ENVIRONMENTAL RISK ASSESSMENT OF GROUND HANDLING OFFICES: CASE STUDY OF NEW ISLAMABAD AIRPORT

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Saba Imran

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LIST OF ABBREVIATIONS

CFP/CF: Carbon Footprint

CO_2e: Carbon dioxide equivalent

ERA: Environmental risk assessment

EF: Emission factor

FIS: Fuzzy inference system

GHA: Ground handling agents

GHG: Greenhouse gases

IEA: International Energy Agency

IPCC: Intergovernmental Panel for Climate Changes

ISO: International Organization for Standardization

L: Likelihood of risk

PCAA: Pakistan Civil Aviation Authority

R: Risk rating

S: Severity of risk

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ABSTRACT

A detailed framework to quantify carbon footprint and environmental risk assessment based on an airport office environment in Pakistan has been presented in this study. As recognition of climate change is increasing, organizations that have recently started to examine their carbon footprint might lack the resources and skilled individuals to conduct a comprehensive risk assessment. To address this gap, a set of quantification methods have been presented in this study that categorizes the emission sources from an office into various categories. According to the findings, the organization's annual carbon footprint was 24642.97 tonnes of CO_2e, with main emissions coming from the printing devices and airport ramp vehicles usage. The study also revealed that this strategy can be used to estimate total emissions as well as identify significant emission sources. Now a days, environmental risk assessment is an effective decision-making approach to reduce the environmental impacts and consequences of diverse activities to accomplish sustainable development. The likelihood-severity matrix approach, which is known as a quantitative approach for risk assessment, is one of the most applied environmental risk assessment techniques. Numerical assumptions of the likelihood and severity of risk occurrence are extremely challenging with this technique because these components are related with high degree of uncertainty. Hence, a risk analysis that considers the uncertainties associated with emission from office operations is required to assess existing risks and prioritize them for further precautionary measures and decisions to reduce, mitigate, and/or potentially eliminate the involved risks. Therefore, this study provides a risk assessment model based on Fuzzy set theory principles to analyze risk occurrences in an office environment. To evaluate the validity of Fuzzy risk model, the results of Fuzzy risk assessment are compared to those of conventional risk assessment. Study findings discovered that the Fuzzy logic model has a high potential to accurately model the risk evaluation associated with uncertainty.

Chapter 1 Introduction

1.1 Environmental risk assessment

An environmental risk assessment is a systematic process aimed at identification, evaluation, assessment, and mitigation of the potential adverse effects of human activities (Kaplan & Garrick, 1981) on the environment mainly because of exposure to chemical and non-chemical stressors from anthropogenic activities (Vora et al., 2021). It involves analysis of various factors such as ecological sensitivity, air pollutants and potential pathways mainly of GHG emissions (Unnewehr et al., 2022). Steps of the environmental risk assessment (ERA) along with their relationship to overall risk management is demonstrated by (ESFA, 2010), as shown in Figure 1.1. The potential risks to ecosystems, human health, and natural resources can be comprehensively evaluated through this assessment (Oelkers, 2020).

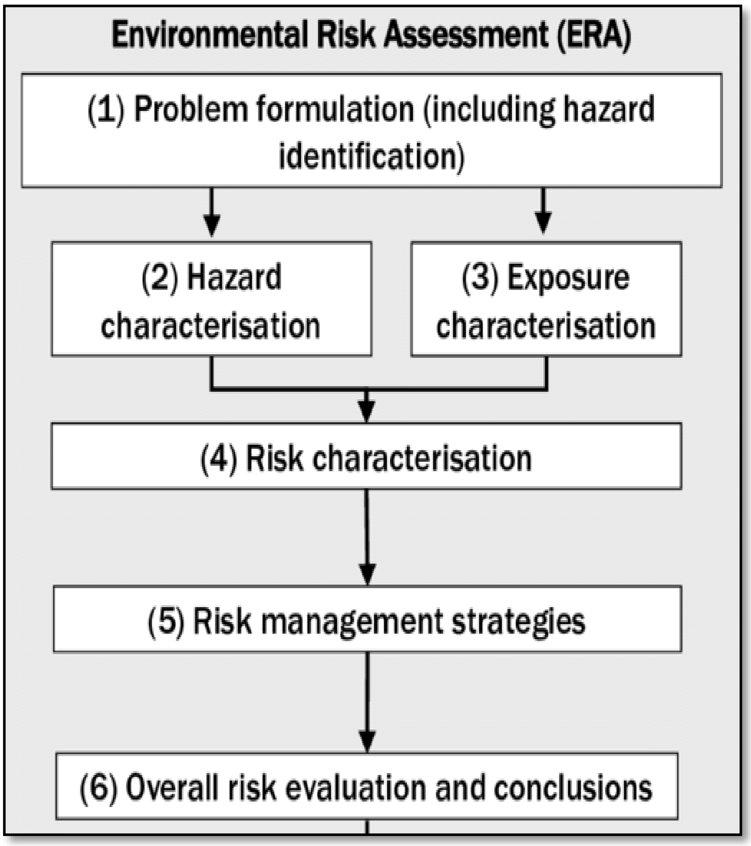

Figure 1.1: Steps of environmental risk assessment

Environmental risk assessment plays an essential role for promoting responsible growth and ensuring the well-being of the planet. Environmental risk assessment is a dynamic and thorough process that includes a meticulous examination of exposure pathways, potential consequences, and the likelihood of adverse impacts (Shakil et al., 2023) The main objective of environmental risk assessment (ERA) is to offer critical information to decision-makers, regulators, and stakeholders (Garrido & Requena, 2015) that facilitate them to make sensible choices and implement successful risk management methods. ERA provides a significant tool (da Silva et al., 2020) in aligning growth and advancement with the preservation and sustainability of our natural environment by systematically quantifying and qualifying hazards (Fouladgar et al., 2012). This comprehensive process involves the integration of scientific knowledge, data interpretation, modelling methodologies, and ethical considerations (Dalezios, 2017; Idrees & Batool, 2020; Moe et al., 2021). It focuses on a wide range of disciplines, including toxicological studies, ecology, epidemiological studies, and engineering (Spreadbury et al., 2021) to create an in-depth knowledge of the relationships between human activities and the environment.

The collaborative efforts of global initiatives and agreements, such as the United Nations Framework Convention on Climate Change (UNFCCC), US Environmental Protection Agency (USEPA) and the Convention on Biological Diversity (CBD) (Lovelock et al., 2017), have significantly accelerated the development and implementation of rigorous environmental risk assessment (ERA) methodologies (Dalezios, 2017). These essential worldwide frameworks have emerged as driving forces in the advancement of environmental risk assessment practices (Brock et al., 2021) emphasizing the crucial importance of preserving our planet's ecological integrity in the face of growing environmental threats (Hatefi et al., 2019).

1.2 Ground handling organizations in Pakistan

Ground handling organizations are the unseen backbone of air travel (Kabongo et al., 2016), including a wide range of tasks that take place between an aircraft's landing and takeoff (Schmidberger et al., 2009). These firms handle activities ranging from aircraft servicing and maintenance to passenger and cargo management from the time an aircraft touches down on the tarmac before it embarks on a new destination (Fitouri-Trabelsi et al., 2013). Thus, the ground handling groups prove to be the essence of aviation's background expertise, representing efficiency and cooperation (Narendra, 2014).

Pakistan's strategic location at the crossroads of South Asia, Central Asia, and the Middle East has made it a major air transport hub. This geographical advantage has fueled the rise of ground handling businesses, which has become crucial to the nation's aviation sector (ICAO, 1958). Pakistan Civil Aviation Authority (PCAA) acknowledges that the major registered ground handling establishments include Pakistan International Airlines (PIA), Shaheen Airport Services (SAPS), Gerry's Dnata (GD), Menzies Royal Airport Services (Menzies RAS), Askari Aviation Services & Air Blue Ltd (PCAA, 2019). With a wide range of flights being handled at numerous international and domestic airports in Pakistan, these organizations play a major role in ensuring seamless operations and customer comfort (ICAO, 1958).

Ground Handling Agents (GHAs) contribute significantly to a country's economy through their complex involvement in the aviation sector (Narendra, 2014). GHAs generate a significant number of job possibilities in the aviation industry. GHAs generate direct and indirect employment (Bevilacqua et al., 2015), which helps to reduce unemployment and improve general economic stability (PCAA, 2019). The efficient operation of airports and airlines, in turn, increases air travel demand, resulting in greater revenue for airlines, airports, and allied businesses such as hospitality and tourism (Oprea, 2010). GHAs help a country attract tourists and business visitors by offering great passenger experiences and rapid aircraft turnaround times. A study from (Bevilacqua et al., 2013; Ashfaque-ul, 2020) emphasizes that efficient cargo handling operation by GHA's strengthens trade links, boosts exports, and supports local industry, all of which increases economic activity. Airports and airlines both benefit from GHAs in terms of revenue generating (ICAO, 1958). Ground handling services, such as aircraft repairs, baggage handling, and passenger assistance, are paid for by airlines. Airports charge GHAs fees to use their facilities, which include runways, terminals, and parking spaces. (Grubesic et al., 2011) claims that revenue generated by these transactions helps to support the financial health of airports and airlines, both of which are critical components of a country's economic landscape. GHAs frequently use cutting-edge technology to streamline operations, boost efficiency, and improve the passenger experience. Technology adoption can result in cost savings, enhanced service quality, and improved competitiveness (Kovynyov & Mikut, 2019). This drive for innovation can also foster a culture of technological advancement within the country, contributing to economic growth in the technology sector. In essence, ground handling agents play a critical role in shaping a nation's aviation ecosystem, which in turn has broad impacts on various sectors of the economy (ICAO, 1958; PCAA, 2019).

1.3 Environmental risks associated with ground handling offices in Pakistan

Ground handling operations are critical in Pakistan's aviation sector for sustaining effective airport operations and comfortable air travel experiences (Batool et al., 2018). However, the environmental concerns linked with their ground operations are also associated with their workplace environment (Lee et al., 2021) . In general, the following environmental factors can be major causes of GHG emissions in ground handling business.

i. Air Pollution

One major source of concern is air pollution. Ground handling operations frequently necessitate the use of diesel-powered equipment like baggage tugs, ground power units, and aircraft loaders (Nurhayati & Nur, 2017). Harmful pollutants such as particulate matter, carbon dioxide, and nitrogen oxides are released due to fuel combustion (International Energy Agency, 2020). These emissions can contribute to poor air quality near airports as well as the buildup of greenhouse gases, which contribute to climate change (Cabrera & Melo de Sousa, 2022).

ii. Energy consumption

Furthermore, the energy consumption of office premises is notable (Tjandra et al., 2014). Lighting, heating, cooling, and electrical gadgets in offices frequently use fossil fuels, causing greenhouse gas emissions and contributing to climate change. According to study conducted by (Batool et al., 2018), the transition to energy-efficient lighting, appliances, and air conditioning, ventilation, and heating (HVAC) systems, as well as the use of renewable energy sources, can help minimize these environmental implications.

iii. Waste generation

Another consideration is waste generation in offices. The widespread use of plastics, paper, and materials for packaging generates a significant amount of garbage (Nwoke et al., 2022). This garbage can contribute to landfills and deterioration of the environment if not properly managed and recycled. Encouragement of digital documentation, establishment of recycling efforts, and reduction of single-use plastics are good risk-management methods (Gössling & Lyle, 2021).

iv. Indoor air pollution

Indoor air quality is an additional concern. Indoor air pollution can be caused by poor ventilation, insufficient air filtering, and the use of chemical-laden cleaning products, affecting both the well-being and efficiency of office employees (Łuszczyńska, 2022). Conclusions from a study conducted by (Mandin et al., 2017) recommended that appropriate ventilation, use of ecologically friendly cleaning solutions and the introduction of indoor plants can improve indoor air quality and promote a more productive work environment.

v. Water pollution

A case study conducted by (Izzati, 2017) signifies that water pollution is a concern resulting from the potential leakage or spillage, potential chemical and fluid loss or spillage during repair and maintenance procedures. These contaminants can contaminate and harm the environment by infiltrating groundwater or neighboring water bodies (Aprile & Fiorillo, 2016). To avoid such catastrophes, robust containment mechanisms, spill response protocols, and proper drainage systems must be in place (da Silva et al., 2020).

1.4 Problem statement

Increased carbon footprint, excessive resource consumption & environmental degradation pose a serious threat towards sustainability in the aviation industry (Green et al., 2003). According to Country Climate and Development Report (CCDR), the combined risks of extreme climate related events and environmental degradation are projected to reduce GDP of Pakistan by 20 - 50% (The World Bank Group, 2022). To combat such environmental challenges, a comprehensive assessment of all major environmental risks has been addressed in the study. This study has encompassed the risk assessment process through conventional methods as well as modern mathematical models to achieve constructive results. Furthermore, this study serves as a foundation for mitigation efforts proposed for identified high-risk areas, supporting environmentally beneficial alternatives.

1.5 Objectives of study

i. Identification of major environmental aspects and calculation of annual carbon footprint produced by XYZ company offices.

ii. To conduct a risk assessment based on calculated carbon footprint using conventional risk assessment matrix and Fuzzy risk assessment model.

1.6 Reason/justification for selection of topic

In a country's aviation industry, particularly ground handling operations, can pose significant environmental damage to the environment. Understanding and minimizing these impacts has become crucial for combating climate change challenges worldwide. Despite the importance of ground handling business, there is no study done in Pakistan on the comprehensive environmental risk assessments in this field and this gap can be addressed through this study. As the emphasis on sustainability and corporate social responsibility has grown in recent times, the environmental risk assessment linked with ground handling activities will also assist us in aligning with global trends and prioritizing the reduction of environmental carbon footprint. Thus, this topic was chosen after conducting sufficient related studies to assist the aviation sector in meeting its environmentally friendly goals and implementing emission reduction strategies.

1.7 Relevance to the national needs

Understanding the potential environmental concerns connected with ground handling operations at airports directly affects the country's requirement for sustainable growth and responsible resource management. As our country has been continuously striving for balancing economic growth with environmental preservation, the emphasis of this study on identifying and managing risks aligns with the essential need to protect the environment by means of sensible resource consumption. It will also help to shape our country's regulatory frameworks and sustainability activities in the aviation and related sectors. Implementation of eco-friendly practices in the aviation sector can also be adopted by recognizing the specific hazards and offering mitigation solutions. Ultimately, this study will drive the potential to enhance the country's environmental image, attract responsible investment, and strengthen the well-being of both the local community and the broader ecosystem.

1.8 Advantages

i. Identification of key risk factors & potential environmental risks related to ground handling operations can be helpful for other airport operations to conduct a comprehensive risk assessment.
ii. By considering environmental safety as a priority, penalties by authorities can be avoided by ensuring adherence to environmental regulations.
iii. After using fuzzy risk model into real life challenges at national & global level, better understanding of its usefulness will be achieved.
iv. Exhibiting environmental responsibility can foster a favorable organizational reputation, thereby drawing in prospective business opportunities.

Chapter 2 Literature Review

2.1 Background

This chapter examines earlier work that is related to our research. It includes discussing how to categorize the environmental aspects associated with ground handling office environment and conduct a comprehensive risk assessment based on carbon footprint emissions designed for potential mitigation strategies using both the traditional and modern techniques. This chapter also advances our understanding of conventional risk matrices and fuzzy inference risk modeling along with its application in identifying, assessing, and analyzing the environmental risks by connecting pertinent research literature.

The ranking of risk is one of the most important criteria to determine its success (Morgan et al., 2000; Baccarini & Archer, 2001). The process of risk ranking includes arrangement of potential risks in order of their priority or significance based on their calculated likelihood and impact (Stefana et al., 2022). The most problematic dispute in corporate office environment includes complaint by environmental certification bodies for not complying with the International Organization for Standardization (ISO) environmental management standard (i.e. ISO 14001:2015) and achieving their goals of reducing carbon emissions (Bourgougnon et al., 2007). This objection can lead to the suspension of the organization's environmental standard certification. Therefore, conducting frequent risk assessments and limiting carbon footprint emissions is essential for long-term survival and sustainability of an organization (Brock et al., 2021).

A practical and sound risk management along with mitigation strategies is essential for minimizing workplace carbon emissions. Due to uncertainty and complexity in risk matrix, it is believed that fuzzy risk model is a flexible approach that will provide a more precise illustration of uncertain risk factors, providing decision-makers with a clearer understanding of risk levels and more up-to-date choices within designated budget (A.D. et al., 2017).

2.2 Existing environmental risk assessment frameworks

(Bourgougnon et al., 2007) conducted a study using matricial calculations as a risk assessment tool to estimate environmental impact, prioritize objectives, and drive improvement plans for waste management & treatment offices in France. This approach comprised of periodic quantitative risk assessment and annual environmental audit on each site. The results of the study showed that applied risk structure helped the company to align with ISO 14001:2015 Standard and minimize environmental pollution.

To assess the risk factors that may have impact on offices in a construction sector, a process was developed by (Koulinas et al., 2021) that combines a quantitative and qualitative risk classification approach, using a popular multicriteria TOPSIS method and the powerful Monte Carlo Simulation approach. The major contribution of this study was the development of an innovative risk assessment framework that helped to effectively predict the uncertainties in identification of key risk factors affecting the environment.

In another comprehensive study, (Papamichael et al., 2023) analyzed & reviewed the evaluation of environmental performance, exposing the vast diversity of potential paths for choosing efficient and reliable monitoring systems, that are crucial for informed decision-making. For this purpose, he utilized Analytical Hierarchy Process (AHP) and SWOT analysis methodologies for environmental risk assessment within the scope of legal regulations. Various risk assessment tools were also recommended in the study which include recognized environmental standards (such as ISO 14001, ISO 14031, ISO 37101, ISO 37120 etc.), environmental management systems, predictive models, software tools, and key performance indicators. These tools provide clear and reliable instructions and processes for measuring the environmental performance of selected entities, whether they are corporations, cities, or countries. Moreover, the study results also suggested that the use of software tools for recording and analyzing data related to many elements of environmental performance is quite beneficial.

2.3 Carbon footprint emissions associated with offices

(Aroonsrimorakot et al., 2013) conducted a study to reduce the amount of greenhouse gases by management offices of Faculty of Environment and Resource Studies at Mahidol University in Thailand. He focused on the method of carbon footprint measurement to calculate greenhouse gas emissions. For calculation, data was collected from different GHG sources that includes consumption of electricity & water supply, waste generation and fuel consumption etc. These emissions were calculated in units of carbon dioxide equivalent (CO_2e). Study findings revealed that electricity consumption produced higher carbon footprint emissions, followed by waste generation.

