR72 200/500/600	71
AVROLINER RJ85	94
BOEING 737-300	152
BOEING 737-400	85
BOEING 737-700	135
BOEING 737-800	189
BOEING 737-900	176
BOEING 757-200	177
BOEING 757-300	277
BOEING 767-300ER/F	220
BOEING 777-200	223
BOEING 777-300	357
BOEING 787-800 DREAMLINER	293
BOMBARDIER DASH 8 Q400	78

EMB ERJ170 (170-100)	85
EMBRAER ERJ190	105
Long-haul Flights	
AIRBUS A310	246
AIRBUS A320-100/200	171
AIRBUS A321	158
AIRBUS A330-200	281
AIRBUS A330-300	278
AIRBUS A340-300	267
AIRBUS A340-600	307
AIRBUS A350-900	291
AIRBUS A380-800	499
BOEING 737-800	164
BOEING 747-400	344
BOEING 757-200	170
BOEING 767-300ER/F	201
BOEING 777-200	246
BOEING 777-300	340
BOEING 777-300ER	300
BOEING 787-800 DREAMLINER	254
BOEING 787-900 DREAMLINER	263

Table 23. Specifications of Average seat data for specific aircrafts.

9.6 Sample Calculations using different emission methodologies.

9.6.1 DEFRA Calculations

Total carbon emission per route = *Distance flown directly between two airports (km) x total weight of receptacles transported on this route (kg) x appropriate DEFRA factor based on the flown distance* (PostNL, 2019).

Example:

A freight is flown from Chicago (US) to Frankfurt (DE). Based on a great circle calculation, the distance between both airports in a straight line is 6927 km. In total, 229,9 kg of receptacles were transported. 6927 km x 229,9 kilogram(= 1.593 ton-km) x 0,770081 (DEFRA factor for long haul freight) = 1.226 kgCO2 emission.

9.6.2 MyClimate Calculator

The following formula is used to calculate the total CO2-equivalent emissions:

$$E = \frac{ax^2 + bx + c}{S * PLF} * (1 - CF) * CW * (EF * M + P) + AF * X + A$$

For calculations considering Airbus A320

=(4211(1-0.8)*1*(3.16*2+0.54)+(0.00038*1100)+0)/(171*80.89)

= 5830.16 kgs Co2

Where,

E: Passenger CO2 eq emissions [kg]
x: flight distance [km] defined as the sum of GCD, large circle distance and DC, distance correction for detours and holding patterns, and air traffic control system inefficiencies [km]=1100km
S: Maximum number of seats (total for all levels of cabins) =171
PLF: Load factor for passengers =80.89%
CF: The freight component =80%
CW: Cabin class weighting factor =1
EF: emission factor for the combustion of jet fuel (kerosene) =3.16
M: Multiplier accounting for potential consequences other than CO2
P: emission factor CO2e for jet fuel preproduction, kerosene =0.54
AF: aircraft factor =0.00038
A: The pollution from airport services
The part ax+ bx + c is a nonlinear approximation of f(x) + LTO
LTO: Fuel consumption during landing and takeoff cycle including taxi [kg]
Short-haul is defined as x<1500km and long-haul as x>2500km. In between, a linear interpolation is used.

9.6.3 Modified Zurich Carbon Emission Calculator

The following equation has been applied for the estimation of the standard aircraft emission factor:

$$EF_{Region} = \frac{FB_{Flightblock} * EI_{CO2}}{Distance_{Flightblock/Region} * Payload}$$

Where for Boeing 747-8:

EF_{Region} = Emission factor [kg CO2 / t*km] per world region = 2.234

FB $_{Flightblock}$ = Total Fuel Burn of aircraft [kg fuel] to that region = 30960

EI_{CO2} = CO2 [kg / kg fuel] emissions index = 3.16

DistanceFlightblock /Area = Flight block distance [km] per particular region of the world = 550kms GCD Distance

Payload = Passenger number (=Average no. of seats*Passenger load factor) *100 kg + Cargo Freight by PostNL(kg) =31060(including 100 kgs of PostNL freight weight)

The emissions for an aircraft cargo shipment to a particular region are calculated using the equation:

CO2 [kg] = EFRegion [kg CO2/t*km] * Flight distance (GCD + correction factor) [km] * cargo mass [t]
= 2.234*550*0.8*0.001= 98.32 kgs

9.6.4 ICAO Methodology and other related methodologies.

The methodology calculates the Co2 associated with each passenger using the trip frequency, equivalent aircraft fuel consumption, passenger to seat load factor and passenger to freight load factor for the route category and the number of Y-seats. However, as the proposed model doesn't need the Co2 associated with each passenger and also does not take into account the passenger to load factor, the sample calculations are not taken into consideration and used as a theoretical model for the current research.

The New Zealand emission calculation methodology, along with the IATA methodology, takes into account a similar calculation methodology using confidential resources from the datasets privately available by the airline companies. The Passenger load factor is approximately dependent on 67-100 % depending on the region for the NZL methodology, and for the IATA methodology, the passenger load factor and the average seating capacity is representative from the CAA Data and carries out a linear algorithm for fuel emission calculation using privately owned datasets.

The Atmosfair emission calculator was not included in the sample calculations as it just provides a conceptual background to the research, and the algorithm and methodology in place was strictly confidential. Also, It is evident that the methodologies differ significantly from one another in terms of algorithms, usage of confidential and public data sources as well as country-specific requirements.

The discrepancies in the results can be subjected to the usage of different variables in the sourced datasets and the usage of different simple to advanced modeling techniques with input data improvements. However, similar models can be used for the calculations when the required input datasets are easily available.

9.7 Fuel Comparison and Pattern Charts for Boeing 777-300ER and Airbus A320

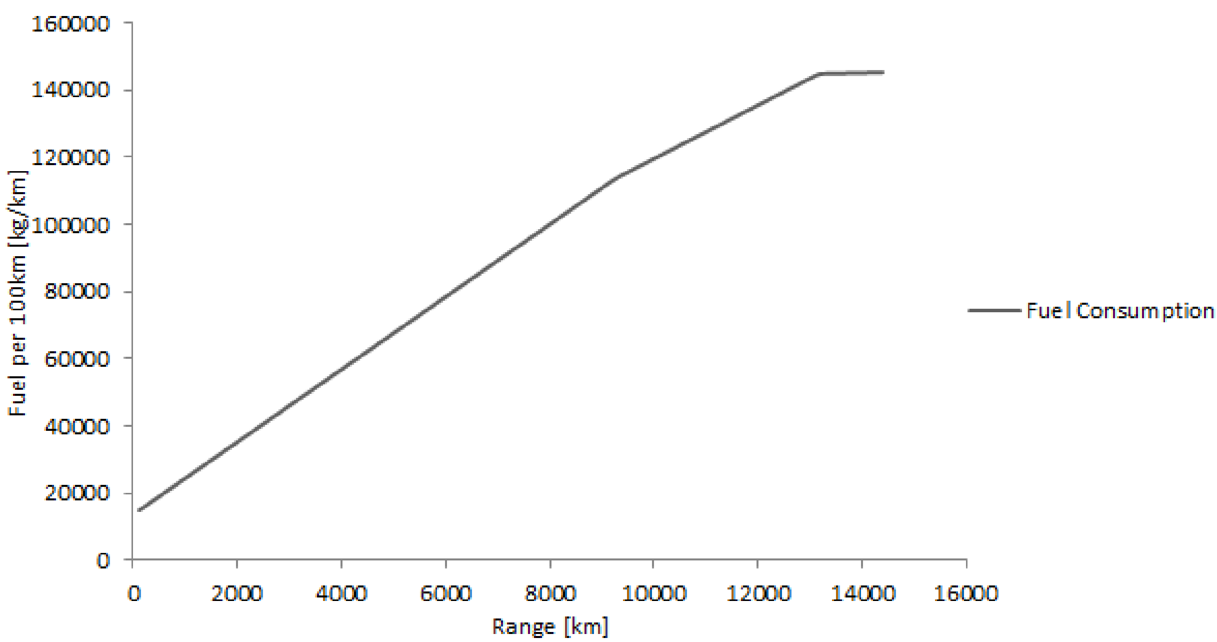

Fig 38. Fuel Consumption vs. Range of a Boeing 777-300ER

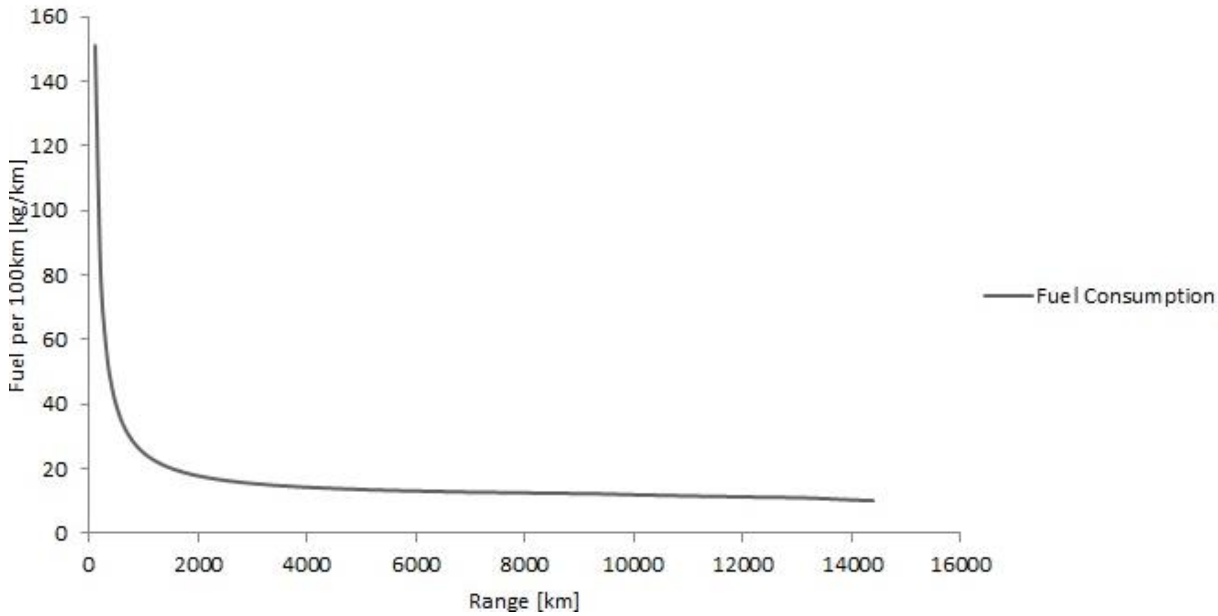

Fig 39. Fuel/Range vs. Range Chart of Boeing 777-300ER

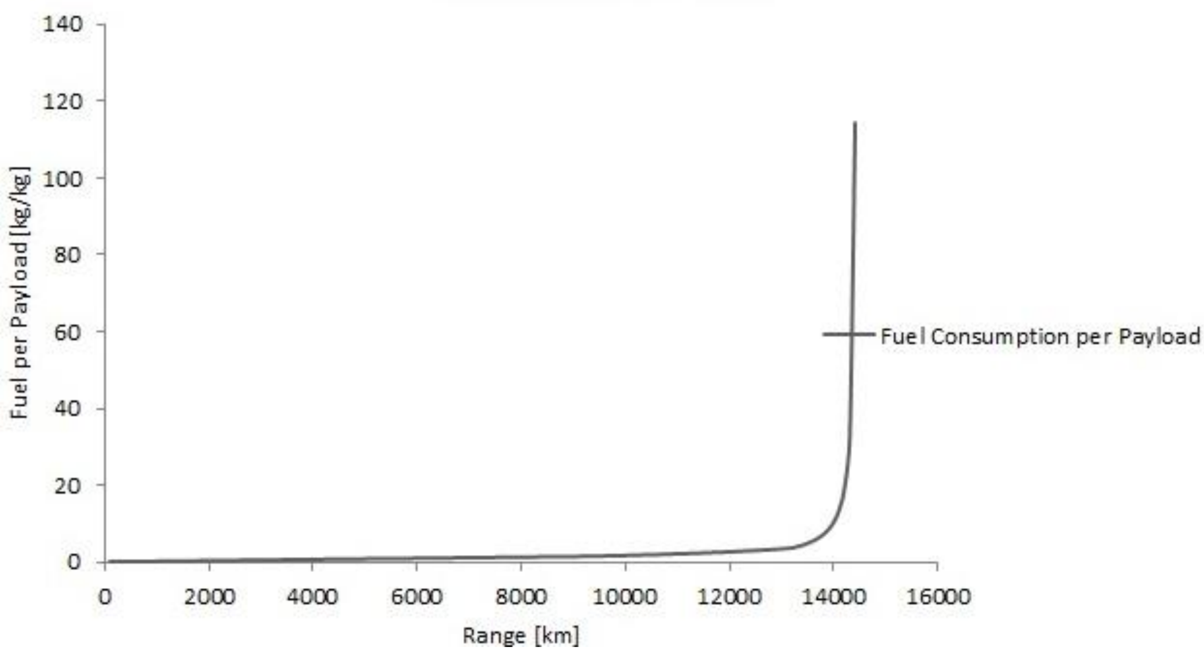

Fig 40. Fuel per Payload vs. Range of Boeing 777-300ER

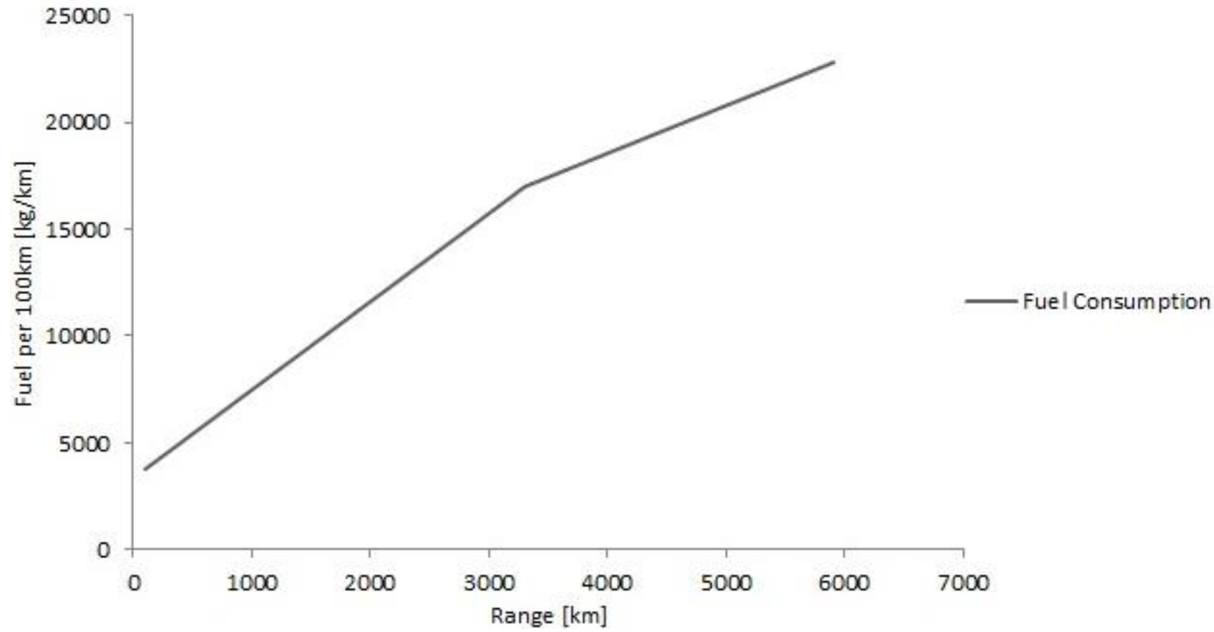

Fig 41. Fuel Consumption vs. Range of an Airbus A320

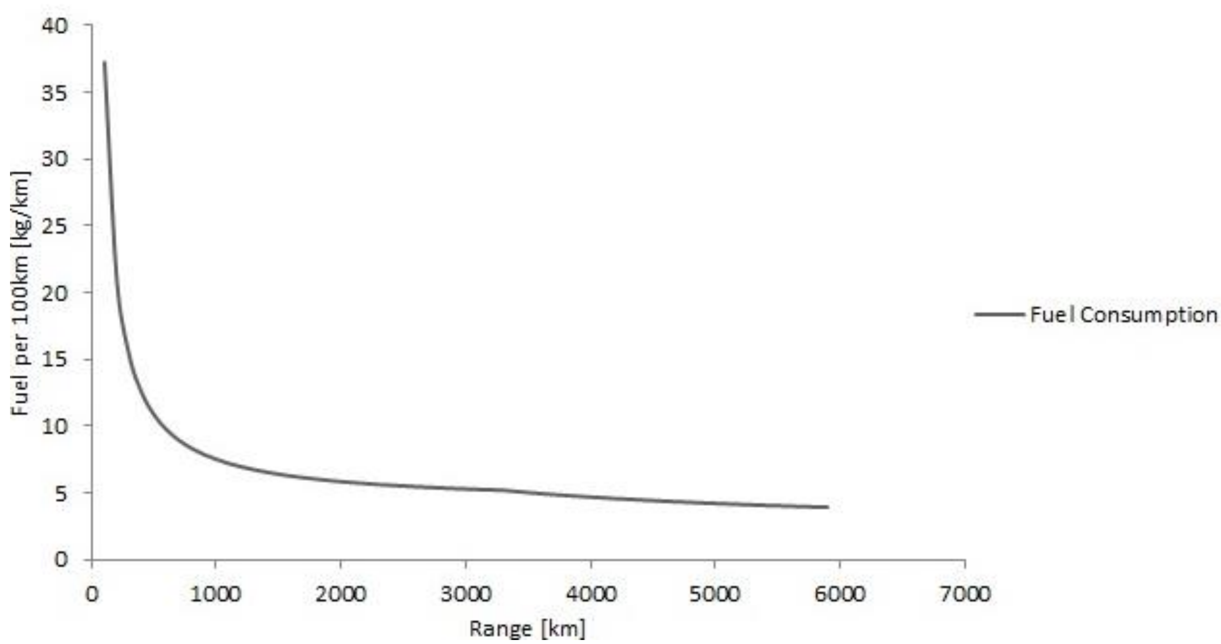

Fig 42. Fuel/Range vs. Range Chart of Airbus A320

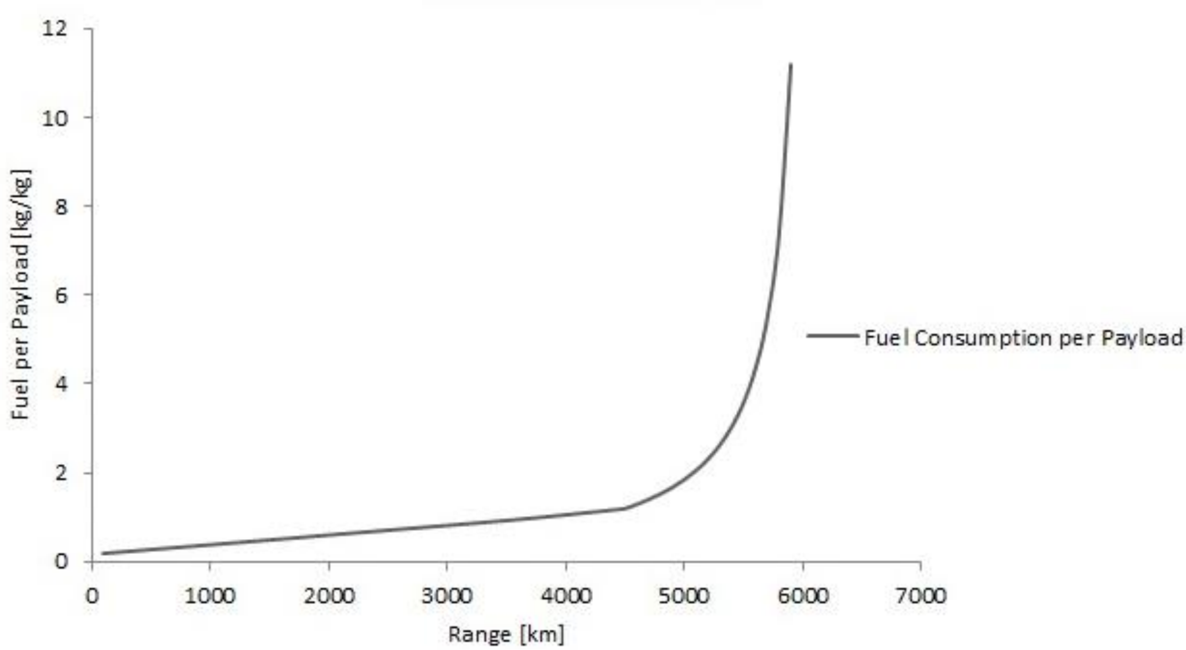

Fig 43. Fuel per Payload vs Range of Airbus A320

9.8 VBA Code with Comments.

Note: The use of this particular code is subject to the model developed. However, the overall code and the algorithm can be modified and be used in different files/systems, respectively.

1. Model 1.

1. a) Module code - Defining global variables.

```
'All global constants are declared here, these constants can be accessed from any module/UserForm module

Public Const snCostLead = "Cost & Lead Time"

Public Const snAircraftRoutes = "Aircraft Routes"

Public Const snEmissionCalculation = "Emission Calculation"

Public Const snFuelData = "Fuel Data"

Public Const snOptimize = "Optimize"


Public Const stRow = 5
```

```
Public shtCostLead

Public shtAircraftRoutes

Public shtEmissionCalculation

Public shtFuelData

Public shtOptimize

Sub LoadVariables()

'These routine just loads all the Sheet objects, it uses the sheet name constants declared at the top of this module for the same

'Any routine can call this sub and all the sheet objects get loaded to be used

Set shtCostLead = Sheets(snCostLead)