(Awanthi & Navaratne, 2018) assessed the carbon footprint of a divisional secretariat office located in southern Sri Lanka. He also suggested suitable methods to reduce their annual carbon footprint. Carbon Footprint (CFP) of each source was calculated in tCO_2e/year by multiplying activity data with relevant emission factors (EF). Monthly bills, personal communication, data sheets and questionnaire were used to collect the activity data. Emission factors for this study were generated according to the 2006 IPCC guidelines for National Greenhouse Gas Inventories. Employee commuting (i.e staff transportation) contributed about 56.73% of the total carbon footprint of the organization. Therefore, public transportation was more supported by the company for its employees as compared to private transportation.

(Tjandra et al., 2014) endeavored to fill in a significant gap in the literature regarding the quantification of carbon footprint emissions for the firms in the early stages that lack resources & trained personnel to perform full scale carbon emissions assessments. A comprehensive framework method for carbon footprint calculation of an office environment in Singapore is presented in this study. The categorization and set of quantification methodologies for significant office emission sources were also proposed which aided in the calculation aspect. The results showed that monthly office carbon footprint was 2306.57 CO_2e(kg) comprising of major emission sources from usage of private car and air conditioning system. Hence, the proposed quantification method proved to be useful in assessment of overall emissions along with the identification of major emission sources.

2.4 Risk assessment using carbon footprint emissions

In another study, (Lovelock et al., 2017) attempted to identify and estimate carbon emissions sources from degraded coastal ecosystem. Conventional risk matrix was used in this study. A 5x5 risk matrix was developed and designed for risk assessment. In this matrix, frequency of emissions was considered as the likelihood factor and severity of carbon emissions was considered as impact factor. Carbon emissions were measured in categories ranging from low to very high applying the product of likelihood and impact. Results obtained from this matrix were helpful in estimation of carbon stock released in atmosphere through the degradation of organic matter.

A risk assessment method for identification of environmental aspects and impacts at an industry in Indonesia was developed by (Susanto & Mulyono, 2018). According to the international standard of environmental management system, identification of environmental aspects related to operations is considered as the preliminary step of environmental management. The author designed a strategic approach to identify the environmental aspects and impacts to conduct evaluation on the risks & opportunities. For determination of environmental risks, this methodology involved the combination of carbon footprint-based life cycle approach and risk assessment matrix. The final results provided a detailed overview of the industry's potential environmental aspects and impacts for the recommendation of risk prevention strategies.

2.5 Fuzzy logic modelling

(A.D. et al., 2017) presented a study report on the use of Fuzzy controls and fuzzy inference logic system. This study provided a research report on Fuzzy control and Fuzzy inference system (FIS), with an emphasis on its use in risk management practices in engineering projects. The report also exhibited the effectiveness of FIS model in determining a project performance evaluation based on the project emphasis. The knowledge base along with the reasoning processes of a framework of Fuzzy rules has proved to be excellent. By doing so, the quantitative assessment of the development of initiatives and difficulties through visualization became much easier. Furthermore, the benefits and consequences of the planning and execution processes can also be identified in order to make judgments on improvement areas. Different fuzzy concepts for risk management strategies were also clearly discussed that can help a lot of companies to prepare proper management solutions.

In a study, (Nguyen & Sugeno, 1998) has defined fuzzy logic modeling as a computational method that simulates human reasoning to deal with uncertainty and imprecision. Unlike classical binary logic, which only relies on true or false values, fuzzy logic allows for subtle transitions between these states. This allows for more precise modeling of complicated and confusing topics.

(Wang, 1997) has introduced the basic concepts on the important topics of fuzzy sets, fuzzy intersection, fuzzy union and fuzzy complement. This study provides detailed information on the steps of applying the fuzzy logic principles to work in control theory especially for the professional engineers and students. This model also serves as a flexible tool that can improve our capacity to deal with real-life circumstances including varying degrees of truth and ambiguity.

2.6 Fuzzy logic model as a tool for risk assessment

For assessing process hazards, (Ahn & Chang, 2016) conducted a study in which the method of fuzzy based HAZOP (Hazard & Operability Analysis) was utilized. The target method for the fuzzy-based and traditional HAZOPs assessment was a cryogenic LNG (liquefied natural gas) testing facility. Uncertain states were expressed using fuzzy theory. This idea was discovered to be a beneficial method for dealing with the inherent uncertainty in HAZOP assessments. It was also observed that frequency is the most important index for determining risk ranking of hazards. After analysis and comparison of results, it was determined that the fuzzy-based HAZOP presents more comprehensive risks as compared to the standard HAZOP. Furthermore, the fuzzy risk matrix also correlated the relevance of risks, insignificant risks, and the importance of risk reduction.

A case study on large airport was conducted by (Fitouri-Trabelsi et al., 2013). In this study, he detected the management of ground handling fleet as one of the major challenges at airport. The authors of this study indicated that this problem needs to be resolved as a priority to achieve the aim of smooth aircraft servicing, while keeping the budget of the ground service fleets in mind. Their collective efforts led to the proposal of an online decentralized management structure in which the significance of each aircraft demand for service was periodically assessed using a specific fuzzy model approach. The study results claims that a significate decrease in problems related to fleet management was observed by airlines, airport authorities and managers after successful implementation of this model structure.

(Yazdani-Chamzini, 2014) proposed a fuzzy inference risk model for conducting risk assessment of a tunneling project. The author also carried out a comprehensive risk analysis considering the uncertainties and hazards associated with underground projects. This analysis turned out to be effective in assessing existing risks, prioritizing them for protective measures and making decisions to eliminate, mitigate or reduce the risks involved in this project. Consequently, this work provided a risk assessment model based on the notions of fuzzy set theory to analyze risk occurrences and their impacts during tunnel building activities. The suggested model's results were compared to those of traditional risk assessment to demonstrate its efficacy. This comparison revealed that the fuzzy inference system had a significant potential for effectively modeling such challenges.

2.7 Key features of Fuzzy logic risk model

It has been acknowledged through various studies conducted by (Nguyen & Sugeno, 1998; Yunior & Kusrini, 2018) that the fuzzy models had the ability to adapt subtle transitions and quantify degrees of truth even in the system with uncertain, vague or complex information. This means that one element might belong to numerous categories to variable degrees, indicating the degree of ambiguity and error found in real-world circumstances.

(Markowski & Mannan, 2008) recognized that one of the key features of fuzzy risk model is remarkable representation of nonlinear relationships. Unlike typical linear models, which presume direct correlations, fuzzy logic can identify complex interactions in which variations in one variable do not result in corresponding changes in another. This ability to handle intricate and irregular connections increases its utility in representing real-world phenomena with non-linear dynamics.

Chapter 3 Study Methodology

3.1 Introduction

This chapter describes a systematic strategy to evaluate environmental risks, which includes identifying potential aspects, assessing their impacts and developing appropriate mitigation measures based on measured carbon footprint from each aspect. It also includes a framework for conducting carbon footprint assessment of ground handling organization offices at Islamabad Airport. For analysis, raw data was received from airport terminal offices, cargo terminal offices and IPCC 2019 reports.

3.2 Flowchart of study methodology

Study was conducted based on the following steps:

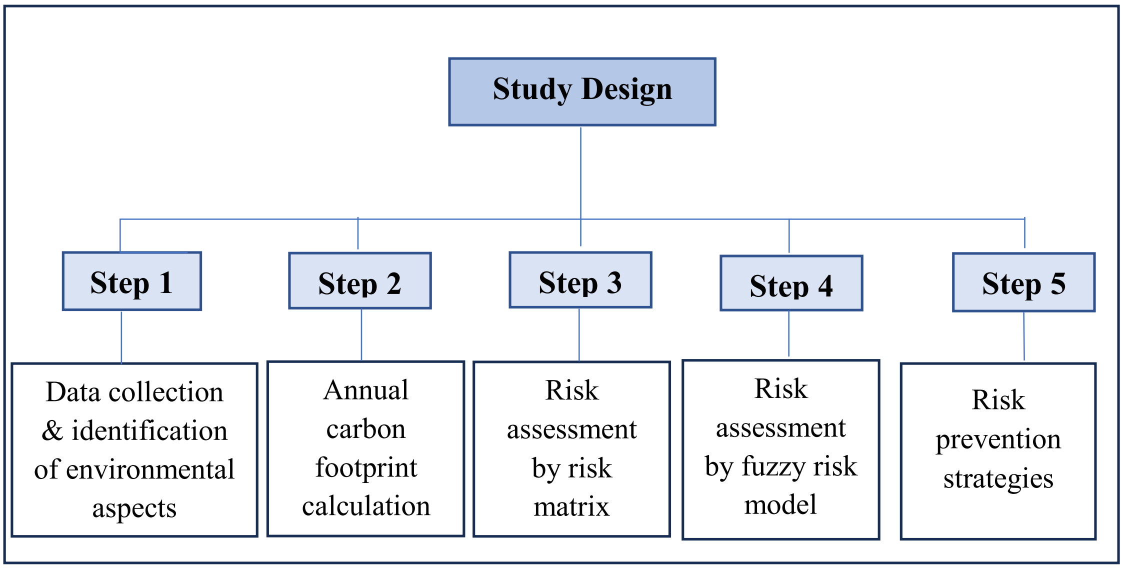

Figure 3.1: Flow diagram of research methodology

3.3 Study area

The study area for this research is XYZ company offices located at both airport terminal and cargo terminal of Islamabad International Airport. Islamabad International airport, formerly known as Benazir Bhutto International Airport, is spread around 19 square kilometers with the capacity of handling 9 million passengers annually. It is located 2 km (16 mi) south-west of Islamabad city and is accessed via Srinagar Highway. It is situated at longitude 33.549083 and latitude 72.82565 in Islamabad. It was formally inaugurated on 20 April 2018 for regular international and domestic flight operations. Increased carbon footprint & environmental degradation is posing threat towards sustainable environment that has projected to reduce Pakistan's GDP at least 18 to 20% by 2050 (The World Bank Group, 2022).

Figure 3.2: Islamabad International Airport

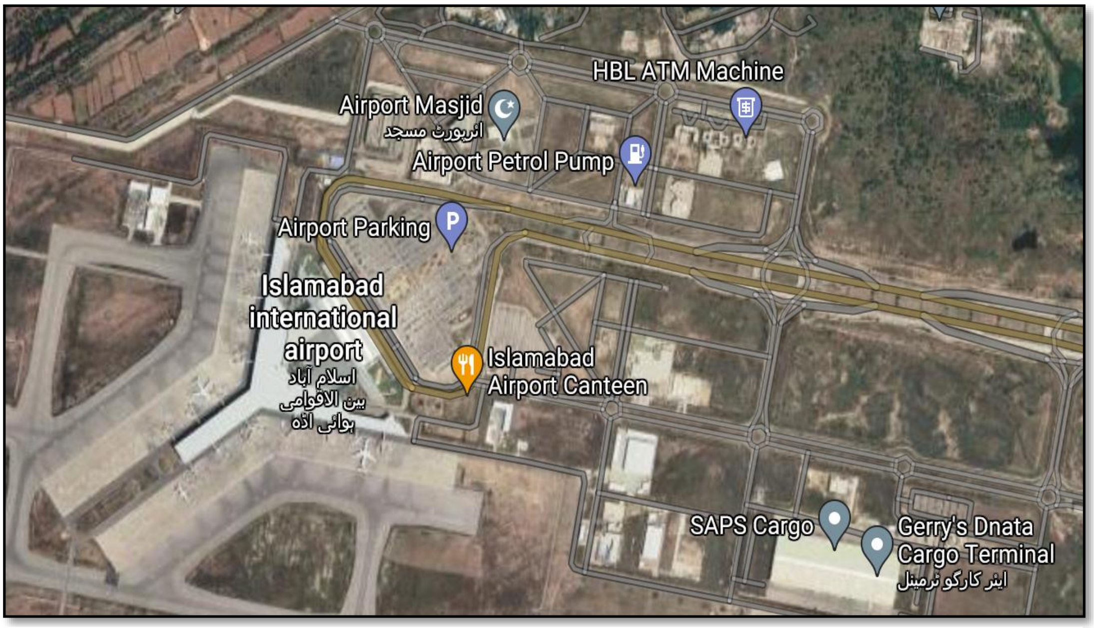

Figure 3.3: Islamabad International Airport Map (Source: Google Maps)

3.4 Data Collection

3.4.1 Primary and secondary data

A physical inspection was conducted in the study area. The data for major GHG emission sources (e.g electricity, petrol, diesel & paper) was collected from different departments including cargo export & import offices, admin offices, human resource offices, training room, security office, IT office, baggage office, ticketing offices, risk office, finance office, flight operations office, ramp offices and kitchen rooms of XYZ organization at airport. Annual data for each aspect of GHG source was collected through office record sheets, monthly bills, invoices and logbooks for the period of January 2021 to Dec 2021. The gathered data was then compiled into Microsoft Excel sheets for further analysis. Secondary data of GHG emission factors for identified emission sources was obtained from different international & national organizations e.g. United Nations Framework Convention on Climate Change (UNFCCC), Intergovernmental Panel on Climate Change (IPCC), International Energy Agency (IEA) & Ministry of Finance (MoF) Pakistan.

3.5 Method for carbon footprint calculation

(IPCC, 2006) guidelines for comprehensive calculation approach for GHG emissions contributing to the total carbon footprint at organization level and is extensively used worldwide. The total carbon footprint of all GHG emissions from all energy sources (Thermal, Hydel, Nuclear & Renewable) was estimated by multiplying activity data (e.g. consumption of electricity, paper and fuel) with the corresponding emission factor. Total carbon footprint emissions from all energy sources categories are summed as given below (Eq 3.1). Total carbon footprint emissions were reported in the unit of carbon dioxide equivalent (CO_2e).

$$CFP = \sum A \times EF \qquad \text{(Eq 3.1)}$$

Where CFP is total carbon footprint including carbon emissions from all its source categories; A is the activity data (obtained from data records & physical inspection) which generates carbon emissions and EF is the emission factor of carbon dioxide by its source category.

3.5.1 Carbon footprint calculation for electricity consumption

Major GHG emissions have been produced by fossil fuel combustion particularly during electricity generation & consumption at global level. In the current study, increased usage of electrical appliances i.e. desktops, printer, office lightings, air conditioning, microwave oven & refrigerator were observed as the major contributors to overall emissions from electricity consumption. Total carbon footprint from electricity consumption including all sources was calculated using Eq 3.2

$$CFP_e = \sum A_e \times EF_e \qquad \text{(Eq 3.2)}$$

Where CFP_e is the total carbon footprint from electricity consumption per year; A_e is the electricity consumption data per year and Ef_e is the country specific or default emission factor for electricity.

Activity data (i.e electricity consumption data) for these appliances were obtained through electrical device owner's manual, manufacturer's website, monthly data logs, contracts & electricity bills. Emissions resulting from electricity consumption are classified as indirect emissions, implying that our utilization of electricity inherently involves us in the emissions generated during its production phases (Khan & Siddiqui, 2017).

Emission factors play a crucial role in environmental assessment as they provide standardized metrics for measuring the quantity of greenhouse gases and other pollutants released per unit of activity or energy produced (Unnewehr et al., 2022). Country specific emission factors for electricity consumption can be achieved through the energy mix (coal, hydro, natural-gas, solar, nuclear etc.) of specific country (Brander et al., 2011). Table 3.1 represents energy mix of Pakistan for the period of 2021 to 2022. Emission factor for electricity consumption of Pakistan was generated by multiplying IPCC default emission factor of each energy source (thermal, hydro, nuclear & renewable) with the corresponding energy share as explained in Eq 3.3.

$$(EF_e)_x = EF_x \times ES \qquad \text{(Eq 3.3)}$$

Where "x" represents energy source category; EF_e stands for electricity emission factor; EF_x is default emission factor and ES is corresponding energy share value.

Table 3.1: Pakistan energy mix (Year 2021 - 2022)

Energy source category	Pakistan energy share (%)
Thermal	59.42
Hydro	30.52
Nuclear	7.82
Renewable	2.23

(Source: Pakistan Economic Survey Report, 2021)

As electricity powers our modern lives, its generation from various sources, including fossil fuels like coal and natural gas, releases significant amounts of carbon dioxide and other greenhouse gases into the atmosphere. (Tjandra et al., 2014) developed a detailed quantification method which was used to calculate annual carbon footprint emissions from electricity consumption of each source as represented in Figure 3.4.