Set shtAircraftRoutes = Sheets(snAircraftRoutes)

Set shtEmissionCalculation = Sheets(snEmissionCalculation)

Set shtFuelData = Sheets(snFuelData)

Set shtOptimize = Sheets(snOptimize)

End Sub

Sub ShowForm()

'The SHOW FORM button on the optimize sheet calls this sub

'It simply shows the UserForm

UserForm1.Show

End Sub
```

1. b) Main UserForm Code.

```
'These variables can be accessed by any sub/function of this userform module only

Dim arrRoutes

Dim arrVia

Dim bnRouteChange As Boolean

Dim bnFilterChange As Boolean

Private Sub UserForm_Initialize()

'This sub is automatically triggered when the UserForm is initiated

LoadVariables 'Calls LoadVariables so that all sheet objects can be assigned to be used further below
```

lrRoutes = shtCostLead.Range("B" & Rows.Count).End(xlUp).Row *'Gets the last row of the Cost and Lead sheet*

arrRoutes = shtCostLead.Range("B2:E" & lrRoutes).Value *'All values from starting from Cell B2 to the last cell of Column E are copied to an array called arrRoutes*

'It is considered a good practice to load all cell values of a range into an array. This way all cell values of that range

'get loaded into memory and accessing those values becomes much faster. On the other hand if you do not load the cell values

'into an array and instead get value from each and every cell individually when required it increases the traffic between

'the worksheet and VBA which slows down the code tremendously

ReDim arrFrom(1 To UBound(arrRoutes)) *'Declaring an array called arrFrom. The number of values that this array can store is*

'UBound(arrRoutes) which means the upper bound of array arrRoutes which means the index of the last element of array arrRoutes

'Basically arrFrom contains the same number of rows as the arrRoutes array

'Next, we will populate arrFrom with the unique ORIGIN values from the Cost and Lead sheet (arrRoutes)

```
ind1 = 0 'Setting ind1 equal to zero before initiating the loop
For n = 1 To UBound(arrRoutes) 'Loop through each row of arrRoutes
  bnAdd = True 'Setting bnAdd as true before intiating the next loop
  For n2 = 1 To ind1 'Loop from 1 to ind1
    If arrFrom(n2) = arrRoutes(n, 1) Then 'Check if the value already exists in arrFrom
      bnAdd = False 'if it already exists we set bnAdd to False which means we dont need to add this ORIGIN, we already have it
      Exit For 'exit for loop
    End If
  Next n2
  If bnAdd Then 'if bnAdd is still TRUE after the above loop it means this ORIGIN does not already exist in arrFrom and we need to add it
    ind1 = ind1 + 1 'increase the index by 1
    arrFrom(ind1) = arrRoutes(n, 1) 'Add the ORIGIN value to arrFrom
```

```
  End If
Next n

Me.cbFrom.Clear 'Clear combobox cbFrom
For n = 1 To ind1 'Loop from 1 to ind1
  Me.cbFrom.AddItem arrFrom(n) 'add each value in arrFrom to this combobox
Next n

'Populating the cbDay combobox with the following day values
Me.cbDay.AddItem "Monday"
Me.cbDay.AddItem "Tuesday"
Me.cbDay.AddItem "Wednesday"
Me.cbDay.AddItem "Thursday"
Me.cbDay.AddItem "Friday"
Me.cbDay.AddItem "Saturday"
Me.cbDay.AddItem "Sunday"

'Call FilterViaRoutes
FilterViaRoutes
End Sub
Private Sub cbFrom_Change()
'This sub is triggered when selection in combobox cbFrom changes
bnRouteChange = True 'We set bnRouteChange variable to TRUE which means something with the route selection has changed.
'this is a module level variable declared at the top of this module which can be accessed by any sub/function of this module
'When the user clicks on the GENERATE button, we will check if bnRouteChange is TRUE and if yes we will regenerate our results
'If bnRouteChange is FALSE it means user hasnt changed any option related to the route and therefore we do not need to regenerate
'our results
```

```
FilterToRoutes 'FilterToRoutes is called

End Sub

Sub FilterToRoutes()

'This sub is used to get the possible DESTINATIONS for the selected ORIGIN and populate them in the cbTo combobox


mFrom = Me.cbFrom.Value 'retrieve the ORIGIN selected by the user

ReDim arrTo(1 To UBound(arrRoutes)) 'Declare an array arrTo which has the same number of rows as arrRoutes

ind1 = 0 'set index to zero

For n = 1 To UBound(arrRoutes) 'loop through each row of arrRoutes

  If arrRoutes(n, 1) = mFrom Then 'Check if the ORIGIN value in the arrRoutes row matches the ORIGIN selected by the user

    bnAdd = True 'Set bnAdd equal to TRUE before intiating the next loop

    For n2 = 1 To ind1 'loop from 1 to ind1

      If arrTo(n2) = arrRoutes(n, 2) Then 'Check if the DESTINATION already exists in arrTo

        bnAdd = False 'if Yes then set bnAdd = FALSE

        Exit For 'exit for loop

      End If

    Next n2

    If bnAdd Then 'if bnAdd is still TRUE after the above loop it means that this DESTINATION does not already exist in arrTo and thus needs to be added

      ind1 = ind1 + 1 'increment index by 1

      arrTo(ind1) = arrRoutes(n, 2) 'add DESTINATION to arrTo

    End If

  End If

Next n


Me.cbTo.Clear 'Clear combobox cbTo

For n = 1 To ind1 'Loop from 1 to ind1
```

```
   Me.cbTo.AddItem arrTo(n) 'Add each value in arrTo to combobox cbTo

Next n

End Sub

Private Sub cbTo_Change()

bnRouteChange = True 'Mark bnRouteChange = TRUE which indicates that something with the Route
selection has changed

FilterViaRoutes 'Call FilterViaRoutes

End Sub

Sub FilterViaRoutes()

'This sub works along the exact same lines as FilterToRoutes

'This sub looks at the selected ORIGIN and DESTINATION values and populates the VIA dropdown with
the possible values


ReDim arrVia(1 To UBound(arrRoutes), 1 To 2)

mFrom = Me.cbFrom.Value

mTo = Me.cbTo.Value


ind1 = 0

For n = 1 To UBound(arrRoutes)

   If arrRoutes(n, 1) = mFrom And arrRoutes(n, 2) = mTo Then bnAdd = True Else bnAdd = False

   If bnAdd Then

      For n2 = 1 To ind1

         If arrVia(n2, 1) = arrRoutes(n, 3) And arrVia(n2, 2) = arrRoutes(n, 4) Then

            bnAdd = False

            Exit For

         End If

      Next n2

      If bnAdd Then

         ind1 = ind1 + 1

         For x = 1 To 2

            arrVia(ind1, x) = arrRoutes(n, x + 2)
```

```
        Next x
      End If
    End If
Next n

Me.cbVia.Clear
For n = 1 To ind1
    Me.cbVia.AddItem arrVia(n, 1) & IIf(arrVia(n, 2) <> "", "-" & arrVia(n, 2), "")
Next n
End Sub
Private Sub cbVia_Change()
bnRouteChange = True 'Mark bnRouteChange = TRUE which indicates that something with the Route selection has changed
End Sub
Private Sub cbDay_Change()
bnRouteChange = True 'Mark bnRouteChange = TRUE which indicates that something with the Route selection has changed
End Sub
Private Sub CommandButton1_Click()
If bnRouteChange Then GenerateRoutes 'if bnRouteChange = TRUE it means user has made some changes to the route selections i.e.
'ORIGIN, DESTINATION, VIA or DAY and hence we need to regenerate our results
If bnFilterChange Then ApplyFilters 'if bnFilterChange = TRUE it means user has made some changes to the filters and hence
'we need to reapply the filters
End Sub
Sub GenerateRoutes()
'This sub is called by the GENERATE button and generates the output on the Optimize sheet

If Me.cbFrom.Value = "" Then 'check if the ORIGIN is blank
    MsgBox "Please select a FROM location to proceed!", vbCritical 'if yes, then throw an error prompt
```

```
    Exit Sub 'exit this sub
ElseIf Me.cbTo.Value = "" Then 'check if the DESTINATION is blank
    MsgBox "Please select a TO location to proceed!", vbCritical 'if yes, then throw an error prompt
    Exit Sub 'exit this sub
ElseIf Me.cbDay.Value = "" Then 'check if the DAY is blank
    MsgBox "Please select a DAY to proceed!", vbCritical 'if yes, then throw an error prompt
    Exit Sub 'exit this sub
End If

mFrom = Me.cbFrom.Value 'Get the ORIGIN value selected by the user
mTo = Me.cbTo.Value 'Get the DESTINATION value selected by the user
If Me.cbVia.ListIndex > -1 Then 'If the user has also selected a VIA option get the selected VIA values
    mVia1 = arrVia(Me.cbVia.ListIndex + 1, 1)
    mVia2 = arrVia(Me.cbVia.ListIndex + 1, 2)
Else 'if user hasnt selected the VIA values set the VIA values to blank
    mVia = ""
    mVia2 = ""
End If

'Divide the complte routes into individual sections
'For instance A-D via B-C means three individual route sections of A-B, B-C, C-D
Dim arrAllRoutes(1 To 3, 1 To 2)
arrAllRoutes(1, 1) = Me.cbFrom.Value
If mVia1 <> "" Then
    arrAllRoutes(1, 2) = mVia1
    arrAllRoutes(2, 1) = mVia1
    If mVia2 <> "" Then
        arrAllRoutes(2, 2) = mVia2
        arrAllRoutes(3, 1) = mVia2
        arrAllRoutes(3, 2) = mTo
```

```
    Else
        arrAllRoutes(2, 2) = mTo
    End If
Else
    arrAllRoutes(1, 2) = mTo
End If


lrAcRoutes = shtAircraftRoutes.Range("A" & Rows.Count).End(xlUp).Row 'Get last row of Aircraft Routes sheet
arrAcRoutes = shtAircraftRoutes.Range("A2:E" & lrAcRoutes).Value 'transferring aircraft routes to an array
lcFuelData = shtFuelData.Cells(1, Columns.Count).End(xlToLeft).Column 'get last row of fuel data sheet
arrDistance = shtFuelData.Range("B1").Resize(, lcFuelData).Value 'transferring distance data to an array

ReDim arrOutput(1 To 1000, 1 To 15) 'declaring output array, this array will contain all the output data
ind1 = 0
For rt = 1 To 3 'loop through each individual route breakup
    If arrAllRoutes(rt, 1) <> Empty Then 'check if route breakup is not empty
        For p = 1 To UBound(arrRoutes) 'loop through all the routes in arrRoutes
            If arrRoutes(p, 1) = mFrom And arrRoutes(p, 2) = mTo And arrRoutes(p, 3) = mVia1 And arrRoutes(p, 4) = mVia2 Then 'check if route in arrRoute equals selected route by the user
                For n = 1 To UBound(arrAcRoutes) 'loop through all routes in arrAcRoutes
                    If arrAcRoutes(n, 1) = arrAllRoutes(rt, 1) And arrAcRoutes(n, 2) = arrAllRoutes(rt, 2) Then 'check if route in arrAcRoute equals individual route breakup
                        ind1 = ind1 + 1 'increment index by 1
                        arrOutput(ind1, 1) = arrAllRoutes(rt, 1) & "-" & arrAllRoutes(rt, 2) 'Route
                        arrOutput(ind1, 2) = arrAcRoutes(n, 4) 'Distance

                        'Find the minimum distance
                        clDist = 0
```

```
            minDif = 9999999
            For k = 1 To UBound(arrDistance, 2)
              If Abs(arrDistance(1, k) - arrOutput(ind1, 2)) < minDif Then
                minDif = Abs(arrDistance(1, k) - arrOutput(ind1, 2))
                clDist = arrDistance(1, k)
              End If
            Next k


            arrOutput(ind1, 3) = clDist 'Closest distance (hidden column)
            arrOutput(ind1, 4) = arrAcRoutes(n, 3) 'Flight no
            arrOutput(ind1, 5) = arrAcRoutes(n, 5) 'Aircraft type
            arrOutput(ind1, 6) = shtCostLead.Cells(p + 1, 12 + Me.cbDay.ListIndex).Value 'cargo weight
limit
            arrOutput(ind1, 7) = arrOutput(ind1, 6) 'cargo weight
            arrOutput(ind1, 8) = shtCostLead.Cells(p + 1, 11).Value 'lead time
            arrOutput(ind1, 9) = "=G" & ind1 + stRow - 1 & "*" & shtCostLead.Cells(p + 1, 6).Value 'cost
(priority)
            arrOutput(ind1, 10) = "=G" & ind1 + stRow - 1 & "*" & shtCostLead.Cells(p + 1, 7).Value
'cost (non-priority)
            arrOutput(ind1, 11) = "=E" & ind1 + stRow - 1 & "&""$""&C" & ind1 + stRow - 1 &
"&""$""&G" & ind1 + stRow - 1 'this is a hidden column used for getting the emission values
            If ind1 = 1 Then arrOutput(ind1, 12) = "='" & snEmissionCalculation & "'!L2" 'This is the first
formula cell of the Co2 emission column, the rest are generated using a data table using the parameters
in the previous column
            arrOutput(ind1, 13) = "=I" & ind1 + stRow - 1 & "*H" & ind1 + stRow - 1 'cost-lead (priority)
            arrOutput(ind1, 14) = "=J" & ind1 + stRow - 1 & "*H" & ind1 + stRow - 1 'cost-lead (non-
priority)
            arrOutput(ind1, 15) = "=L" & ind1 + stRow - 1 & "/G" & ind1 + stRow - 1 'Co2 emissions per
kg)
          End If
        Next n
      End If
    Next p
```

```
   End If
Next rt

shtOptimize.Unprotect "Password" 'unprotect the sheet
On Error Resume Next
shtOptimize.ShowAllData 'remove all filters
On Error GoTo 0

shtOptimize.Range("A" & stRow & ":O" & Rows.Count).ClearContents 'clear existing output
If ind1 > 0 Then 'check if there are any rows in the output
   shtOptimize.Range("A" & stRow).Resize(UBound(arrOutput), UBound(arrOutput, 2)).Value =
arrOutput 'transfer the output array to the optimize sheet
   shtOptimize.Range("AA1").Value = "=K" & stRow 'this cell is used for the data table
   If ind1 > 1 Then shtOptimize.Range("K" & stRow).Resize(ind1, 2).Table ColumnInput:=Range("AA1")
'make a data table for Co2 emission calculation
   'to know more about the data table, goto data tab > what if analysis > data table...
End If
shtOptimize.Protect "Password" 'protect the sheet

bnRouteChange = False 'set bnRouteChange to false
ApplyFilters 'apply filters
End Sub
Private Sub ftCostNP1_Change()
bnFilterChange = True 'Mark bnFilterChange = TRUE which indicates that something with the filter
selection has changed
End Sub
Private Sub ftCostNP2_Change()
bnFilterChange = True 'Mark bnFilterChange = TRUE which indicates that something with the filter
selection has changed
End Sub
Private Sub ftCostP1_Change()
```