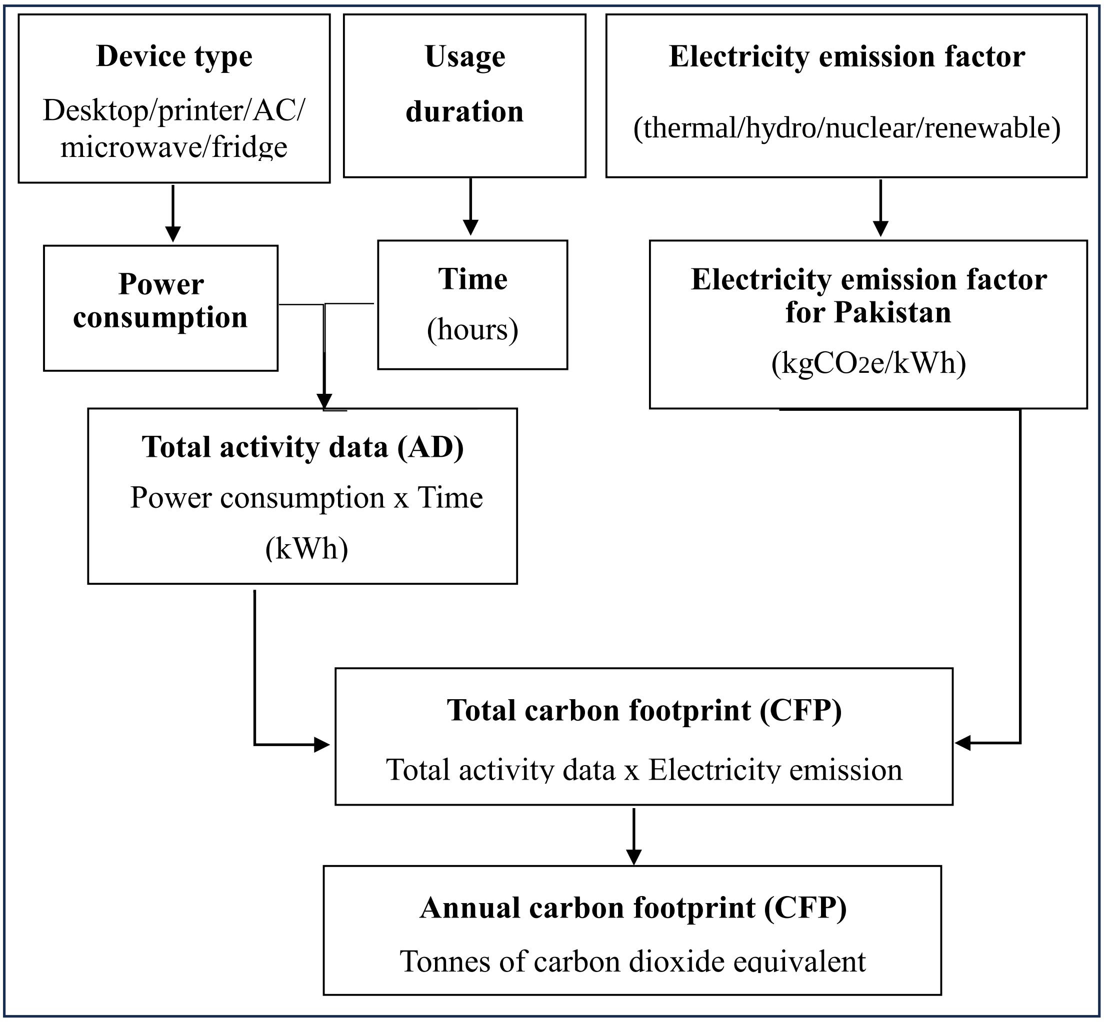

Figure 3.4: Carbon footprint calculation method from electricity consumption

3.5.2 Carbon footprint calculation for fuel consumption

Staff transportation & airport ground support equipment (GSE) were observed as major sources of fuel emissions in the present study. To calculate total carbon footprint, entire carbon emissions from fuel consumption were calculated by multiplying the actual amount of consumed fuel with the corresponding IPCC fuel emission factors as described in Eq 3.4 & Eq 3.5.

$$CFP_d = \sum A_d \times EF_d \quad \text{(Eq 3.4)}$$

$$CFP_g = \sum A_g \times EF_g \quad \text{(Eq 3.5)}$$

Where CFP_d is total carbon footprint from diesel consumption per year; A_d is the diesel consumption data per year; Ef_d is default emission factor for diesel; CFP_g is total carbon footprint from gasoline consumption per year; A_g is the gasoline consumption data per year ; Ef_g is default emission factor for gasoline.

Activity data (i.e fuel consumption data) of GSE equipment and staff buses were obtained through company fuel card records, monthly fuel consumption databases, monthly invoices & physical checks of each vehicle’s hour meter. An extensive study conducted by (Bao et al., 2023) exhibited that airport ground support equipment (GSE) stands out as a significant contributor to carbon emissions, accounting for approximately 13% of the overall airport energy consumption derived from diesel fuel & gasoline. (IPCC, 2006; DEFERA, 2011) provide annually updated default emission factors that were used in this case for conversion of fuel consumption into emissions data. Figure 3.5 corresponds to the detailed carbon footprint (CF) quantification method that was adopted to calculate the overall emissions from staff transportation and airport ground support equipment operation as elaborated by (Luo et al., 2016).

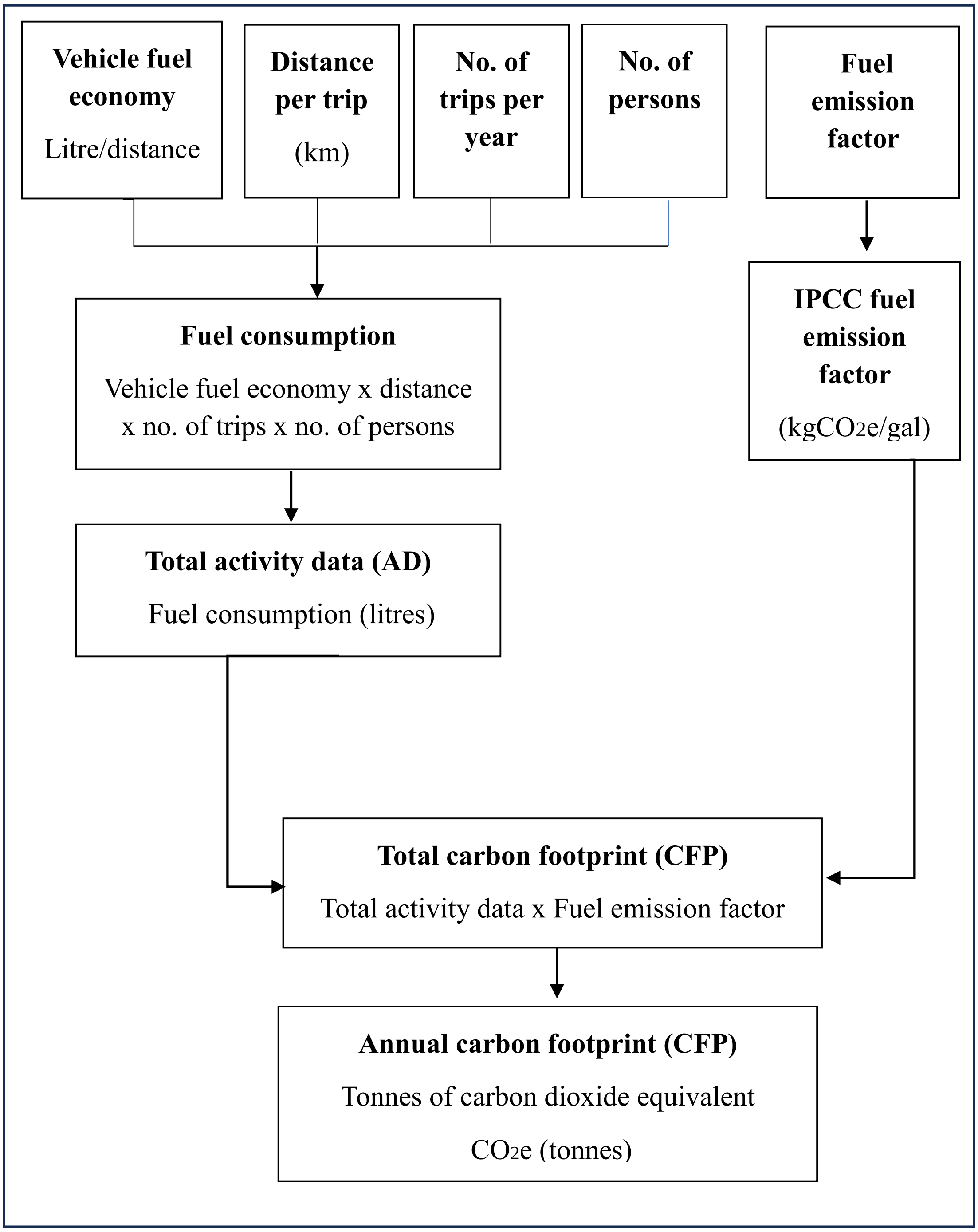

Figure 3.5: Carbon footprint calculation method from fuel consumption

3.5.3 Carbon footprint calculation for paper consumption

Overall carbon emissions from paper consumption in offices were calculated by considering total numbers of papers consumed for printing purposes. Carbon emissions from paper consumption were calculated by multiplying the total number of consumed pages with default paper emission factors as described in Eq 3.6.

$$CFP_p = \sum A_p \times EF_p \qquad \text{(Eq 3.6)}$$

Where CFP_p is total carbon footprint from paper consumption per year; A_p is the paper consumption data per year and Ef_p is default emission factor for paper.

Hence, in this case, total paper consumption was considered as the activity data. Emission factor was selected using SimaPro software (Aroonsrimorakot et al., 2013). Figure 3.6 illustrates the calculation steps that were used for calculation of overall paper emission's carbon footprint (Awanthi & Navaratne, 2018).

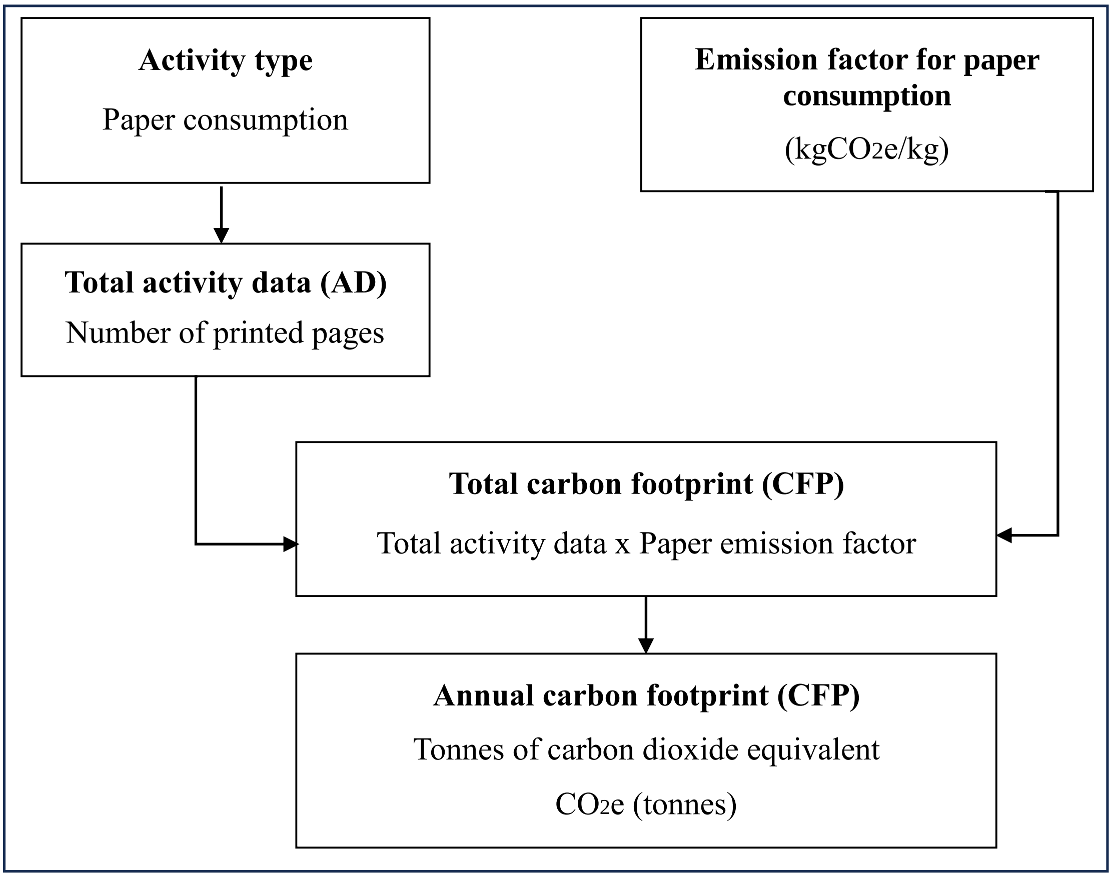

Figure 3.6: Carbon footprint calculation method from paper consumption

3.6 Tools for risk analysis

After completing a comprehensive calculation of the overall carbon footprint, the next process was to begin the critical process of conducting a thorough risk assessment. This stage involved risk evaluation using likelihood and severity of carbon emissions arising from each distinct source. By evaluating the severity of these emissions, it was easier to target the high priority risk areas for prevention & mitigation strategies. Risk assessment was conducted using two different techniques i.e conventional risk assessment method and fuzzy inference risk assessment model (Hatefi et al., 2019). Eventually, the results yielded by both methodologies were contrasted to evaluate their efficacy and accuracy, thereby assessing the effectiveness of both the traditional approach and the risk model (Yazdani-Chamzini, 2014).

3.6.1 Conventional risk assessment method

The conventional risk assessment method consisted of three phases to systematically evaluate potential hazards and their associated risks (Dalezios, 2017). In the first phase, relevant data was collected and analyzed from company records and industry standards, forming the foundation for risk identification. The second phase included the risk factors that were established by considering their severity and likelihood of occurrence. In the last phase, established risk matrices were utilized and risk levels were assigned to each identified hazard, facilitating the prioritization for subsequent mitigation efforts. Several studies conducted on risk assessment (Kaplan & Garrick, 1981; Alidoosti et al., 2012; Fouladgar et al., 2012) also stated that the risk index of occurrence is the product of severity and likelihood ratings, and their relationship is mathematically defined in Eq 3.7

$$\text{Risk (R)} = \text{Likelihood (L)} \times \text{Severity (S)} \qquad \text{(Eq 3.7)}$$

This method assessed the probability of risk associated with various risk activities using a well-known tool called as likelihood severity matrix (Yazdani-Chamzini, 2014). The likelihood of all events of carbon emissions and the severity of these emissions were combined in this matrix to conduct risk assessment process as shown in Figure 3.7.

Likelihood of risk events		Severity of carbon footprint in CO_2e (tonnes)				
		Low carbon footprint	Moderate carbon footprint	Moderate to high carbon footprint	High carbon footprint	Very high carbon footprint
		1	2	3	4	5
Improbable	1	1 (Insignificant)	2 Insignificant)	3 (Insignificant)	4 (Insignificant)	5 (Tolerable)
Remote	2	2 (Insignificant)	4 (Insignificant)	6 (Tolerable)	8 (Tolerable)	10 (Substantial)
Occasional	3	3 (Insignificant)	6 (Tolerable)	9 (Tolerable)	12 (Substantial)	15 (Significant)
Probable	4	4 (Insignificant)	8 (Tolerable)	12 (Substantial)	16 (Significant)	20 (Intolerable)
Frequent	5	5 (Tolerable)	10 (Substantial)	15 (Significant)	20 (Intolerable)	25 (Intolerable)

Figure 3.7: Risk assessment matrix for carbon footprint emissions (Lovelock et al., 2017)

In the above matrix, a linguistic scale was used to determine the likelihood, which was represented by the digits 1, 2, 3, 4, and 5 which stand for improbable (I), remote (R), occasional (O), probable (P), and frequent (F) respectively. A scale with similar categories was also determined for hazardous consequences of tunnel risk assessment (Hutten et al., 2022; Morgan et al., 2000). Numbers like 1, 2, 3, 4, and 5 were used to categorize the severity level. These numbers corresponded to low (L), moderate (M), moderate to high (MH), high (H), and very high (VH) respectively (Lovelock et al., 2017). To describe the level of output risk, numbers ranging from 1 to 25 have denoted the linguistic terms of insignificant (IN), tolerable (T), substantial (SU), significant (S) and intolerable (IN) (Alidoosti et al., 2012). Definitions for likelihood, severity and risk levels have been listed down in Table 3.2, 3.3 and 3.4 respectively.

Table 3.2: Definition of likelihood labels

Likelihood linguistic term	Definition	Likelihood rating
Improbable (I)	Activities that occur very rarely, such as once a week or less.	1
Remote (R)	Activities that occur occasionally, such as few times a week or less.	2
Occasional (O)	Activities that occur regularly, such as once a day or few times a day.	3
Probable (P)	Activities that occur frequently, such as several times a day.	4
Frequent (F)	Activities that occur almost continuously throughout the day.	5

Table 3.3: Definition of severity labels

Severity linguistic term	Definition	Severity rating
Low carbon footprint (L)	Activities that produce total carbon emissions about 1 to 10 CO_2e (tonnes).	1
Moderate carbon footprint (M)	Activities that produce total carbon emissions about 10 to 100 CO_2e (tonnes).	2
Moderate to high carbon footprint (MH)	Activities that produce total carbon emissions about 100 to 2000 CO_2e (tonnes).	3
High carbon footprint (H)	Activities that produce total carbon emissions about 2000 to 10000 CO_2e (tonnes).	4
Very high carbon footprint (VH)	Activities that produce total carbon emissions greater than 10000 CO_2e (tonnes).	5

Table 3.4: Definition of risk levels

Risk linguistic term	Definition	Risk rating
Insignificant (IN)	A risk that has minimal impact or consequence and is unlikely to cause any significant harm or disruption	1 - 4
Tolerable (T)	A risk that is within acceptable limits and can be managed effectively with existing controls or mitigation measures.	5 - 9
Substantial (SU)	A risk with a notable potential to cause significant negative outcomes or disruption.	10 - 12
Significant (S)	A risk with a considerable potential for severe impact or consequences.	15 - 16
Intolerable (IN)	A risk that exceeds acceptable levels of risk and causes severe consequences or damage.	20 - 25

3.6.2 Fuzzy inference risk assessment method

The subsequent phase involved conducting risk assessment utilizing a fuzzy inference model that integrated risk evaluations from the conventional risk model. (Yazdani-Chamzini, 2014) has identified the fuzzy inference system as the mapping process from a given input set to an output set applying fuzzy logic. For this study, Mamdani type for fuzzy inference engine was selected as it is commonly used for modelling the problems with uncertainty & complexity as stated by (Nguyen & Sugeno, 1998). The Mamdani type fuzzy inference tool was downloaded in MATLAB version 21 software. Figure 3.8 shows all steps involved in functioning of this model. In the first step, input and output variables were established (Tjandra et al., 2014). The second step was to design the membership functions describing the relevant linguistic terms and membership degrees (Yazdani-Chamzini, 2014). All membership functions defined for input and output variables for this study have been explained in Table 3.5 & 3.6. In third step, a comprehensive fuzzy rule base consisting of 25 rules was constructed as described in previous literature (Alidoosti et al., 2012), with the help of mapping input membership function values to output values as depicted in Table 3.7. After rules construction, the fuzzy inference process was executed which evaluated rule antecedents and aggregated the outputs. In the last step, the resulting fuzzy output sets were produced through defuzzification techniques to obtain crisp output values (Yunior & Kusrini, 2018). The defuzzification technique used in this case was the center of gravity (COG) method as employed by (Yazdani-Chamzini, 2014).

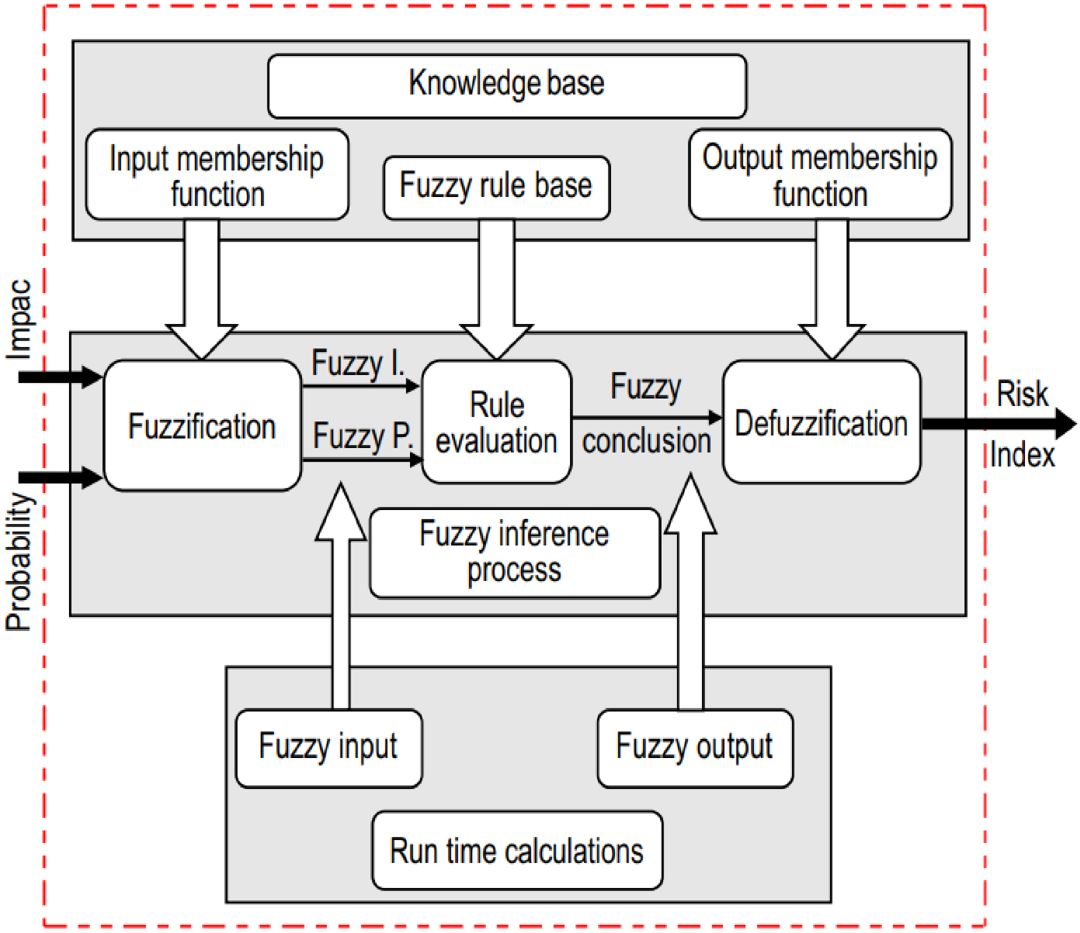

Figure 3.8: Steps of fuzzy risk assessment model (Yunior & Kusrini, 2018)

Table 3.5: Membership functions defined for input variables

Input factors	Linguistic term	Fuzzy rating	Universe of discourse
Likelihood	Improbable	$1 \leq$ Likelihood ≤ 2.5	X € (1,5)
	Remote	$1 \leq$ Likelihood ≤ 3.5	
	Occasional	$1.5 \leq$ Likelihood ≤ 4.5	
	Probable	$2.5 \leq$ Likelihood ≤ 5	
	Frequent	$3.5 \leq$ Likelihood ≤ 5	
Severity	Low	$1 \leq$ Severity ≤ 2.5	X € (1,5)
	Moderate	$1 \leq$ Severity ≤ 3.5	
	Moderate to High	$1.5 \leq$ Severity ≤ 4.5	
	High	$2.5 \leq$ Severity ≤ 5	
	Very High	$3.5 \leq$ Severity ≤ 5	

Table 3.6: Membership functions defined for output variables

Output factors	Linguistic term	Fuzzy rating	Universe of discourse
Risk	Insignificant	$1 \leq$ Risk ≤ 10	X € (1,25)
	Tolerable	$1 \leq$ Risk ≤ 15	
	Substantial	$5 \leq$ Risk ≤ 20	
	Significant	$10 \leq$ Risk ≤ 25	
	Intolerable	$15 \leq$ Risk ≤ 25	

Rule No.	Rules description
1	If (Likelihood is Improbable) & (Severity is Low) Then (Risk is Insignificant).
2	If (Likelihood is Remote) & (Severity is Low) Then (Risk is Insignificant).
3	If (Likelihood is Occasional) & (Severity is Low) Then (Risk is Insignificant).
4	If (Likelihood is Probable) & (Severity is Low) Then (Risk is Insignificant).
5	If (Likelihood is Frequent) & (Severity is Low) Then (Risk is Tolerable).
6	If (Likelihood is Improbable) & (Severity is Moderate) Then (Risk is Insignificant).
7	If (Likelihood is Remote) & (Severity is Moderate) Then (Risk is Insignificant).
8	If (Likelihood is Occasional) & (Severity is Moderate) Then (Risk is Tolerable).
9	If (Likelihood is Probable) & (Severity is Moderate) Then (Risk is Tolerable).
10	If (Likelihood is Frequent) & (Severity is Moderate) Then (Risk is Substantial).
11	If (Likelihood is Improbable) & (Severity is Moderate to High) Then (Risk is Insignificant).
12	If (Likelihood is Remote) & (Severity is Moderate to High) Then (Risk is Tolerable).
13	If (Likelihood is Occasional) & (Severity is Moderate to High) Then (Risk is Tolerable).
14	If (Likelihood is Probable) & (Severity is Moderate to High) Then (Risk is Substantial).
15	If (Likelihood is Frequent) & (Severity is Moderate to High) Then (Risk is Significant).
16	If (Likelihood is Improbable) & (Severity is High) Then (Risk is Insignificant).
17	If (Likelihood is Remote) & (Severity is High) Then (Risk is Tolerable).
18	If (Likelihood is Occasional) & (Severity is High) Then (Risk is Substantial).
19	If (Likelihood is Probable) & (Severity is High) Then (Risk is Significant).
20	If (Likelihood is Frequent) & (Severity is High) Then (Risk is Intolerable).
21	If (Likelihood is Improbable) & (Severity is Very High) Then (Risk is Tolerable).
22	If (Likelihood is Remote) & (Severity is Very High) Then (Risk is Substantial).
23	If (Likelihood is Occasional) & (Severity is Very High) Then (Risk is Significant).
24	If (Likelihood is Probable) & (Severity is Very High) Then (Risk is Intolerable).
25	If (Likelihood is Frequent) & (Severity is Very High) Then (Risk is Intolerable).

Table 3.7: Rules evaluation for membership functions

Chapter 4 Results & Discussion

The present study was intended to estimate the annual carbon footprint emissions of both airport terminal & cargo terminal offices of XYZ organization and highlight the contribution of emission sources to potential environmental hazards by the process of risk assessment using both conventional and modern techniques. This study encompasses categories of carbon footprint emission sources produced from the daily operations of offices environment for the period of year 2021-2022. Data from different departments of offices were obtained and analyzed by following the methodological aspects from previous case studies.

4.1 Identification of major emission sources

The main sources of emission were identified through walk through inspections and analysis of yearly records obtained from different offices. It is the first and most important step to conduct this study because carbon footprint measurement is based on the outcomes of this step as illustrated in Figure 3.1. Based on detailed literature review and thorough study of gathered data, a framework was designed to categorize emission sources based on office activities as described in Figure 4.1 (Di Giacomo et al., 2017). Moreover, it can also be used as a reference tool in determining emission sources. However, when analyzing the office's carbon footprint, the categories mentioned inside this framework should not be limited by the organization themselves (Charles et al., 2019). Therefore, the structure of identification framework for this study research was customized according to its needs and requirements, eliminating any categories which were not applicable for the desired job and adding new ones as appropriate.

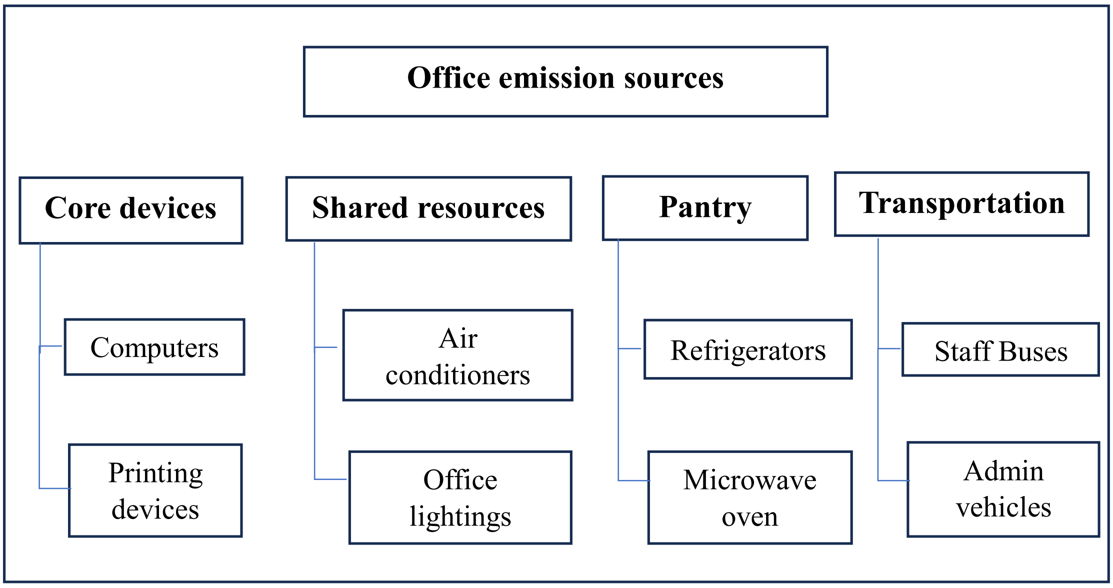

Figure 4.1: Emission sources framework for office operation

The framework structure presented in Figure 4.1 is designed according to common operations of offices in Pakistan. One of its major purposes was to be generic and adaptable. According to this framework, emission sources were grouped into four categories including core devices, shared resources, pantry, and transportation (Jenkins & Newborough, 2007; Aroonsrimorakot et al., 2013; Mendes et al., 2017; Susanto & Mulyono, 2018). Personal computers and printing devices were included in core devices. These two types of devices are found in many modern work environments and are often utilized as the backbone of office activity. Shared resources, often known as facility operations, included the usage of air conditioning and lighting systems (Jones, 2001; Mandin et al., 2017). Almost every modern office has a pantry where employees can prepare meals and have refreshments during breaks; thus, pantry was considered a part of the office. Refrigerators and microwave ovens were covered in the pantry section. Lastly, emission from transportation modes is created to support office activities for admin functions & transportation of office personnel to and from the office is included (Valenti et al., 2019). After comprehensive examination & analysis of emission sources using physical inspection and collected data, three major environmental aspects were identified that appeared to be involved in greater proportion of emissions in annual operation of XYZ company's offices at airport & cargo terminal. Table 4.1 corresponds to these aspects along with their emission sources, location & data sources.

Table 4.1: Identification of major environmental aspects

Environmental aspect	Emission source	Areas	Data sources
Electricity consumption	Desktops, printers, air conditioners, office lightings, refrigerator and microwaves	Admin and human resource offices, cargo offices, main conference room, meeting rooms, risk offices, IT offices, finance office, training room, security office, ramp offices, flight ops offices, traffic ops offices, baggage offices, ticketing offices and kitchens.	Monthly bills, personal communication, data records, purchasing invoices etc
Fuel consumption	Ramp vehicles, admin vehicles & staff commuting		
Paper consumption	Paper for printing purpose		

The first aspect taken into consideration was electricity consumption at offices of all departments. Electricity consumption is the amount of electrical energy utilized by various appliances, entities, or systems over a certain period (Unnewehr et al., 2022). Consumption of electricity was considered a substantial environmental concern in offices because of its frequent use and excessive working hours. The equipment and devices being used in offices mostly relied on electricity, thus contributing to the overall carbon footprint & increasing environmental concerns e.g., global warming (Lee & Lee, 2021). Therefore, it can be said that higher consumption of electricity has emitted greater carbon emissions in the atmosphere (Chuang et al., 2018). Moreover, excessive electricity usage during peak hours could also strain the grid and force the use of inefficient backup power sources, adding to environmental deterioration (Brander et al., 2011). The second major environmental aspect identified for carbon emissions was fuel combustion from airport ramp vehicles, employee commuting buses and admin vehicles. All these vehicles used to run on diesel and gasoline. As a result of combustion, considerable amounts of carbon dioxide (CO_2) and nitrogen oxides (NOx) are emitted into the atmosphere. The release of CO_2 from the combustion of fossil fuels is considered one of the major contributors to climate change. Thus, airports mainly contribute to the accumulation of these pollutants causing climate change effects due to their heavy vehicle fleets and frequent day & night operations (Bao et al., 2023). Paper consumption was the last major aspect identified in this step for estimating carbon emissions. The paper used for printing purposes was primarily focused. It was observed that large quantities of paper were being utilized in offices daily for printing purposes. A lot of energy is used in paper manufacturing along with its printing process that contributes to environmental pollution.

4.2 Measurement of annual carbon footprint emissions

The next stage was to estimate the total amount of annual carbon footprint (CFP) emissions produced by each of the identified environmental aspects across all offices. Periodic supervision and various metrics were used to collect activity data for power use, fuel consumption, and paper consumption. One study also confirmed that these tools & techniques were helpful in assessing the emissions produced by carbon footprint of an organization (Awanthi & Navaratne, 2018). Some of the parameters used were also based on fundamental engineering terms, and their values were available from reasonably common sources, such as the device owner's handbook or the manufacturer's website. Emission factors were generated for electricity. For fuel and paper consumption, the default emission factors were used. By combining all these inputs as specified in Eq 3.1, total carbon footprint from yearly operations of all offices was estimated, along with the corresponding percentages for each emission source in relation to the total carbon footprint as explained in Table 4.2. Breakdown of this carbon footprint was based on emission source categories presented in Figure 4.1.

Table 4.2: Annual carbon footprint emissions from offices

S. No	Office emission sources	Annual carbon footprint CO_2e (tonnes)	% of total
1.	Desktop operation	1235.73	5.01
2.	Printing device operation	14272.13	57.92
3.	Office lights operation	8.51	0.03
4.	Air conditioner operation	11.08	0.04
5.	Pantry operation	0.48	0.002
6.	Paper consumption	1078.21	4.38
7.	Ramp vehicles operation	8006.73	32.49
8.	Admin vehicles operation & staff commuting	30.11	0.12
Grand total carbon footprint		24642.97	100

The results showed that environmental aspects identified from each activity produced an annual carbon footprint of about 24642.97 CO_2e (tonnes) in the organization. A similar study has also showed that an organization in Sri Lanka produced carbon footprint equivalent to 27678.84 CO_2e tonnes form their yearly office operation (Tjandra et al., 2014). According to Table 4.2, it was noted that major proportion of carbon footprint emissions came from the usage of printing devices in the offices which accounted for 14272.13 tonnes of CO_2e, corresponding to 57.92% of total carbon footprint. Office emissions from printing devices have also been reported to contribute significantly to environmental degradation due to resource-intensive paper consumption, energy consumption and chemical exposure (Mendes et al., 2017). Operation from ramp vehicles were seen to contribute to the second highest emissions of around 8006.73 tonnes of CO_2e, accounting for approximately 32.49% of the total footprint. (Bao et al., 2023) also explored that ramp vehicles consume high quantities of fuel, thus causing the major environmental pollution. Performing the backbone of office work, it was seen that emissions from desktop operation ranked the third highest by emitting 1235.73 CO_2e (tonnes). Emission contribution from paper consumption was substantial producing 1078.21 CO_2e (tonnes) accounting for about 4.38% of total emissions. (Trzeciak, 2021) also studied that the most common environmental risks associated with enterprises occurred from the utilization of paper in daily routine and especially from the personal computers and desktops of staff. Moreover, it was also observed that the operation of administrative vehicles and employee commuting accounted for about 0.12% of the overall carbon footprint. (Hussain et al., 2013) also conducted a study at New Islamabad International Airport to evaluate its structural environmental performance by comparing the emissions from staff commuting to the industry standards for setting realistic improvement targets leading to less harmful environment. Categories like office lights operation and air conditioner operation made minimal impacts by contributing 0.03% and 0.04%, respectively. Likewise, the office pantry operation also made a negligible contribution of 0.002%. A case study conducted by (Łuszczyńska, 2022) at a public utility building has also discovered that office electronics & gadgets used to possess a minimal impact on the overall emissions generated in offices and classrooms. A graphical distribution of overall office emissions has been described in Figure 4.2. Further breakdown of these emission sources was conducted in the next stage to focus on areas that offer the most significant potential for improvement.

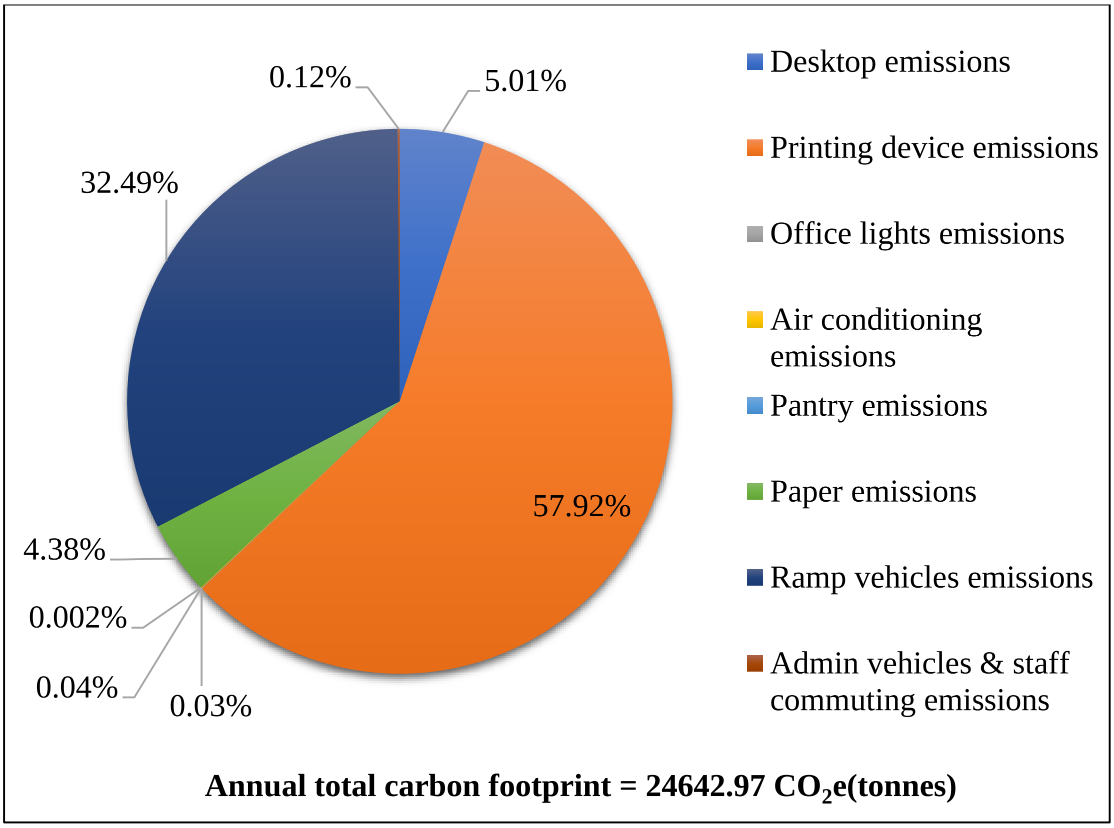

Figure 4.2: Proportion of overall office emission categories

4.2.1 Breakdown of emissions from electricity consumption

To assess emissions from office power consumption, a complete analysis was performed, categorizing the sources into five essential components. These included personal desktop computers, printers, workplace lighting systems, air conditioners, refrigerators, and ovens. All necessary data was collected to measure the carbon footprint from electricity consumption by using the steps mentioned in Figure 3.4.