bnFilterChange = True *'Mark bnFilterChange = TRUE which indicates that something with the filter selection has changed*

End Sub

Private Sub ftCostP2_Change()

bnFilterChange = True *'Mark bnFilterChange = TRUE which indicates that something with the filter selection has changed*

End Sub

Private Sub ftEmission2_Change()

bnFilterChange = True *'Mark bnFilterChange = TRUE which indicates that something with the filter selection has changed*

End Sub

Private Sub ftEmission1_Change()

bnFilterChange = True *'Mark bnFilterChange = TRUE which indicates that something with the filter selection has changed*

End Sub

Private Sub ftLeadTime1_Change()

bnFilterChange = True *'Mark bnFilterChange = TRUE which indicates that something with the filter selection has changed*

End Sub

Private Sub ftLeadTime2_Change()

bnFilterChange = True *'Mark bnFilterChange = TRUE which indicates that something with the filter selection has changed*

End Sub

Private Sub ftCLP1_Change()

bnFilterChange = True *'Mark bnFilterChange = TRUE which indicates that something with the filter selection has changed*

End Sub

Private Sub ftCLP2_Change()

bnFilterChange = True *'Mark bnFilterChange = TRUE which indicates that something with the filter selection has changed*

End Sub

Private Sub ftCLNP1_Change()

```
bnFilterChange = True 'Mark bnFilterChange = TRUE which indicates that something with the filter selection has changed

End Sub

Private Sub ftCLNP2_Change()

bnFilterChange = True 'Mark bnFilterChange = TRUE which indicates that something with the filter selection has changed

End Sub

Sub ApplyFilters()

shtOptimize.Unprotect "Password" 'Unprotect the Optimize sheet so that filters can be applied


On Error Resume Next 'Turn off errors. This is done for the next statement.

shtOptimize.ShowAllData 'Remove any existing filters. This statement throws an error if no filters exist and therefore we have turned off the errors in the previous statement

On Error GoTo 0 'Turn Errors back on

lrOptimize = shtOptimize.Range("A" & Rows.Count).End(xlUp).Row 'Get the last row of the Optimize sheet


'Apply Cost (priority) filter

shtOptimize.Range("$A$" & stRow - 1 & ":$O$" & lrOptimize).AutoFilter Field:=9, Criteria1:=">=" & IIf(Me.ftCostP1.Value = "", 0, Me.ftCostP1.Value), _

    Operator:=xlAnd, Criteria2:="<=" & IIf(Me.ftCostP2.Value = "", 999999999, Me.ftCostP2.Value)


'Apply Cost (Non-priority) filter

shtOptimize.Range("$A$" & stRow - 1 & ":$O$" & lrOptimize).AutoFilter Field:=10, Criteria1:=">=" & IIf(Me.ftCostNP1.Value = "", 0, Me.ftCostNP1.Value), _

    Operator:=xlAnd, Criteria2:="<=" & IIf(Me.ftCostNP2.Value = "", 999999999, Me.ftCostNP2.Value)


'Apply Lead Time filter

shtOptimize.Range("$A$" & stRow - 1 & ":$O$" & lrOptimize).AutoFilter Field:=8, Criteria1:=">=" & IIf(Me.ftLeadTime1.Value = "", 0, Me.ftLeadTime1.Value), _

    Operator:=xlAnd, Criteria2:="<=" & IIf(Me.ftLeadTime2.Value = "", 999999999, Me.ftLeadTime2.Value)
```

```
'Apply CO2 filter

shtOptimize.Range("$A$" & stRow - 1 & ":$O$" & lrOptimize).AutoFilter Field:=12, Criteria1:=">=" & IIf(Me.ftEmission1.Value = "", 0, Me.ftEmission1.Value), _
    Operator:=xlAnd, Criteria2:="<=" & IIf(Me.ftEmission2.Value = "", 999999999, Me.ftEmission2.Value)

'Apply Cost-Lead (priority) filter

shtOptimize.Range("$A$" & stRow - 1 & ":$O$" & lrOptimize).AutoFilter Field:=13, Criteria1:=">=" & IIf(Me.ftCLP1.Value = "", 0, Me.ftCLP1.Value), _
    Operator:=xlAnd, Criteria2:="<=" & IIf(Me.ftCLP2.Value = "", 999999999, Me.ftCLP2.Value)

'Apply Cost-Lead (non-priority) filter

shtOptimize.Range("$A$" & stRow - 1 & ":$O$" & lrOptimize).AutoFilter Field:=14, Criteria1:=">=" & IIf(Me.ftCLNP1.Value = "", 0, Me.ftCLNP1.Value), _
    Operator:=xlAnd, Criteria2:="<=" & IIf(Me.ftCLNP2.Value = "", 999999999, Me.ftCLNP2.Value)

shtOptimize.Protect "Password" 'Re-Lock the sheet
bnFilterChange = False 'Set bnFilterChange to FALSE
End Sub
Private Sub cbSort1_Click()
SortResults "I" 'Sort result by column I
End Sub
Private Sub cbSort2_Click()
SortResults "J" 'Sort result by column J
End Sub
Private Sub cbSort3_Click()
SortResults "H" 'Sort result by column H
End Sub
Private Sub cbSort4_Click()
SortResults "L" 'Sort result by column L
End Sub
```

```
Private Sub cbSort5_Click()

SortResults "M" 'Sort result by column M

End Sub

Private Sub cbSort6_Click()

SortResults "N" 'Sort result by column N

End Sub

Sub SortResults(sortColumn)

'Sort results

shtOptimize.Unprotect "Password" 'Unprotect sheet optimize

On Error Resume Next

shtOptimize.ShowAllData 'Remove filters if any

On Error GoTo 0

lrOptimize = shtOptimize.Range("A" & Rows.Count).End(xlUp).Row 'Get the last row of the optimize
sheet


shtOptimize.Range("L" & stRow & ":L" & lrOptimize).ClearContents 'Clear contents of the optimize sheet

shtOptimize.Range("A" & stRow & ":O" & lrOptimize).Sort key1:=shtOptimize.Range(sortColumn &
stRow), Header:=xlNo, order1:=xlAscending 'Sort Optimize sheet by the sortColumn


shtOptimize.Range("AA1").Value = "=K" & stRow

shtOptimize.Range("L" & stRow).Value = "='" & snEmissionCalculation & "'!L2"

shtOptimize.Range("K" & stRow).Resize(lrOptimize - stRow + 1, 2).Table ColumnInput:=Range("AA1")

shtOptimize.Protect "Password"

End Sub

Private Sub UserForm_QueryClose(Cancel As Integer, CloseMode As Integer)

'This sub is called when the user clicks on the close button of the userform

Cancel = True 'Setting Cancel to TRUE cancels the closing of the userform

Me.Hide 'Instead of closing the userform, we just hide the userform

'This has been done so that when the userform is shown again, all previously filled values show up

'If we rather just closed the userform then the next time userform was loaded it would come up blank and
user would have
```

```
'to re-fill all values
End Sub
```