4.2.1.1 Annual electricity emissions from office desktops

Table 4.3 illustrates the annual activity data of 42 office desktops as well as the accumulated emissions from various emission sources inside the organization, quantified in tonnes of CO_2 equivalent (CO_2e). Annual carbon footprint emissions from electricity consumption of desktops were estimated to be about 1235.73 tonnes of CO_2e(tonnes). According to Table 4.3, most activity data in form of annual energy consumption was resulted from the training room i.e., 28392.81 kWh, thus accounting for about 247.81 CO_2e tonnes, or 20.05% of total emissions. Further data analysis showed that training room exhibited highest CO_2 emissions due to extensive energy consumption from electronic devices during prolonged training sessions for morning, afternoon and night shifts along with the potential lack of energy-efficient equipment and practices. A significant case study conducted by (Luo et al., 2016) has also summed up and compared the emissions arising from daily office operations of about 78 office buildings in China to estimate the embodied carbon emissions. In the current research, it was seen that administrative and human resource offices generated about 17.80 CO_2e tonnes annually, accounting for 1.44% of total emissions. (Wilkinson & Reed, 2006) conducted research on emissions linked with office buildings characteristics whose results indicated a strong association between heightened emissions and the hectic operations of the administrative department. Furthermore, cargo export and import offices generated about 159.35 CO_2e tonnes each year, accounting for 12.90% of total emissions. According to (Boyd & McNevin, 2015), elevated carbon emissions have a strong association with the dynamic operations of the cargo department which emphasizes the critical significance of cargo-related activities in dramatically increasing the overall carbon footprint of office buildings. It was also observed that the main conference room produced 5.7 CO_2e tonnes (0.46% of total), whereas meeting room 1 and meeting room 2 each emitted 43.77 CO_2e tonnes, accounting for 7.08% of total emissions. Furthermore, finance & IT offices both made considerable contributions, with 51.04 CO_2e tonnes (4.13%) and 167.58 CO_2e tonnes (13.56%), respectively. (Charles et al., 2019) also conducted detailed research on identification of parameters to reduce energy consumption of an office building in Vancouver which exhibited that energy consumption of electronic equipment, data centers and financial data processing in personal offices and board room along with need of their controlled environmental conditions such as HVAC has amplified carbon footprint of offices at a striking rate. Figure 4.3 represents the graphical distribution of annual carbon footprint produced by energy utilization from office desktops.

Table 4.3: Breakdown of annual CFP from electricity consumed by desktops

S.no	Emission sources	Annual activity data (kwh)	Annual emissions (thermal + hydro + nuclear + renewable)	
			CO_2e (tonnes)	% of total
1.	Admin & HR offices	2039.35	17.80	1.44
2.	Cargo export & import offices	18256.73	159.35	12.90
3.	Main conference room	653.04	5.7	0.46
4.	Meeting room 1	5014.73	43.77	3.54
5.	Meeting room 2	5014.73	43.77	3.54
6.	IT office	5847.65	51.04	4.13
7.	Finance office	19199.64	167.58	13.56
8.	Training room	28392.81	247.81	20.05
9.	Risk office 1	14403.74	125.72	10.17
10.	Risk office 2	8381.94	73.16	5.92
11.	TGS & ramp offices	11485.64	100.25	8.11
12.	Traffic offices	5406.55	47.19	3.82
13.	Flight operations offices	3572.29	31.18	2.52
14.	Security office	9685.75	84.54	6.84
15.	Baggage & ticketing offices	6047.04	52.78	4.27
Total carbon footprint in CO_2e (tonnes)			**1235.73**	**100**

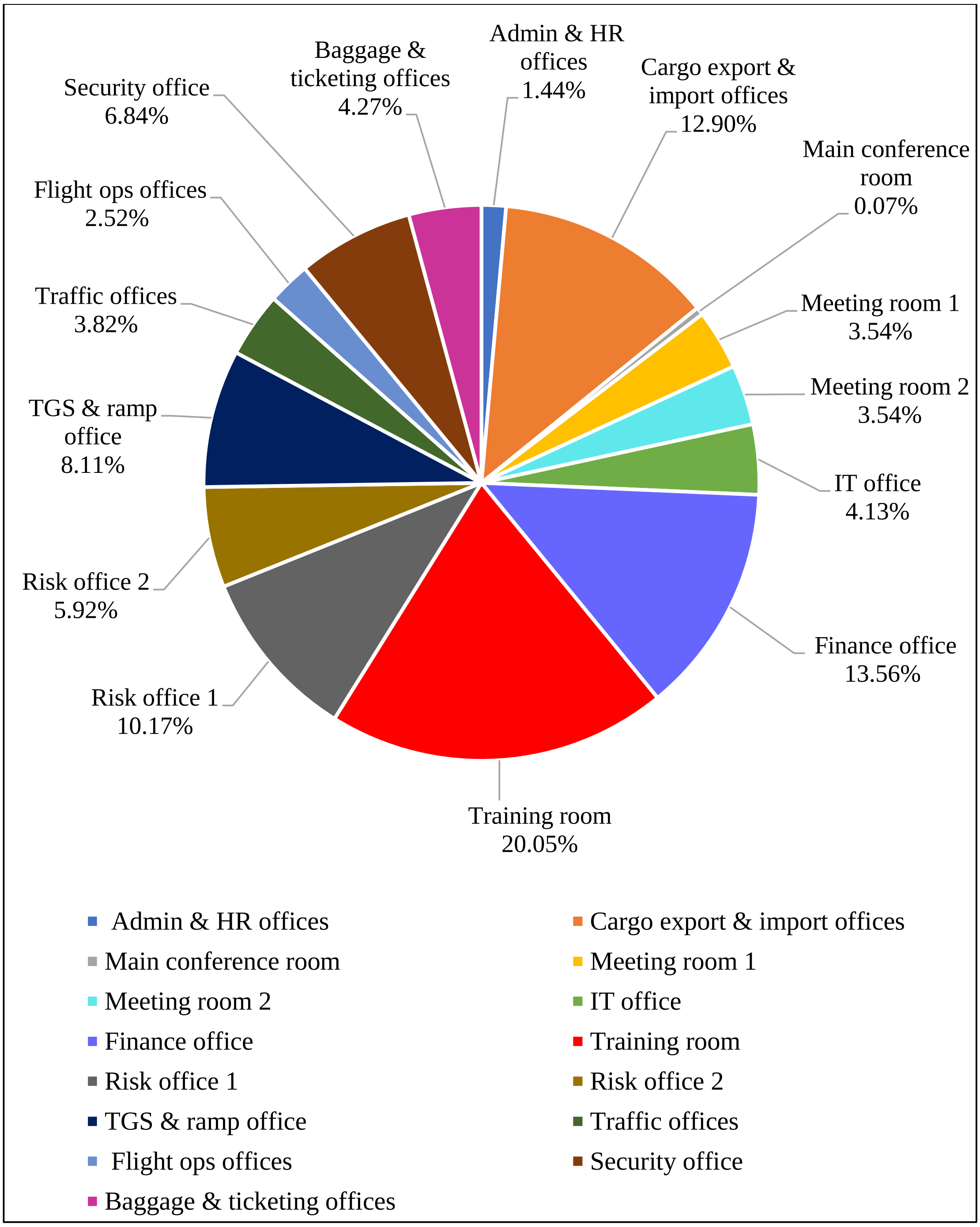

Figure 4.3: Annual CFP contribution from electricity consumed by office desktops

Annual carbon footprint share from desktops was further classified into the energy distribution shares over that period. It involved major energy sources of Pakistan which included renewable, thermal, hydro, and nuclear shares. Figure 4.4 depicts a detailed overview of the energy sources contributing to desktop emissions in which most of the contribution is provided by thermal sources, followed by hydro sources and least contribution by renewable energy sources. Energy source classification for carbon emissions has helped countries in more specific understanding of the environmental impact of each energy type, hence assisting strategic actions to increase reliance on cleaner, more sustainable energy sources (Slameršak et al., 2022).

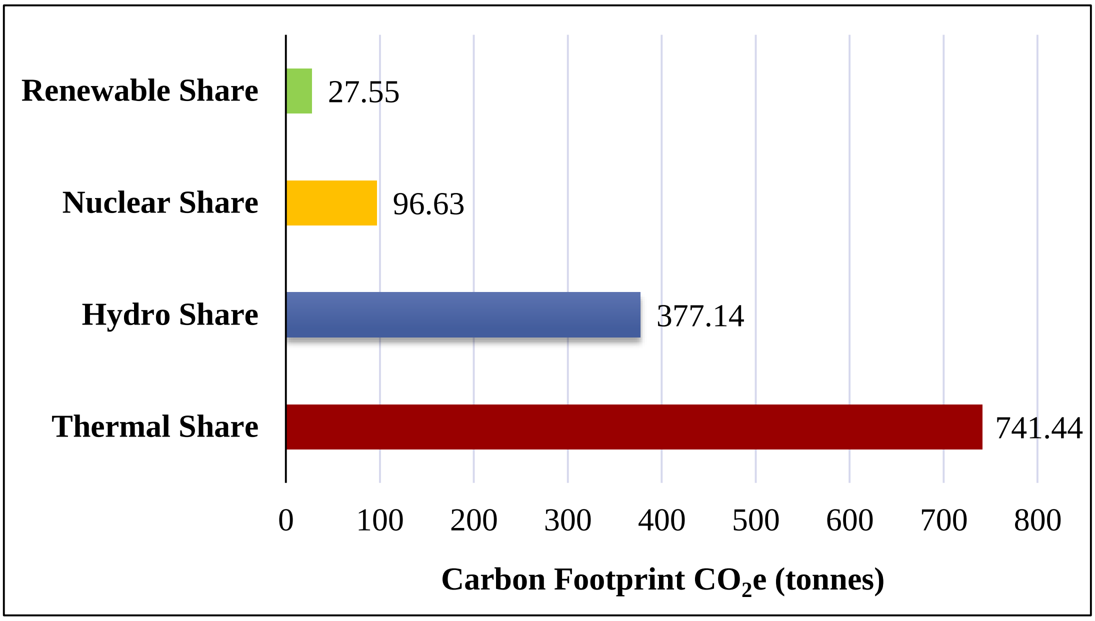

Figure 4.4: Energy distribution of annual desktop's electricity emissions

4.2.1.2 Annual electricity emissions from office printing devices

A detailed overview of annual activity data and associated emissions of 11 printing devices across several departments within the organizational framework, given in both units of energy consumption (kWh) and tonnes of CO_2 equivalent (CO_2e) has been depicted in Table 4.4.

Table 4.4: Breakdown of annual CFP from electricity consumed by printers

S.no	Emission sources	Annual activity data (kwh)	Annual emissions (thermal + hydro + nuclear + renewable)	
			CO_2e (tonnes)	% of total
1.	Admin & HR offices	118849.19	1037.35	7.27
2.	Cargo export & import offices	234850.17	2049.84	14.36
3.	IT office	112622.31	983.08	6.89
4.	Finance office	112966.02	986.66	6.91
5.	Training offices	137272.05	1198.15	8.39
6.	Risk offices	14403.74	125.72	10.17
7.	TGS & ramp offices	113192.87	987.98	6.92
8.	Flight operations offices	174579.47	1523.78	10.68
9.	Traffic offices	141507.69	1235.12	8.65
10.	Security office	183848.19	1604.68	11.24
11.	Baggage & ticketing offices	158285.33	1381.56	9.68
Total carbon footprint in CO_2e (tonnes)			**14272.13**	**100**

An annual carbon footprint emission of about 14272.13 CO_2e (tonnes) was calculated from electricity consumed by printing devices. Notably, the cargo export & import offices have a significant environmental impact, accounting for 14.36% of total emissions, followed closely by the security office at 11.24% and the flight operations offices at 10.68%. In this scenario, it was observed that printing devices of cargo offices were contributing to highest emissions because the substantial paperwork needed in shipping management, such as printing invoices, shipping labels, and documentation required to successfully handle the growing volume of logistical paperwork demanded a greater reliance on printing technologies. Furthermore, it was also noted thar the considerable contribution to carbon emissions by security offices was due to the frequent printing of various access control badges, identification cards, and incident reports required for regular and fast documentation. Thus, the necessity for immediate access to printed materials and security paperwork has proved to largely contribute to an increase in the demand for printing resources within office departments

(Łuszczyńska, 2022). Moreover, in the case of flight operations, it was noted that the constant need to print flight plans, weather reports, and operational papers important for real-time decision-making in aviation led to increased use of printers (Steinle, 2016). The aviation sector's reliance on contemporary printed materials has not only expanded the use of printers in several departments but has also resulted in an increase in emissions related to these operational demands (Fitouri-Trabelsi et al., 2013). In contrast, the admin & human resource offices, IT office, finance offices, workshop & ramp offices have lower emissions, ranging from 6.89 to 7.27%, indicating a more varied spectrum of carbon footprints across departments. The consumption of printing resources in the IT department was utilized for printing technical documentation and progress reports, whereas finance departments utilized them for the purpose of printing their financial statements and transaction records. However, admin & human resource offices mostly used printers to create recruitment brochures, employee contracts, and administrative paperwork required for human resource administration. The diverse printing requirements in IT, finance, and HR departments have corresponded to the various information and documentation requirements connected with their respective jobs and responsibilities (Krozer, 2017). The graphical distribution of annual carbon footprint produced by energy consumption from printing devices has been represented in Figure 4.5.

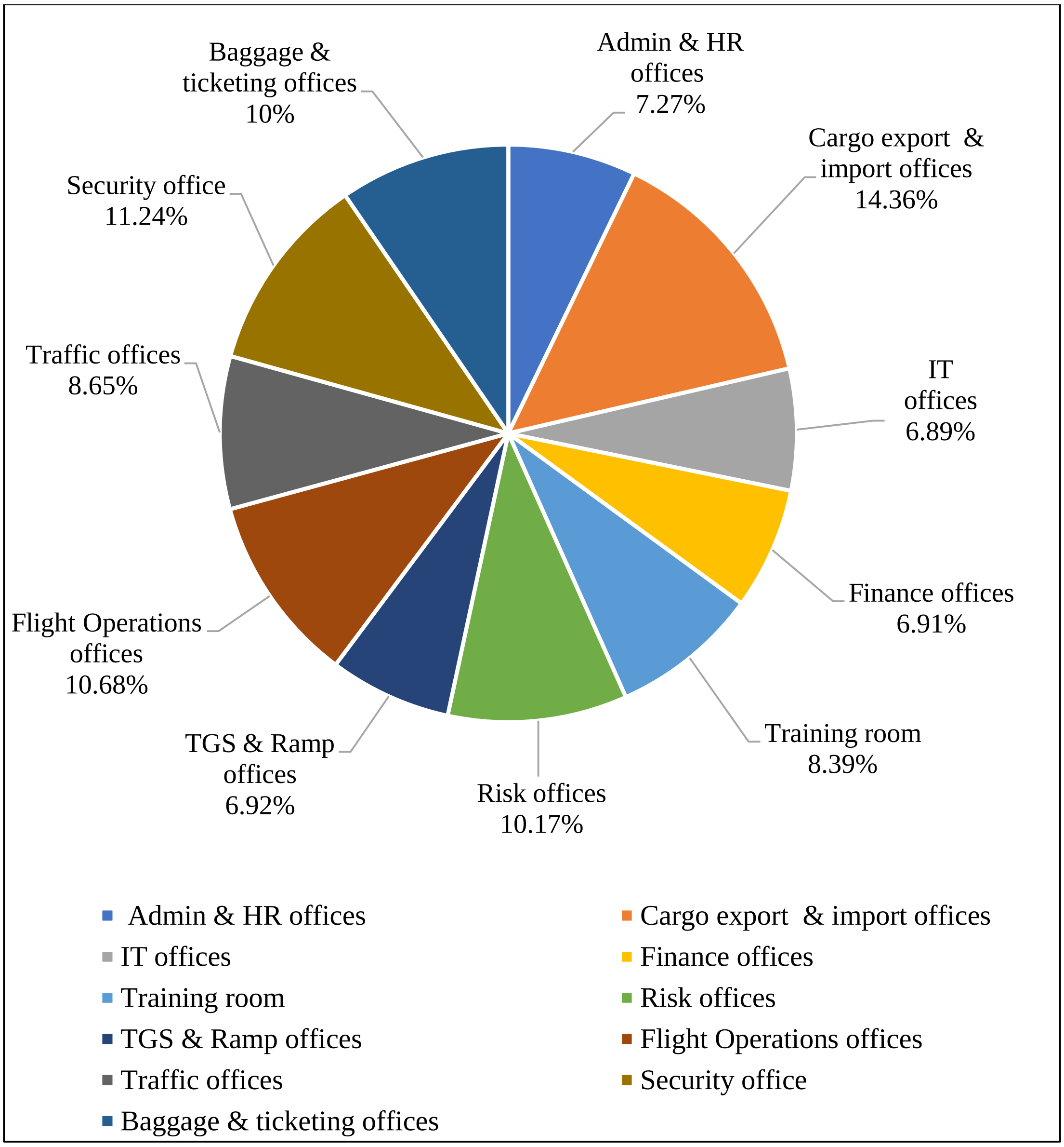

Figure 4.5: Annual CFP contribution from electricity consumed by office printers

A detailed overview of the energy shares contributing to annual emissions produced by electricity consumption of printing devices has been represented in Figure 4.6. It shows that most of the contribution is provided by thermal sources, followed by hydro sources and the least contribution by nuclear & renewable energy sources.

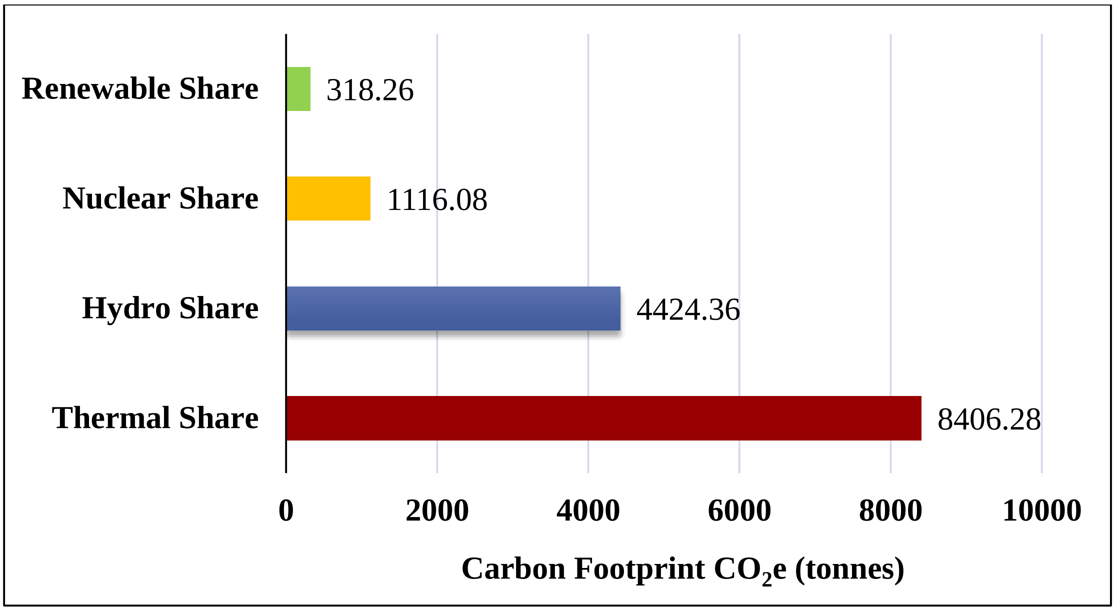

Figure 4.6: Energy distribution of annual printer's electricity emissions

4.2.1.3 Annual electricity emissions from office lightings

An annual carbon footprint emission of about 8.51 CO_2e (tonnes) was calculated from electricity consumed by operations of office lightings. The data presented in Table 4.5 has provided a detailed analysis of annual activity data and its associated emissions, measured in kilowatt-hours (kWh) of energy consumption and expressed in tonnes of CO_2 equivalent (CO_2e), across different departments within the organizational framework. As per the calculated emission results presented in Table 4.5, it became obvious that cargo export and import offices, along with the TGS workshop and ramp offices, have been categorized as major contributors to the total carbon footprint consuming substantial electricity at 3416.4 kWh and 3679.2 kWh, respectively. Both categories accounted for 24.68and 26.56% of total emissions, respectively, highlighting their significant impact on the organization's environmental footprint. The main reason for high emissions from these areas was the critical need for well-lit spaces to facilitate efficient day and night cargo operations, improve visibility, and ensure the safe handling and processing of goods. Adequate lighting in cargo offices was also mandatory for critical paperwork, document verification, and communication tasks, whereas brightly illuminated TGS mechanical workshop areas were critical for the precision and safety of various mechanical and manual activities of heavy and expensive aircraft operating equipment performed in these areas. Therefore, increased energy consumption from daily office equipment operations has proved to be the reason of high carbon emissions, resulting in an overall higher carbon footprint of organizations in various case studies (Khan & Siddiqui, 2017; Krozer, 2017; Chuang et al., 2018). Further analysis of the results discovered that the traffic and security offices have also produced significant contributions, accounting for about 13.63% and 13.87% of the total carbon footprint, respectively. The environmental impact of energy consumption by lighting is usually more pronounced in the regions where the energy grid is largely dependent on fossil fuels (Jenkins & Newborough, 2007). A case study also revealed that the duration of light usage also enhances its environmental impact, particularly in circumstances where the office operations are running around the clock (Charles et al., 2019; Rehmani et al., 2022). Some areas such as the training room and baggage & ticketing offices exhibited moderate levels of carbon footprint emissions, amounting to approximately 0.81 and 0.66 CO_2e tonnes, respectively. Furthermore, it was also noticed from the results that negligible number of annual emissions ranging from 0.005 to 0.35 CO_2e tonnes were also occurring from the admin & HR offices, main conference room, meeting rooms, IT offices, finance offices & kitchen rooms. Although these emissions were insignificant in terms of consumption, nonetheless they have possessed an important influence on the organization's overall emissions profile. The graphical distribution of annual carbon footprint produced by energy consumption from operations of office lighting has been represented in Figure 4.7. (Di Giacomo et al., 2017) has stated that carbon footprint of any organization is inextricably linked to the energy mix of the country in which it works. Keeping this in view, a detailed analysis of the energy shares contributing to annual emissions by electricity consumption of office lightings has also been represented in Figure 4.8, which demonstrates most of the energy contribution in the country is provided by thermal sources and the least contribution was provided by renewable sources.

Table 4.5: Breakdown of annual CFP from electricity consumed by office lightings

S.no	Emission source	Annual activity data (kwh)	Annual emissions (thermal + hydro + nuclear + renewable)	
			CO_2e (tonnes)	% of total
1.	Admin & HR offices	380.02	0.23	2.70
2.	Cargo export & import offices	3416.4	2.10	24.68
3.	Main conference room	8.42	0.005	0.06
4.	Meeting room 1	56.94	0.03	0.35
5.	Meeting room 2	95.41	0.05	0.59
6.	IT office	112.15	0.07	0.82
7.	Finance office	109.22	0.06	0.71
8.	Training room	1322.11	0.81	9.52
9.	Risk offices	200.45	0.12	1.41
10.	TGS & ramp offices	3679.2	2.26	26.56
11.	Flight operations offices	124.72	0.08	0.94
12.	Traffic offices	1892.16	1.16	13.63
13.	Security office	1993.08	1.18	13.87
14.	Baggage & ticketing offices	1081.72	0.66	7.76
15.	Kitchen room 1	126.34	0.09	1.06
16.	Kitchen room 2	460.72	0.39	4.58
Total carbon footprint in CO_2e (tonnes)			**8.51**	**100**

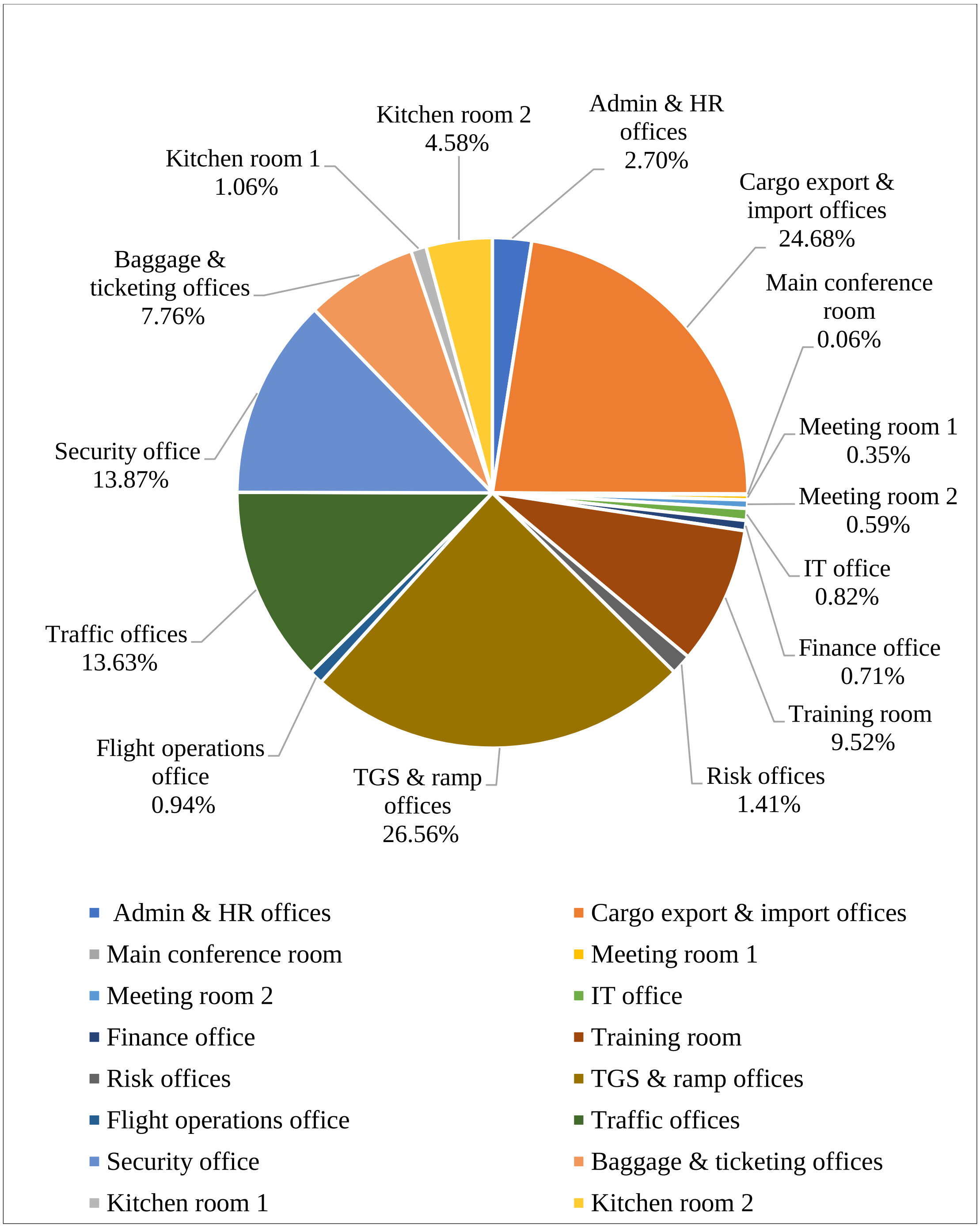

Figure 4.7: Annual CFP contribution from electricity consumed by office lights

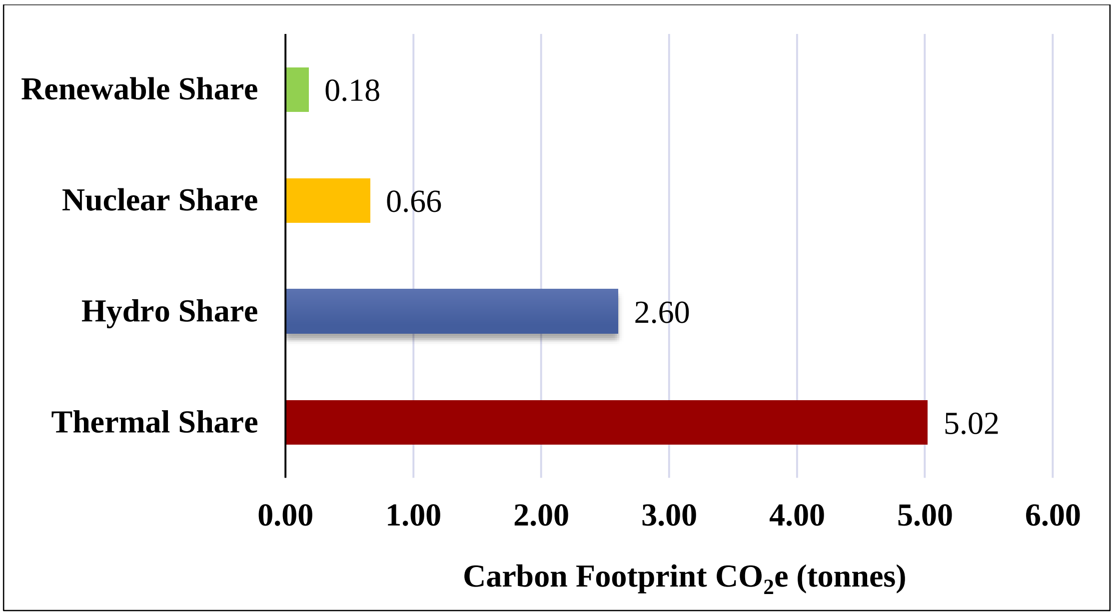

Figure 4.8: Energy distribution of annual office lighting's electricity emissions

4.2.1.4 Annual electricity emissions from office air conditioning

An annual carbon footprint emission of about 11.08 CO_2e (tonnes) was calculated from electricity consumed by operations of office air conditioners. Table 4.6 has provided a detailed analysis of annual activity data and its associated emissions of six air conditioners that were owned by the company, expressed in tonnes of CO_2 equivalent (CO_2e). Rest all the air conditioners in office spaces come under the jurisdiction of Pakistan Civil Aviation Authority (PCAA). Figure 4.9 depicts the annual carbon footprint resulting from energy consumption in air conditioning operations, providing a comprehensive graphical representation of the environmental impact associated with lighting practices within the organizational framework. It can be seen from the results that baggage & ticketing offices were among the key contributors, accounting for about 53.28% of total carbon footprint with annual emissions of 5.90 CO_2e (tonnes). Due to a great deal of foot traffic, continuous customer service, and functional demands, baggage and ticketing offices frequently use more air conditioning (Adisasmita, 2012). The widespread use of air conditioning during peak demand periods can put a significant strain on power grids. As a result, power plants are required to burn more fossil fuels to meet increased energy demands, thus causing increased emissions and putting additional strain on the environment (Wilkinson & Reed, 2006; Lee et al., 2019). On the other hand, the IT and risk offices also made significant contributions emitting about 31 tonnes of CO_2e collectively and accounting for at least 16.66% and

14.81% of total emissions, respectively. While other departments, such as admin & HR, main conference room, and flight operations emitted lower emissions comparatively as their combined impact proclaimed the organization's overall carbon footprint of 11.08 tonnes of CO_2e. (Ye et al., 2018) also concluded in his study results that the energy-intensive nature of air conditioning, particularly in large office environments has intensified the emissions associated with electricity consumption, making it a significant component of the company's environmental footprint, especially when refrigerants such as hydrofluorocarbons (HFCs) are used that has potent impact on global warming. A comprehensive breakdown has been presented in Figure 4.10 exhibiting a detailed analysis of energy shares contributing to annual emissions from electricity consumption of office air conditioning operations.

Table 4.6: Breakdown of annual CFP from electricity consumed by office air conditioning

S.no	Emission source	Annual activity data (kwh)	Annual emissions (thermal + hydro + nuclear + renewable)	
			CO_2e (tonnes)	% of total
1.	Admin & HR offices	4672.64	1.64	14.81
2.	Main conference room	789.82	0.03	0.26
3.	IT offices	5236.72	1.85	16.66
4.	Risk offices	4672.64	1.64	14.81
5.	Flight operations offices	787.23	0.02	0.18
6.	Baggage & ticketing offices	10215.36	5.90	53.28
Total carbon footprint in CO_2e (tonnes)			**11.08**	**100**

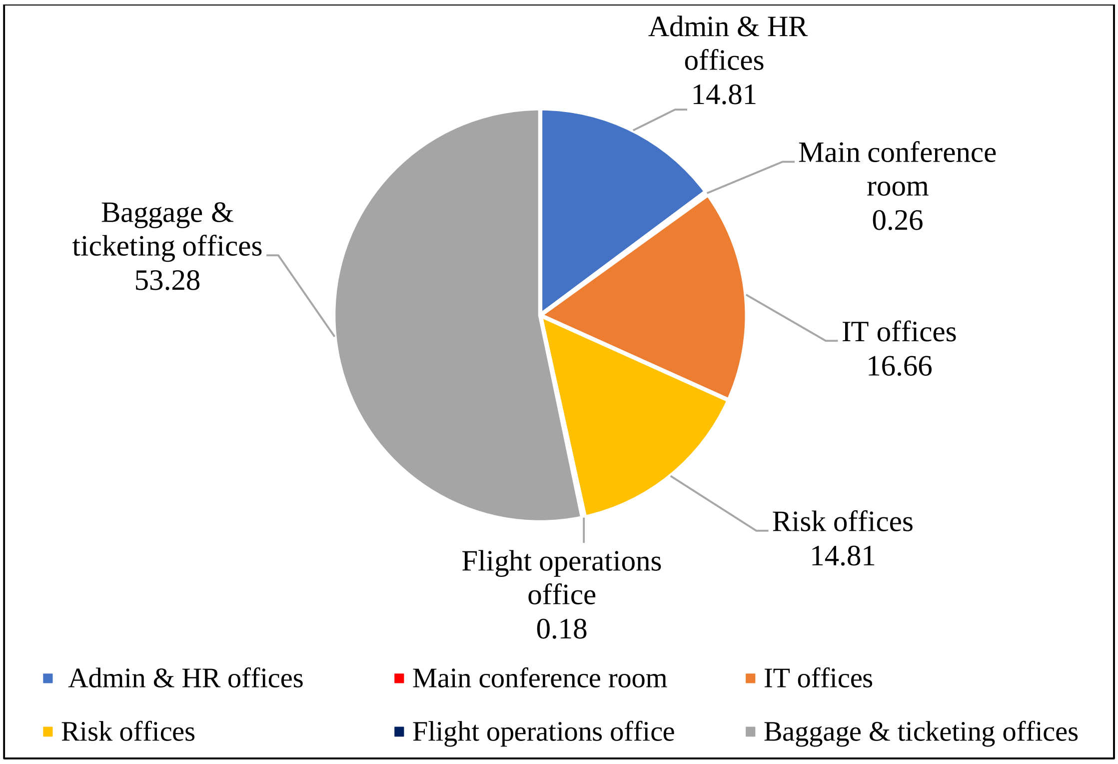

Figure 4.9: Annual CFP contribution from electricity consumed by office air conditioning