2. Model - 2.

2.a) Module code - Defining global variables.

```
'All global constants are declared here, these constants can be accessed from any module/userform module

Public Const snCostLead = "Cost & Lead Time"
Public Const snAircraftRoutes = "Aircraft Routes"
Public Const snEmissionCalculation = "Emission Calculation"
Public Const snFuelData = "Fuel Data"
Public Const snOptimize = "Optimize"
Public Const snCountry = "Country Codes"

Public Const stRow = 5

Public shtCostLead
Public shtAircraftRoutes
Public shtEmissionCalculation
Public shtFuelData
Public shtOptimize
Public shtCountry
Sub LoadVariables()

'This routine just loads all the Sheet objects, it uses the sheet name constants declared at the top of this module for the same
'Any routine can call this sub and all the sheet objects get loaded to be used

Set shtCostLead = Sheets(snCostLead)
Set shtAircraftRoutes = Sheets(snAircraftRoutes)
Set shtEmissionCalculation = Sheets(snEmissionCalculation)
Set shtFuelData = Sheets(snFuelData)
Set shtOptimize = Sheets(snOptimize)
Set shtCountry = Sheets(snCountry)
End Sub
Sub ShowForm()

'The SHOW FORM button on the optimize sheet calls this sub
```

```
'It simply shows the userform

UserForm1.Show
End Sub
```

2.b) Main UserForm Code.

```
'These variables can be accessed by any sub/function of this userform module only

Dim arrRoutes

Dim arrCountry

Dim arrUniqueRoutes

Dim bnRouteChange As Boolean

Dim bnFilterChange As Boolean

Private Sub cbFrom_Change()

If Me.cbFrom.ListIndex = -1 Then Exit Sub

Me.cbTo.Clear

selectedFrom = Me.cbFrom.Value

For n = 1 To UBound(arrUniqueRoutes)

   If arrUniqueRoutes(n, 1) = selectedFrom Then Me.cbTo.AddItem arrUniqueRoutes(n, 2)

Next n

End Sub

Private Sub UserForm_Initialize()

'This sub is automatically triggered when the userform is initiated


LoadVariables 'Calls LoadVariables so that all sheet objects can be assigned to be used further below

lrRoutes = shtCostLead.Range("B" & Rows.Count).End(xlUp).Row 'Gets the last row of the Cost and Lead sheet

arrRoutes = shtCostLead.Range("B2:E" & lrRoutes).Value 'All values from starting from Cell B2 to the last cell of Column E are copied to an array called arrRoutes


lrCountry = shtCountry.Range("A" & Rows.Count).End(xlUp).Row

arrCountry = shtCountry.Range("A2:B" & lrCountry).Value
```

'It is considered a good practice to load all cell values of a range into an array. This way all cell values of that range

'get loaded into memory and accessing those values becomes much faster. On the other hand if you do not load the cell values

'into an array and instead get value from each and every cell individually when required it increases the traffic between

'the worksheet and VBA which slows down the code tremendously

ReDim arrCntUnique(1 To UBound(arrRoutes)) 'Declaring an array called arrFrom. The number of values that this array can store is

'UBound(arrRoutes) which means the upper bound of array arrRoutes which means the index of the last element of array arrRoutes

'Basically arrFrom contains the same number of rows as the arrRoutes array

'Populating the cbDay combobox with the following day values

Me.cbDay.AddItem "Monday"

Me.cbDay.AddItem "Tuesday"

Me.cbDay.AddItem "Wednesday"

Me.cbDay.AddItem "Thursday"

Me.cbDay.AddItem "Friday"

Me.cbDay.AddItem "Saturday"

Me.cbDay.AddItem "Sunday"

Me.cbOptimize.AddItem "Cost-Lead Time (Priority)"

Me.cbOptimize.AddItem "Cost-Lead Time (Non-Priority)"

lrAcRoutes = shtAircraftRoutes.Range("A" & Rows.Count).End(xlUp).Row 'Get last row of Aircraft Routes sheet