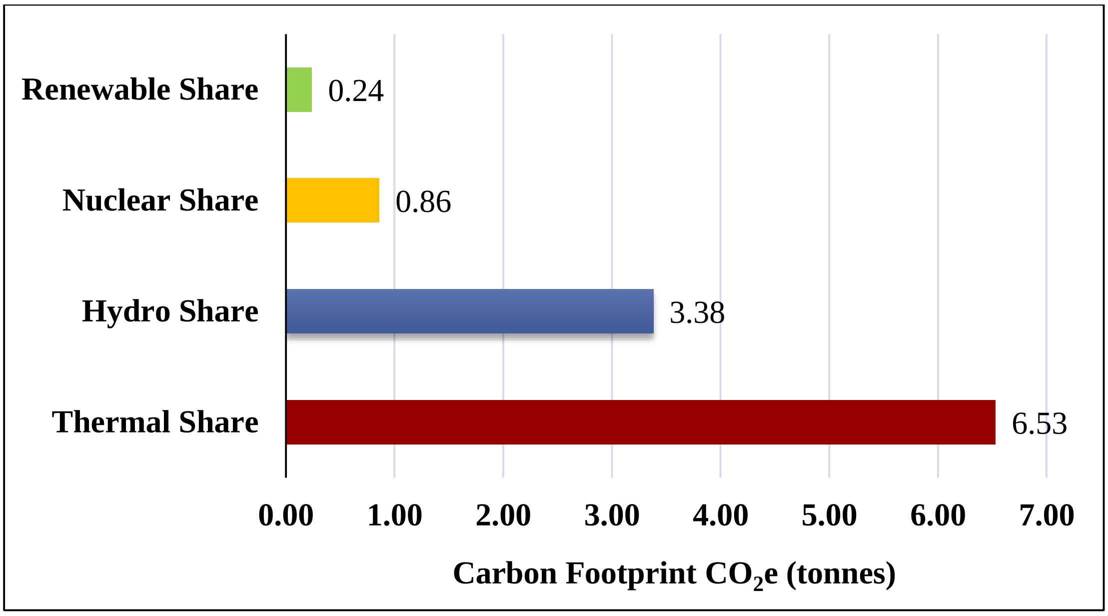

Figure 4.10: Energy distribution of annual office air conditioning's electricity emissions

4.2.1.5 Annual electricity emissions from office pantry operation

An annual carbon footprint emission of about 0.48 tonnes of CO_2e was calculated from electricity consumed by pantry operations. Table 4.7 has provided a detailed breakdown of the annual activity data and associated emissions from specific kitchen appliances classified as microwave and refrigerator in kitchen rooms 1 and 2. As per results, the annual activity data for the microwave in kitchen room 1 was 319.63 kWh, accounting for about 47.91% of the total emissions for this category. The reason for its high usage is because most of the staff frequently relied on this oven to warm up their meals and prepare tea, especially during the busy lunchtime rush. Figure 4.11 has depicted the annual carbon footprint resulting from energy consumption in pantry operations, providing a comprehensive graphical representation of the environmental impact associated with practices within the organizational framework. The microwave in kitchen room 2 has an annual activity data of 139.85 kWh, emitting about 0.09 tonnes of CO_2e and accounting for 18.75% of total emissions. On the contrary, this microwave has less activity data and usage as it was selectively used to warm up meals for guests, organizing occasional serving requests. With an annual activity data of 199.50 kWh, the small refrigerator in kitchen room 1 has contributed 0.16 tonnes of CO_2e, accounting for 33.33% of total emissions in this category. This fridge made a substantial contribution to the overall emissions because it was being used around the clock as storage solution for staff homemade meals, snacks for guests and other perishable items for easy access during work hours. A similar study was also conducted by (Tjandra et al., 2014) to calculate emissions from monthly operation of a small-scale organization in Singapore which showed that the pantry operation in office emitted about 55.63 CO_2e(kg) that contributed about 2.41 % of total emissions of the organization. A comprehensive breakdown has been presented in Figure 4.12 exhibiting a detailed analysis of energy shares contributing to annual emissions from electricity consumption of office pantry operations.

Table 4.7: Breakdown of annual CFP from electricity consumed by office pantry

S.no	Category	Emission source	Annual activity data (kwh)	Annual emissions (thermal + hydro + nuclear + renewable)	
				CO_2e (tonnes)	% of total
1.	Microwave	Kitchen Room 1	319.63	0.23	47.91
		Kitchen Room 2	139.85	0.09	18.75
2.	Refrigerator	Kitchen Room 1	199.50	0.16	33.33
Total carbon footprint in CO_2e (tonnes)				0.48	100

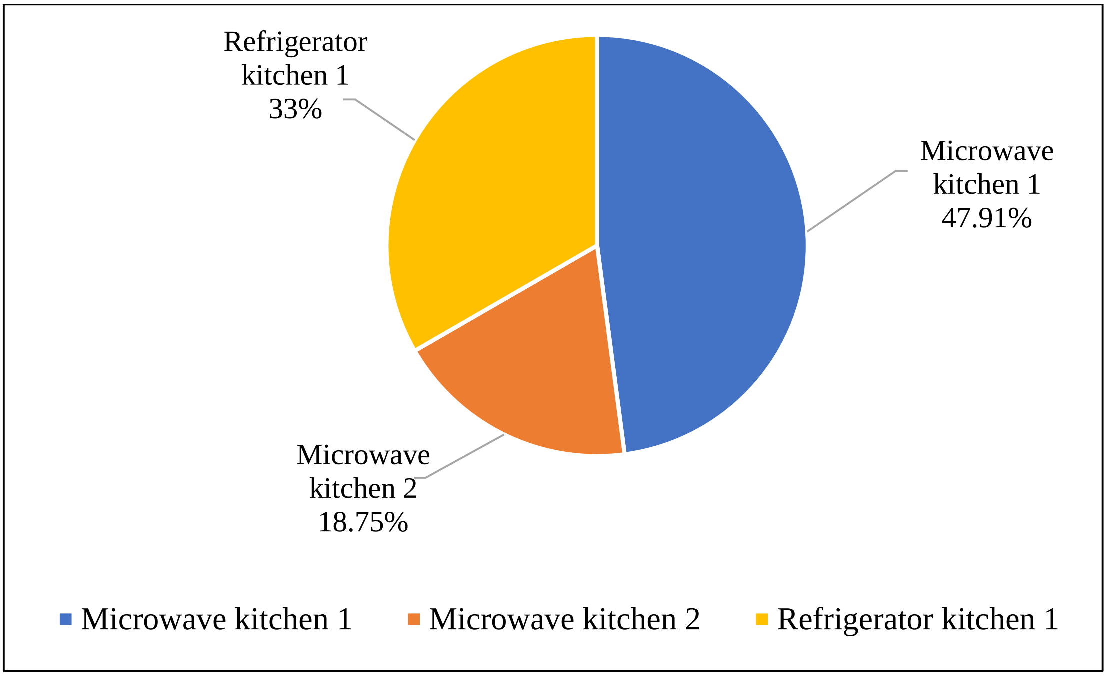

Figure 4.11: Annual CFP contribution from electricity consumed by office pantry

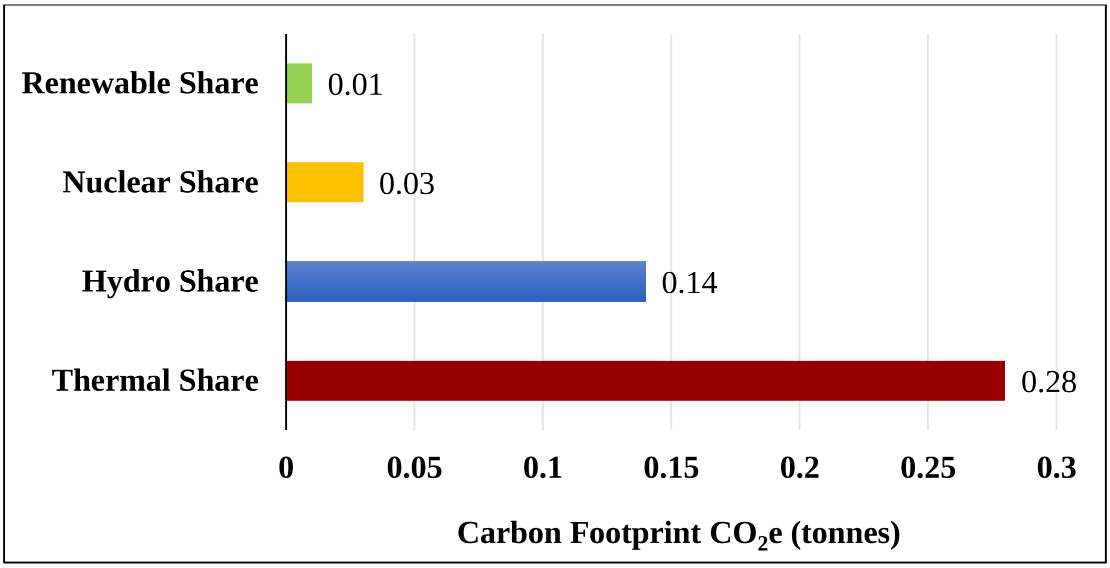

Figure 4.12: Energy distribution of annual office pantry's electricity emissions

4.2.2 Breakdown of emissions from fuel consumption

To assess emissions from fuel consumption, a complete analysis was performed, categorizing the sources into three major components. These included the administrative vehicles operations, staff commuting and airport ramp vehicles operation. All necessary data was collected to measure the carbon footprint from fuel consumption using the methodology steps mentioned in Figure 3.5.

4.2.2.1 Emissions from fuel consumption of admin vehicles and staff commuting

An annual carbon footprint emission of about 30.11 tonnes of CO_2e was calculated from fuel (petrol & diesel) consumption by office staff transportation & admin operation vehicles. Most of the carbon footprint emissions are caused by the operation of ground support equipment that typically rely on internal combustion engines propelled by conventional fuels (Yu et al., 2021). In addition to this, the transportation mode chosen for airport staff also exert a discernible impact on the emissions profile of an office environment (Tjandra et al., 2014). Consequently, staff transportation has largely affected an office's emissions, especially if an organization provides its own means of staff transportation (such as a private bus for staff commuting). From the detailed breakdown, it was obvious that the staff coaster bus used for commuting emerged as the leading contributor, consuming around 1,213.42 gallons of diesel fuel, and emitting approximately 11.12 tonnes of CO_2e annually. This significant figure accounted for 36.93% of total carbon footprint emissions, highlighting its significant impact on the overall annual carbon footprint. In general, high frequency of use for day and night shifts of employees combined with the diesel fuel type has magnified its influence on the total carbon footprint (Vásquez et al., 2015). A similar study was also conducted by (Mendoza-Flores et al., 2019) to measure and evaluate the environmental impact of the public university campus in Mexico, and the results of emissions analysis revealed that commuting contributed to 51% of emissions. Additional modes of transportation for passengers travelling between airport terminals and aircraft including the passenger bus A, with a diesel consumption of 31.61 gallons has emitted approximately 0.29 tonnes of CO_2e. While passenger bus B, with a diesel consumption of 46.87 gallons emitted approximately 0.43 tonnes of CO_2e, also made significant contributions. Since diesel has high emission factor & high energy density as compared to petrol, therefore it is accountable for elevated carbon emissions in the environment (IPCC, 2006; International Energy Agency (IEA), 2020); Cabrera & Melo de Sousa, 2022). Furthermore, it can be seen from the results that vehicles for daily administrative operation such as the Suzuki pickup A, with petrol consumption of 839.58 gallons emitting about 9.74 tonnes CO_2e, and the Suzuki pickup B, with petrol consumption of 342.21 gallons emitting about 3.97 tonnes CO_2e has contributed about 32.33% and 13.18% respectively. A comprehensive breakdown has been presented in Figure 4.13 exhibiting a detailed analysis of annual carbon footprint emissions from fuel consumption of admin vehicles and staff transportation. Although individual vehicle emissions remain lower, it was observed that vehicles such as the Suzuki Bolan A, B, and C, as well as the stavik car contributed substantially about 13% to the overall carbon footprint. This highlighted the diverse impact of various vehicle types on emissions, emphasizing the importance of taking the total effect into account when assessing the environmental footprint of the transportation fleet (Bao et al., 2023). Table 4.8 categorizes all fuel consumption emissions from office staff transport and administrative vehicles, as well as annual activity data in unit of fuel consumed in gallons, showing its annual carbon footprint contribution.

Table 4.8: Breakdown of annual CFP from fuel consumed by admin & staff transportation

S.no	Emission source	Fuel type	Annual activity data (gallons)	Annual emissions	
				CO_2 (tonnes)	% of total
1.	Passenger bus A	Diesel	31.61	0.29	0.99
2.	Passenger bus B		46.87	0.43	1.44
3.	Staff coaster		1213.42	11.12	36.93
4.	Suzuki pickup A	Petrol	839.58	9.74	32.33
5.	Suzuki pickup B		342.21	3.97	13.18
6.	Suzuki Bolan A		85.34	0.99	3.31
7.	Suzuki Bolan B		143.96	1.67	5.54
8.	Suzuki Bolan C		117.23	1.36	4.53
9.	Stavik car		45.68	0.53	1.75
Total carbon footprint in CO_2e (tonnes)				**30.11**	**100**

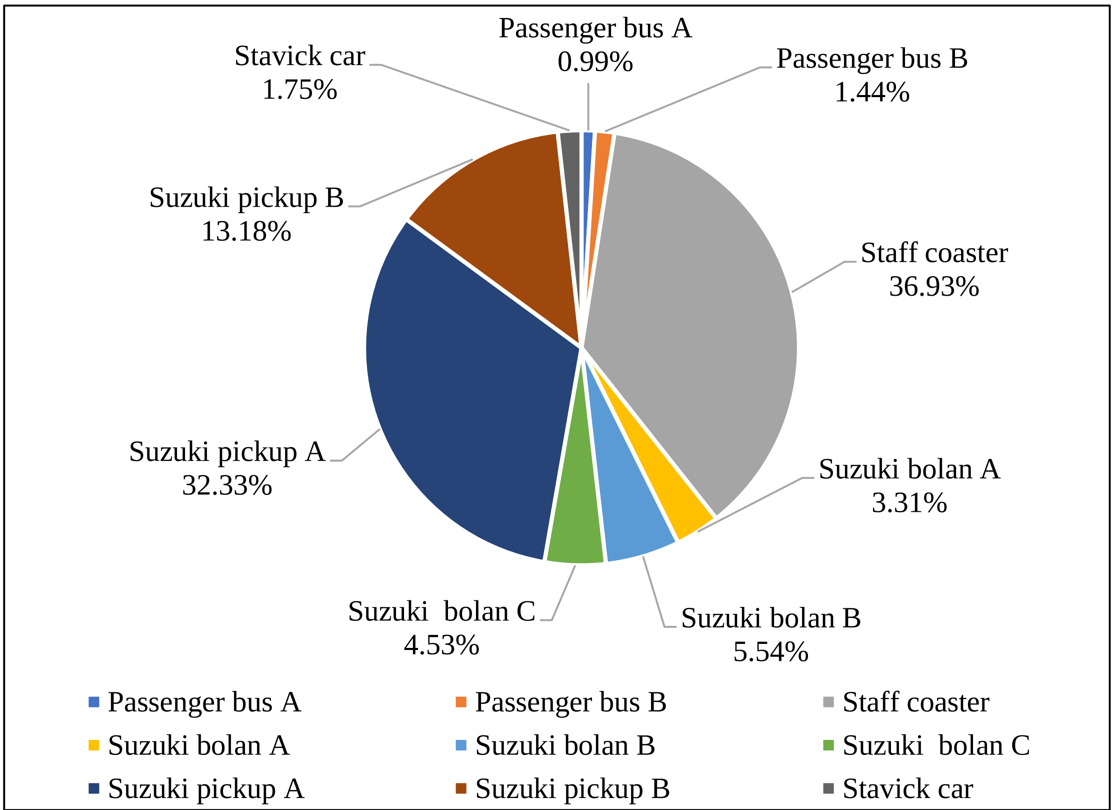

Figure 4.13: Annual CFP contribution from fuel consumed by staff commuting & admin vehicles

4.2.2.2 Emissions from fuel consumption of airport ramp vehicles operation

Approximately 4% to 7% of fuel from a typical airplane is estimated to be consumed during ground support operations on airport tarmac (Ahmadi & Akgunduz, 2023). In the recent years, the greenhouse gas emissions by the airport operations have not only contributed to global warming but made an impact on the health of local communities living near airports (Ahmadi & Akgunduz, 2023). Table 4.9 has represented the annual activity data and associated emissions for different airport ground supporting vehicles withing the organizational framework. According to recent research, logistical supply chains account for about 10% of global CO_2 emissions (Carli et al., 2020).The significant amount of energy required for heating, cooling, lighting, and material handling equipment (MHE) in warehouses accounts for approximately 20% of total logistics costs (Fuc et al., 2017). From the results mentioned in Table 4.9, it was concluded that fork lifters which were being utilized in the airport cargo warehouse for movement & handling of goods has emitted the highest CO_2e showing diesel consumption of 173062.57 gallons and eventually resulting in 1587.73 tonnes of CO_2e, thus accounting for 19.83% of total carbon footprint. An air conditioning van (AC van) used to provide conditioned air to the on-ground aircraft has been accountable for about 10-20% of the total emissions during ground servicing (Baxter et al., 2018). Even when aircraft own engines are not running, the AC van must maintain a comfortable environment inside the aircraft for boarding & preflight operations, thus consuming a large amount of fuel (Miedico, 2018; Greer et al., 2021). In current study, Results also showed that AC van (air conditioning van) has also made significant contributions emitting about 1133.60 tonnes of CO_2e collectively and accounting for at least 14.16% of total emissions. Furthermore, it was also observed that aircraft towing tractors (tow tractors) has emitted around 980.78 tonnes of CO_2e by consumption of 107526.97 gallons of diesel during its year-round operation, contributing to about 12.5% of the total emissions. Typically, diesel-powered engines of towing tractors have possessed the torque and power output required to move large loads efficiently, making them suitable for the demanding task of maneuvering aircraft on airport tarmacs. The high fuel consumption is requirement for the significant power required to effectively tow and position aircraft during ground operations (Gao et al., 2023). During the aircraft turnaround process of aircraft, ground power unit (GPU) is nonetheless a leading source of emission responsible for supplying external electric power to the aircraft prior to take off (Padhra, 2018).These are used on daily basis to provide electrical power to the aircraft until the aircraft service is completed (McNeely, 1994). As per Table 4.9, a large amount of fuel i.e., approximately about 110200.09 gallons of diesel was consumed to carry out yearly aircraft operations. This amount of diesel consumption emitted about 1011.01 tonnes of CO_2e and contributed about 12.61% of the total emissions. Likewise, for the purpose of lifting and transporting large cargo containers, pallet, and passenger's baggage to and from the aircraft cargo hold or main deck, deck loaders are specialized vehicles that are equipped with aircraft (Fuc et al., 2016; Ziółkowski et al., 2022). These vehicles with daily high frequency utilization on annual basis emitted around 1072 tonnes of CO_2e with 116848 gallons of diesel consumed, resulting in 13.39% of total carbon footprint. Likewise, passenger steps utilized for facilitating the passenger's boarding or disembarking from the aircraft, exhibited the consumption of about 95421.87 gallons of diesel fuel on an annual basis and contributing to about 10.93% of annual carbon footprint. In addition to the passengers' steps, ambulifters are equipped with the aircraft to ensure the efficient and safe boarding of passengers with medical condition or reduced mobility (Testa et al., 2014). According to the results, the yearly operation of ambulifters emitted around 687.98 tonnes of CO_2e, thus accounting for 8.59% of total footprint. It can also be seen from the results that lower lobe loaders and conveyer belts utilized for the servicing of the aircraft emitted nearly same amount of CO_2 emissions, contributing about 1.85% of total emissions. These belts have the potential to reduce energy consumption and emissions related to manual transportation by optimizing logistical operations (Skryabin, 2021). However, if conveyor belts are not properly maintained or managed, they may result in massive environmental pollution due to wear and tear or improper disposal at the end of their lifespan (Wang & Jia, 2012). On the contrary, it was observed that other aircraft operating equipment such as flush cart, water cart and baggage tractors collectively made a small contribution of about 4.53% to the overall carbon footprint. Consequently, the above-mentioned values added up to a total carbon footprint of 8006.73 tonnes CO_2e from fuel consumption of airport ramp vehicles under organization's context, demonstrating the diverse impact of ground service vehicles on the company's carbon footprint profile. Figure 4.14 has depicted the annual carbon footprint resulting from fuel consumption by aircraft ramp equipment, providing a comprehensive graphical representation of the environmental impact associated with practices within the organizational framework.