arrAcRoutes = shtAircraftRoutes.Range("A2:E" & lrAcRoutes).Value 'transferring aircraft routes to an array

```
ReDim arrUniqueRoutes(1 To UBound(arrAcRoutes), 1 To 2)

ind1 = 0

For n = 1 To UBound(arrAcRoutes) 'loop through all aircraft routes

    For x = 1 To UBound(arrCountry) 'loop through all countries

        If arrAcRoutes(n, 1) = arrCountry(x, 1) Then 'check match

            tempFrom1 = arrCountry(x, 2) 'get country name

            Exit For

        End If

    Next x


    For x = 1 To UBound(arrCountry) 'loop through all aircraft routes

        If arrAcRoutes(n, 2) = arrCountry(x, 1) Then 'check match

            tempTo1 = arrCountry(x, 2) 'get country name

            Exit For

        End If

    Next x


    bnExists = False

    For n1 = 1 To ind1 'loop  through all rows of unique routes array to check if it already exists

        If arrUniqueRoutes(n1, 1) = tempFrom1 And arrUniqueRoutes(n1, 2) = tempTo1 Then 'check if it
exists

            bnExists = True 'set boolean to true

            Exit For

        End If

    Next n1


    If Not bnExists Then 'if not already there add a row to arruniqueroutes

        ind1 = ind1 + 1

        arrUniqueRoutes(n1, 1) = tempFrom1
```

```
        arrUniqueRoutes(n1, 2) = tempTo1
    End If
Next n

ReDim arrUniqueFrom(1 To UBound(arrUniqueRoutes))
ind1 = 0
For n = 1 To UBound(arrUniqueRoutes)
    bnExists = False
    For x = 1 To ind1 'loop through all items in arrUniqueFrom to check if it already exists
        If arrUniqueFrom(x) = arrUniqueRoutes(n, 1) Then 'check for match
            bnExists = True 'set boolean to true
            Exit For
        End If
    Next x
    If Not bnExists Then 'if it doesnt already exist then add a row to arrUniqueFrom and populate combobox
        ind1 = ind1 + 1
        arrUniqueFrom(ind1) = arrUniqueRoutes(n, 1) 'add row
        Me.cbFrom.AddItem arrUniqueRoutes(n, 1) 'populate combobox
    End If
Next n

End Sub
Sub FilterToRoutes()
'This sub is used to get the possible DESTINATIONS for the selected ORIGIN and populate them in the cbTo combobox
mFrom = Me.cbFrom.Value 'retrieve the ORIGIN selected by the user
ReDim arrTo(1 To UBound(arrRoutes)) 'Declare an array arrTo which has the same number of rows as arrRoutes
ind1 = 0 'set index to zero
```

```
For n = 1 To UBound(arrRoutes) 'loop through each row of arrRoutes
  If arrRoutes(n, 1) = mFrom Then 'Check if the ORIGIN value in the arrRoutes row matches the ORIGIN selected by the user
    bnAdd = True 'Set bnAdd equal to TRUE before intiating the next loop
    For n2 = 1 To ind1 'loop from 1 to ind1
      If arrTo(n2) = arrRoutes(n, 2) Then 'Check if the DESTINATION already exists in arrTo
        bnAdd = False 'if Yes then set bnAdd = FALSE
        Exit For 'exit for loop
      End If
    Next n2
    If bnAdd Then 'if bnAdd is still TRUE after the above loop it means that this DESTINATION does not already exist in arrTo and thus needs to be added
      ind1 = ind1 + 1 'increment index by 1
      arrTo(ind1) = arrRoutes(n, 2) 'add DESTINATION to arrTo
    End If
  End If
Next n

Me.cbTo.Clear 'Clear combobox cbTo
For n = 1 To ind1 'Loop from 1 to ind1
  Me.cbTo.AddItem arrTo(n) 'Add each value in arrTo to combobox cbTo
Next n
End Sub
Private Sub cbTo_Change()
'bnRouteChange = True 'Mark bnRouteChange = TRUE which indicates that something with the Route selection has changed
'FilterViaRoutes 'Call FilterViaRoutes
End Sub
Sub FilterViaRoutes()
'This sub works along the exact same lines as FilterToRoutes
```

```
'This sub looks at the selected ORIGIN and DESTINATION values and populates the VIA dropdown with the possible values


ReDim arrVia(1 To UBound(arrRoutes), 1 To 2)

mFrom = Me.cbFrom.Value

mTo = Me.cbTo.Value


ind1 = 0

For n = 1 To UBound(arrRoutes)

    If arrRoutes(n, 1) = mFrom And arrRoutes(n, 2) = mTo Then bnAdd = True Else bnAdd = False

    If bnAdd Then

        For n2 = 1 To ind1

            If arrVia(n2, 1) = arrRoutes(n, 3) And arrVia(n2, 2) = arrRoutes(n, 4) Then

                bnAdd = False

                Exit For

            End If

        Next n2

        If bnAdd Then

            ind1 = ind1 + 1

            For x = 1 To 2

                arrVia(ind1, x) = arrRoutes(n, x + 2)

            Next x

        End If

    End If

Next n


Me.cbVia.Clear

For n = 1 To ind1

    Me.cbVia.AddItem arrVia(n, 1) & IIf(arrVia(n, 2) <> "", "-" & arrVia(n, 2), "")
```

```
Next n

End Sub

Private Sub cbVia_Change()

bnRouteChange = True 'Mark bnRouteChange = TRUE which indicates that something with the Route selection has changed

End Sub

Private Sub cbDay_Change()

bnRouteChange = True 'Mark bnRouteChange = TRUE which indicates that something with the Route selection has changed

End Sub

Private Sub CommandButton1_Click()

GenerateRoutes

End Sub

Sub GenerateRoutes()

'This sub is called by the GENERATE button and generates the output on the Optimize sheet


If Me.cbFrom.Value = "" Then 'check if the ORIGIN is blank

   MsgBox "Please select a FROM location to proceed!", vbCritical 'if yes, then throw an error prompt

   Exit Sub 'exit this sub

ElseIf Me.cbTo.Value = "" Then 'check if the DESTINATION is blank

   MsgBox "Please select a TO location to proceed!", vbCritical 'if yes, then throw an error prompt

   Exit Sub 'exit this sub

ElseIf Me.cbDay.Value = "" Then 'check if the DAY is blank

   MsgBox "Please select a DAY to proceed!", vbCritical 'if yes, then throw an error prompt

   Exit Sub 'exit this sub

ElseIf Me.tbCargoWeight.Value = "" Then

   MsgBox "Please enter the CARGO WEIGHT to proceed!", vbCritical

   Exit Sub

ElseIf Not IsNumeric(Me.tbCargoWeight.Value) Then
```

```
   MsgBox "Please enter a valid CARGO WEIGHT to proceed!", vbCritical
   Exit Sub
ElseIf Me.tbCargoWeight.Value + 0 < 0 Then
   MsgBox "Please enter a positive CARGO WEIGHT to proceed!", vbCritical
   Exit Sub
ElseIf Me.cbOptimize.ListIndex = -1 Then
   MsgBox "Please select an OPTIMIZATION factor to continue!", vbCritical
   Exit Sub
End If

mFrom = Me.cbFrom.Value 'Get the ORIGIN value selectd by the user
mTo = Me.cbTo.Value 'Get the DESTINATION value selected by the user

ReDim arrAllFrom(1 To UBound(arrCountry))
ReDim arrAllTo(1 To UBound(arrCountry))
ind1 = 0
ind2 = 0

For n = 1 To UBound(arrCountry) 'loop through all countries
   If arrCountry(n, 2) = mFrom Then 'check if country equals that entered by user
      ind1 = ind1 + 1
      arrAllFrom(ind1) = arrCountry(n, 1) 'enter the origin/destination in arrAllFrom
   End If
   If arrCountry(n, 2) = mTo Then 'check if country equals that entered by user
      ind2 = ind2 + 1
      arrAllTo(ind2) = arrCountry(n, 1) 'enter the origin/destination in arrAllTo
   End If
Next n
```

```
ind3 = 0

ReDim arrAllRoutes(1 To ind1 * ind2, 1 To 2)

'loop through all items in arrAllFrom and arrAllTo to create an array of all possible combinations in arrAllRoutes

For n1 = 1 To ind1

  For n2 = 1 To ind2

    ind3 = ind3 + 1

    arrAllRoutes(ind3, 1) = arrAllFrom(n1)

    arrAllRoutes(ind3, 2) = arrAllTo(n2)

  Next n2

Next n1


lrAcRoutes = shtAircraftRoutes.Range("A" & Rows.Count).End(xlUp).Row 'Get last row of Aircraft Routes sheet

arrAcRoutes = shtAircraftRoutes.Range("A2:E" & lrAcRoutes).Value 'transferring aircraft routes to an array

lcFuelData = shtFuelData.Cells(1, Columns.Count).End(xlToLeft).Column 'get last row of fuel data sheet

arrDistance = shtFuelData.Range("B1").Resize(, lcFuelData).Value 'transferring distance data to an array


ReDim arrOutput(1 To 1000, 1 To 15) 'declaring output array, this array will contain all the output data

ind1 = 0

For rt = 1 To UBound(arrAllRoutes) 'loop through each individual route breakup

  If arrAllRoutes(rt, 1) <> Empty Then 'check if route breakup is not empty

    For p = 1 To UBound(arrRoutes) 'loop through all the routes in arrRoutes

      If arrRoutes(p, 1) = arrAllRoutes(rt, 1) And arrRoutes(p, 2) = arrAllRoutes(rt, 2) Then 'check if route in arrRoute equals selected route by the user

        For n = 1 To UBound(arrAcRoutes) 'loop through all routes in arrAcRoutes

          If arrAcRoutes(n, 1) = arrAllRoutes(rt, 1) And arrAcRoutes(n, 2) = arrAllRoutes(rt, 2) Then 'check if route in arrAcRoute equals individual route breakup

            If shtCostLead.Cells(p + 1, 12 + Me.cbDay.ListIndex).Value > 0 Then
```

```
ind1 = ind1 + 1 'increment index by 1

arrOutput(ind1, 1) = arrAllRoutes(rt, 1) & "-" & arrAllRoutes(rt, 2) 'Route

arrOutput(ind1, 2) = arrAcRoutes(n, 4) 'Distance


'Find the closest distance

clDist = 0

minDif = 9999999

For k = 1 To UBound(arrDistance, 2)

   If Abs(arrDistance(1, k) - arrOutput(ind1, 2)) < minDif Then

      minDif = Abs(arrDistance(1, k) - arrOutput(ind1, 2))

      clDist = arrDistance(1, k)

   End If

Next k


arrOutput(ind1, 3) = clDist 'Closest distance (hidden column)

arrOutput(ind1, 4) = arrAcRoutes(n, 3) 'Flight no

arrOutput(ind1, 5) = arrAcRoutes(n, 5) 'Aircraft type

arrOutput(ind1, 6) = shtCostLead.Cells(p + 1, 12 + Me.cbDay.ListIndex).Value 'cargo
weight limit

'arrOutput(ind1, 7) = arrOutput(ind1, 6) 'cargo weight

arrOutput(ind1, 8) = shtCostLead.Cells(p + 1, 11).Value 'lead time

arrOutput(ind1, 9) = shtCostLead.Cells(p + 1, 6).Value 'cost (priority)

arrOutput(ind1, 10) = shtCostLead.Cells(p + 1, 7).Value 'cost (non-priority)

'arrOutput(ind1, 11) = "=E" & ind1 + stRow - 1 & "&""$""&C" & ind1 + stRow - 1 &
"&""$""&G" & ind1 + stRow - 1 'this is a hidden column used for getting the emission values

'If ind1 = 1 Then arrOutput(ind1, 12) = "='" & snEmissionCalculation & "'!L2" 'This is the
first formula cell of the Co2 emission column, the rest are generated using a data table using the
parameters in the previous column

arrOutput(ind1, 13) = shtCostLead.Cells(p + 1, 6).Value * shtCostLead.Cells(p + 1,
11).Value 'cost-lead (priority)
```

```
                    arrOutput(ind1, 14) = shtCostLead.Cells(p + 1, 7).Value * shtCostLead.Cells(p + 1, 11).Value 'cost-lead (non-priority)

                    'arrOutput(ind1, 15) = "=L" & ind1 + stRow - 1 & "/G" & ind1 + stRow - 1 'Co2 emissions per kg)

                End If

              End If

            Next n

          End If

        Next p

    End If

Next rt


totWeight = Me.tbCargoWeight.Value + 0 'get total weight entered by the user

QuickSortArray arrOutput, 1, CLng(ind1), IIf(Me.cbOptimize.ListIndex = 0, 13, 14) 'sort the array - arrOutput

myLastRow = 0

For n = 1 To ind1 'loop through all rows of arrOutput

    tw1 = Application.Min(arrOutput(n, 6), totWeight) 'get the weight to be allocated to this flight

    arrOutput(n, 7) = tw1 'cargo weight

    arrOutput(n, 9) = arrOutput(n, 9) * tw1 'lead time

    arrOutput(n, 10) = arrOutput(n, 10) * tw1 'cost priority

    arrOutput(n, 13) = arrOutput(n, 13) * tw1 'cost lead priority

    arrOutput(n, 14) = arrOutput(n, 14) * tw1 'cost lead non priority

    arrOutput(n, 11) = arrOutput(n, 5) & "$" & arrOutput(n, 3) & "$" & arrOutput(n, 7) 'variables for emissions calculation - hidden column

    If n = 1 Then arrOutput(n, 12) = "='" & snEmissionCalculation & "'!L2" 'enter formula for emission calculation

    arrOutput(n, 15) = "=L" & n + stRow - 1 & "/G" & n + stRow - 1 'Co2 per kg

    totWeight = totWeight - tw1

    If totWeight = 0 Or n = ind1 Then Exit For
```

```
Next n
myLastRow = n

shtOptimize.Unprotect "Password" 'unprotect the sheet
On Error Resume Next
shtOptimize.ShowAllData 'remove all filters
On Error GoTo 0

shtOptimize.Range("A" & stRow & ":O" & Rows.Count).ClearContents 'clear existing output
If myLastRow > 0 Then 'check if there are any rows in the output
   shtOptimize.Range("A" & stRow).Resize(myLastRow, UBound(arrOutput, 2)).Value = arrOutput
'transfer the output array to the optimize sheet
   shtOptimize.Range("AA1").Value = "=K" & stRow 'this cell is used for the data table
   If myLastRow > 1 Then shtOptimize.Range("K" & stRow).Resize(myLastRow, 2).Table
ColumnInput:=Range("AA1") 'make a data table for Co2 emission calculation
   'to know more about the data table, goto data tab > what if analysis > data table...
End If
shtOptimize.Protect "Password" 'protect the sheet

'bnRouteChange = False 'set bnRouteChange to false
'ApplyFilters 'apply filters
End Sub
Private Sub ftCostNP1_Change()
bnFilterChange = True 'Mark bnFilterChange = TRUE which indicates that something with the filter
selection has changed
End Sub
Private Sub ftCostNP2_Change()
bnFilterChange = True 'Mark bnFilterChange = TRUE which indicates that something with the filter
selection has changed
End Sub
```

```
Private Sub ftCostP1_Change()

bnFilterChange = True 'Mark bnFilterChange = TRUE which indicates that something with the filter selection has changed

End Sub

Private Sub ftCostP2_Change()

bnFilterChange = True 'Mark bnFilterChange = TRUE which indicates that something with the filter selection has changed

End Sub

Private Sub ftEmission2_Change()

bnFilterChange = True 'Mark bnFilterChange = TRUE which indicates that something with the filter selection has changed

End Sub

Private Sub ftEmission1_Change()

bnFilterChange = True 'Mark bnFilterChange = TRUE which indicates that something with the filter selection has changed

End Sub

Private Sub ftLeadTime1_Change()

bnFilterChange = True 'Mark bnFilterChange = TRUE which indicates that something with the filter selection has changed

End Sub

Private Sub ftLeadTime2_Change()

bnFilterChange = True 'Mark bnFilterChange = TRUE which indicates that something with the filter selection has changed

End Sub

Private Sub ftCLP1_Change()

bnFilterChange = True 'Mark bnFilterChange = TRUE which indicates that something with the filter selection has changed

End Sub

Private Sub ftCLP2_Change()

bnFilterChange = True 'Mark bnFilterChange = TRUE which indicates that something with the filter selection has changed
```

End Sub

Private Sub ftCLNP1_Change()

bnFilterChange = True 'Mark bnFilterChange = TRUE which indicates that something with the filter selection has changed

End Sub

Private Sub ftCLNP2_Change()

bnFilterChange = True 'Mark bnFilterChange = TRUE which indicates that something with the filter selection has changed

End Sub

Sub ApplyFilters()

shtOptimize.Unprotect "Password" 'Unprotect the Optimize sheet so that filters can be applied

On Error Resume Next 'Turn off errors. This is done for the next statement.

shtOptimize.ShowAllData 'Remove any existing filters. This statement throws an error if no filters exist and therefore we have turned off the errors in the previous statement

On Error GoTo 0 'Turn Errors back on

lrOptimize = shtOptimize.Range("A" & Rows.Count).End(xlUp).Row 'Get the last row of the Optimize sheet

'Apply Cost (priority) filter

shtOptimize.Range("A" & stRow - 1 & ":O" & lrOptimize).AutoFilter Field:=9, Criteria1:=">=" & IIf(Me.ftCostP1.Value = "", 0, Me.ftCostP1.Value), _

Operator:=xlAnd, Criteria2:="<=" & IIf(Me.ftCostP2.Value = "", 999999999, Me.ftCostP2.Value)

'Apply Cost (Non-priority) filter

shtOptimize.Range("A" & stRow - 1 & ":O" & lrOptimize).AutoFilter Field:=10, Criteria1:=">=" & IIf(Me.ftCostNP1.Value = "", 0, Me.ftCostNP1.Value), _

Operator:=xlAnd, Criteria2:="<=" & IIf(Me.ftCostNP2.Value = "", 999999999, Me.ftCostNP2.Value)

'Apply Lead Time filter

```
shtOptimize.Range("$A$" & stRow - 1 & ":$O$" & lrOptimize).AutoFilter Field:=8, Criteria1:=">=" & IIf(Me.ftLeadTime1.Value = "", 0, Me.ftLeadTime1.Value), _
    Operator:=xlAnd, Criteria2:="<=" & IIf(Me.ftLeadTime2.Value = "", 999999999, Me.ftLeadTime2.Value)

'Apply CO2 filter
shtOptimize.Range("$A$" & stRow - 1 & ":$O$" & lrOptimize).AutoFilter Field:=12, Criteria1:=">=" & IIf(Me.ftEmission1.Value = "", 0, Me.ftEmission1.Value), _
    Operator:=xlAnd, Criteria2:="<=" & IIf(Me.ftEmission2.Value = "", 999999999, Me.ftEmission2.Value)

'Apply Cost-Lead (priority) filter
shtOptimize.Range("$A$" & stRow - 1 & ":$O$" & lrOptimize).AutoFilter Field:=13, Criteria1:=">=" & IIf(Me.ftCLP1.Value = "", 0, Me.ftCLP1.Value), _
    Operator:=xlAnd, Criteria2:="<=" & IIf(Me.ftCLP2.Value = "", 999999999, Me.ftCLP2.Value)

'Apply Cost-Lead (non-priority) filter
shtOptimize.Range("$A$" & stRow - 1 & ":$O$" & lrOptimize).AutoFilter Field:=14, Criteria1:=">=" & IIf(Me.ftCLNP1.Value = "", 0, Me.ftCLNP1.Value), _
    Operator:=xlAnd, Criteria2:="<=" & IIf(Me.ftCLNP2.Value = "", 999999999, Me.ftCLNP2.Value)

shtOptimize.Protect "Password" 'Re-Lock the sheet
bnFilterChange = False 'Set bnFilterChange to FALSE
End Sub
Private Sub cbSort1_Click()
SortResults "I" 'Sort result by column I
End Sub
Private Sub cbSort2_Click()
SortResults "J" 'Sort result by column J
End Sub
Private Sub cbSort3_Click()
```

```
SortResults "H" 'Sort result by column H

End Sub

Private Sub cbSort4_Click()

SortResults "L" 'Sort result by column L

End Sub

Private Sub cbSort5_Click()

SortResults "M" 'Sort result by column M

End Sub

Private Sub cbSort6_Click()

SortResults "N" 'Sort result by column N

End Sub

Sub SortResults(sortColumn)

'Sort results

shtOptimize.Unprotect "Password" 'Unprotect sheet optimize

On Error Resume Next

shtOptimize.ShowAllData 'Remove filters if any

On Error GoTo 0

lrOptimize = shtOptimize.Range("A" & Rows.Count).End(xlUp).Row 'Get the last row of the optimize sheet


shtOptimize.Range("L" & stRow & ":L" & lrOptimize).ClearContents 'Clear contents of the optimize sheet

shtOptimize.Range("A" & stRow & ":O" & lrOptimize).Sort key1:=shtOptimize.Range(sortColumn & stRow), Header:=xlNo, order1:=xlAscending 'Sort Optimize sheet by the sortColumn


shtOptimize.Range("AA1").Value = "=K" & stRow

shtOptimize.Range("L" & stRow).Value = "='" & snEmissionCalculation & "'!L2"

shtOptimize.Range("K" & stRow).Resize(lrOptimize - stRow + 1, 2).Table ColumnInput:=Range("AA1")

shtOptimize.Protect "Password"

End Sub
```

```
Private Sub UserForm_QueryClose(Cancel As Integer, CloseMode As Integer)

'This sub is called when the user clicks on the close button of the userform

Cancel = True 'Setting Cancel to TRUE cancels the closing of the userform

Me.Hide 'Instead of closing the userform, we just hide the userform

'This has been done so that when the userform is shown again, all previously filled values show up

'If we rather just closed the userform then the next time userform was loaded it would come up blank and user would have

'to re-fill all values

End Sub
```