Table 4.9: Breakdown of annual CFP from fuel consumed by airport ramp vehicles

S.no	Emission source	Fuel type	Annual activity data (gallons)	Annual emissions	
				CO_2e (tonnes)	% of total
1.	Tow tractors	Diesel	107526.97	980.78	12.25
2.	Lower lobe loaders		16125.46	147.94	1.85
3.	Deck loaders		116848	1072	13.39
4.	Passenger steps		95421.87	875.43	10.93
5.	Baggage tractors		26198.15	240.35	3.00
6.	Ground power unit		110200.09	1011.01	12.61
7.	AC van		123562.4	1133.6	14.16
8.	Water cart		1704.76	15.65	0.20
9.	Flush cart		11600.87	106.43	1.33
10.	Conveyer belts		16254.08	149.12	1.86
11.	Ambulifter		74989.82	687.98	8.59
12.	Forklifts		173062.57	1587.73	19.83
Total carbon footprint in CO_2e (tonnes)				**8006.73**	**100**

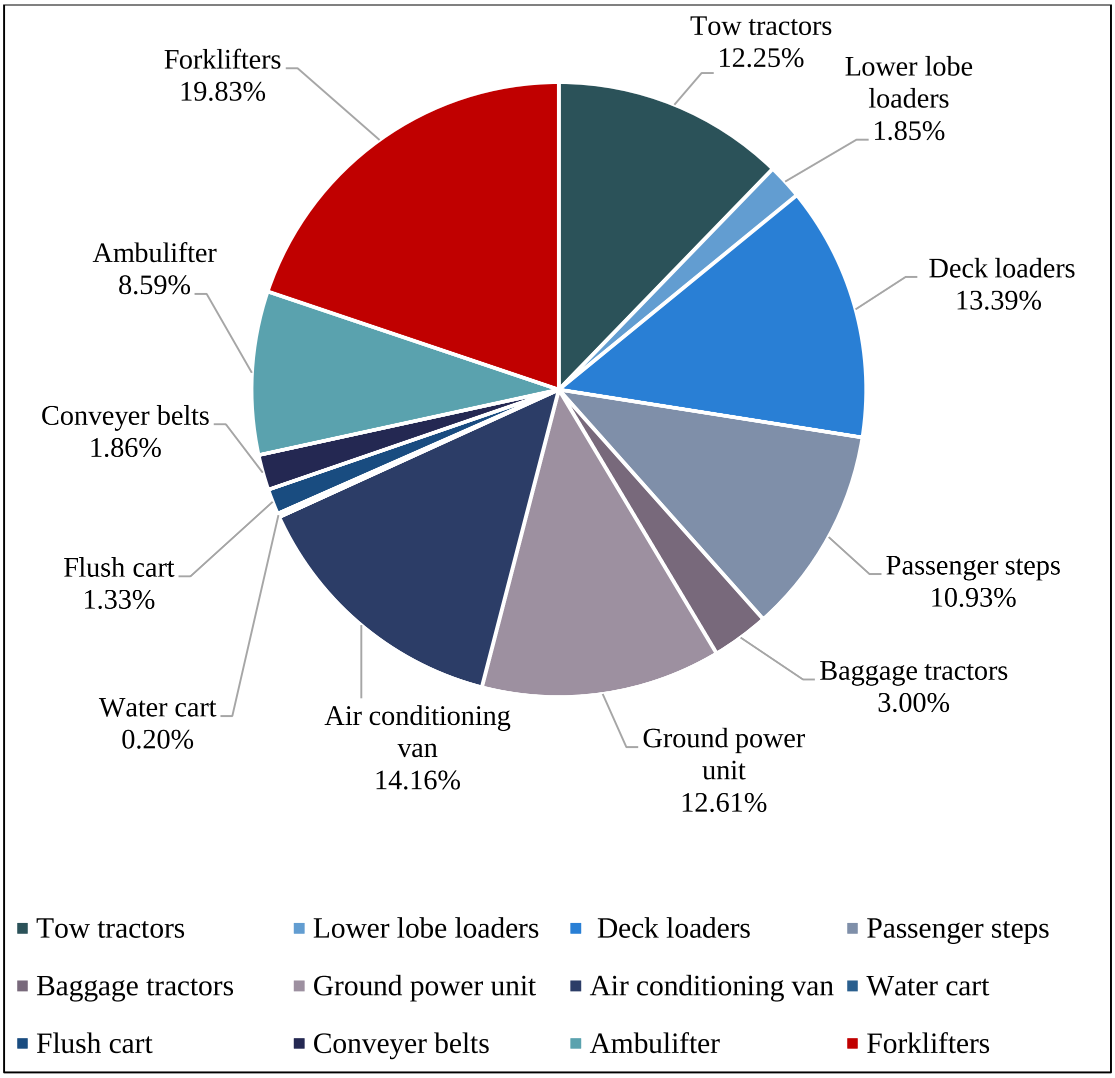

Figure 4.14: Annual CFP contribution from fuel consumed by aircraft ramp operating vehicles

4.2.3 Breakdown of emissions from paper consumption

To assess emissions from paper consumption, a complete analysis was performed and key areas as emission sources were identified. All necessary data was collected to measure the carbon footprint from paper consumption using the steps for carbon footprint calculation as mentioned in Figure 3.6. The total carbon footprint from annual paper consumption of office operation is 1078.21 tonnes of CO_2e. (Reyes, 2013) also conducted a case study for carbon footprint calculation of a public university in Philippines that depicted an annual emission of 2150.23 metric tonnes of CO_2e for consumption of 159.3 metric tonnes of paper using the EPA emission factor for office paper (virgin paper). The breakdown of annual carbon footprint from paper consumption based on the emission sources has been explained in Table 4.10. From this detailed breakdown, it can be seen that more than half of the emissions were emitted from cargo export and import offices (474.05 tonnes of CO_2e, 43.94%); with TGS and ramp offices contributing to the second highest emissions (176.4 tonnes of CO_2e, 16.35%). In case of cargo export & import offices, the complex nature of worldwide trade and transportation has always required a thorough paper trail to assure regulatory compliance, promote efficient cargo handling, and properly trace shipments (Vega, 2008). Furthermore, cargo offices used to frequently interact with a wide range of parties, such as customs officials, shipping firms, and clients, enhancing the requirement for significant paperwork (Dettmer et al., 2014). Emission from admin & human resource offices ranked the third-highest emitting about 112.08 tonnes of CO_2e and contributing nearly 10.39% to overall footprint. Furthermore, an annual paper consumption of 172.08 kgs was shown by traffic offices that produced about 66.44 tonnes of CO_2e, contributing to 6.16% of total annual emissions. Annual emissions from flight operations offices due to high amount of printing of flight plans, operational manuals, crew briefings and communication logs was also estimated, resulting in 84.53 tonnes of CO_2e and accounting for about 7.83% of total emissions. In addition to this, the need for documentation, as well as the issuing of paper tickets, boarding permits, and baggage tags, was shown to participate significantly to the high paper consumption at baggage and ticketing offices (Adisasmita, 2012). Almost 44.10 tonnes of CO_2e were emitted by these offices contributing about 4.09% to total emissions. The operation of printers and copiers within office environment consume paper and energy in large amounts, thus contributing indirectly to CO_2 emissions (Fouladvand et al., 2023). Risk and security offices each generated roughly 1.70% of total emissions, resulting in an annual output of 18.37 tonnes of carbon dioxide equivalent. IT offices have generated the least number of emissions since the majority of their work is done using the web, thus accounting for only 1.19% of total emissions from office activities. The use of paper in printing operations has always showed a variety of environmental implications, most notably in terms of carbon emissions (Doğan et al., 2022).

Table 4.9: Breakdown of annual CFP from paper consumed by offices

S.no	Emission sources	Annual activity data (kg)	Annual emissions	
			CO_2e (tonnes)	% of total
1.	Admin & HR offices	290.28	112.08	10.39
2.	Cargo export & import offices	1230	474.05	43.94
3.	IT office	33.30	12.86	1.19
4.	Finance office	76.14	29.40	2.73
5.	Training room	109.45	42.26	3.92
6.	Risk offices	47.58	18.37	1.70
7.	TGS & ramp offices	456.88	176.40	16.35
8.	Flight operations offices	218.93	84.53	7.83
9.	Traffic offices	172.08	66.44	6.16
10.	Security office	47.60	18.38	1.70
11.	Baggage & ticketing offices	114.21	44.10	4.09
Total carbon footprint in CO_2e (tonnes)			**1078.21**	100

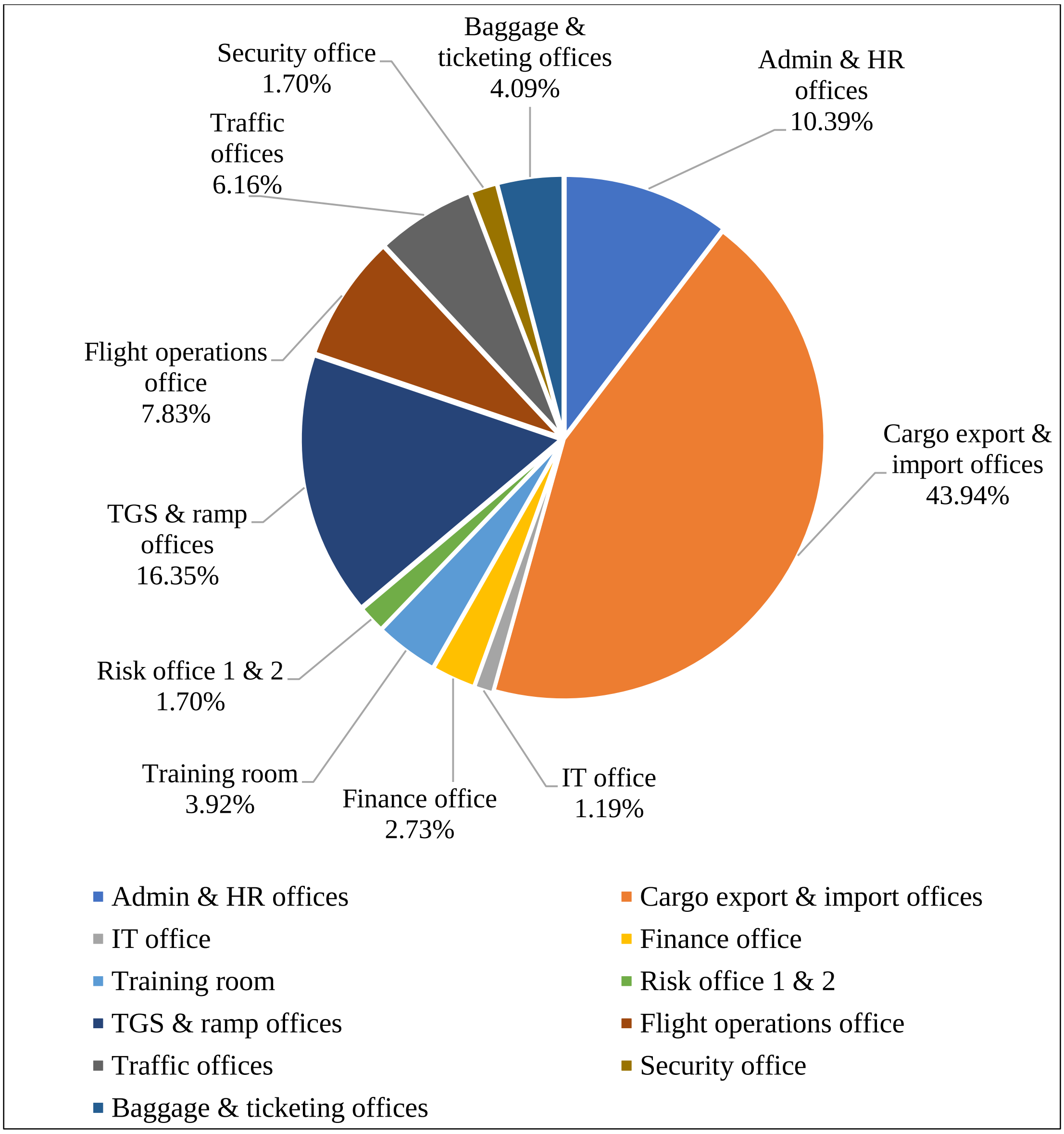

Figure 4.15: Annual CFP contribution from paper consumption by offices

4.3 Risk assessment based on carbon footprint emissions

According to methodology steps designed in Figure 3.1, the next step after carbon footprint calculation was to conduct risk assessment based on emission results. Research studies have also showed that comprehensive examination of the risks associated with carbon emissions has helped many international companies by receiving insights into the possible consequences of legislative changes, carbon pricing schemes, and growing consumer expectations time to time (Dalezios, 2017; Trzeciak, 2021; Brock et al., 2021; Stefana et al., 2022). Management of these elements have enabled worldwide corporations to not only reduce risks, but also focus on opportunities for innovation and long-term success in a changing business environment (Dalezios, 2017). Hence, for the purpose of attaining constructive and reliable results from current study, the risk assessment was carried out following two different approaches which are named as under:

i. Conventional risk matrix technique
ii. Fuzzy risk assessment model

4.3.1 Risk assessment using conventional risk matrix

Global businesses have come under heightened scrutiny since climate change issues and regulatory demands have expanded in recent years (Lee et al., 2021). Assessing the risks associated with carbon emissions allows organizations to anticipate the effects of legislative changes, carbon pricing, and changing customer preferences. Plus, it enables businesses to discover operational inefficiencies, possible supply chain disruptions, and reputational concerns associated with high carbon intensity on a global level (Hanafiah et al., 2022). This risk quantification method has involved a structured approach in assigning figures to various characteristics of identified emission sources. Using this approach, various statistical methodologies, historical data, and some prediction models have also been utilized by experts using extensive literature review to quantify the likelihood and severity of each identified risk factor. To achieve the likelihood of the occurrence and severity of each identified emission risk, all expert persons presented their views on the likelihood of occurrence and the severity of the risk. Likelihood value for each emission source was determined using Table 3.1. Severity value for each emission source was assigned using Table 3.2. The risk was calculated using the product of likelihood and severity as mentioned in Eq 3.7. The risk labels have been defined in Table 3.3. Table 4.11 has presented the detailed risk assessment results for each emission source with the help of risk assessment matrix based on carbon emission values as mentioned in Figure 3.7. From the risk assessment results, it was seen that carbon footprint emissions from printing equipment operation have been ranked as first, thus posing an intolerable risk factor of 25. Since the printing devices were the source of highest carbon footprint production among all other sources, therefore they possess a major threat on environment based on their frequent utility for daily operations (Mendes et al., 2017). Emissions from ramp vehicles were ranked second showing an intolerable risk factor of 20. Since ramp vehicles were the second largest source of carbon footprint generation among all emission sources, they pose a serious environmental risk mainly caused by diesel consumption during its regular business activities, highlighting the importance of strategic mitigation actions in this critical category (Valenti et al., 2019; Bao et al., 2023). Emissions from both desktop operation and paper consumption were ranked third exhibiting a significant risk rating of 15. The increased use of desktop computers and paper in the workplace has not only added to a significant carbon footprint, but also raised the risk factor owing to their prevalent and frequent use for daily office work (Reyes, 2013). With a likelihood rating of 'probable' and severity rating of 'moderate', the emissions from air conditioners were ranked as fourth showing tolerable risk rating of 8. The carbon footprint from air conditioners has been considered acceptable due to their limited consumption and confined deployment by the organization inside specific regions in workplaces, reducing the total annual risk associated with its environmental effect. Furthermore, the carbon footprint emissions from office lightings, microwave and refrigerator were ranked as fifth, sixth and seventh respectively. This numerical method of risk rating has helped in risk ranking based on their quantitative significance (Haq et al., 2022). Many organizations have implemented this technique to rank and prioritize their risks based on their likelihood and potential effects that has helped them in effective resource allocation and targeted mitigation actions (Dalezios, 2017; Idrees & Batool, 2020). Furthermore, proactive actions by companies can also be taken to cut carbon emissions, improve sustainability practices and align with major environmental objectives by including carbon footprint risk assessment into strategic planning, assuring long-term viability in a shifting business context (Vora et al., 2021). However, various case studies have also revealed that the conventional risk matrix method contain some uncertainty factor owing to a variety of causes, including subjective judgement in assigning likelihood and severity ratings, the dynamic nature of risks, changing environmental circumstances, and the inherent challenges in predicting and quantifying the impact of specific risks (Shakil et al., 2023). Similarly, diverse opinions among stakeholders and evolving information can also cause ambiguity regarding the risk assessment process, requiring continuous evaluation and revision of risk assessments (Hatefi et al., 2019).

Table 4.10: Conventional risk assessment method

S.	Office emissions	Annual carbon footprint CO_2e (tonnes)	Likelihood (L)	Severity (S)	Risk (R)	Risk rank	Risk category
1.	Desktops	1235.73	5	3	15	3	Significant
2.	Printing devices	14272.13	5	5	25	1	Intolerable
3.	Office lightings	8.51	5	1	5	5	Tolerable
4.	Air conditioners	11.08	4	2	8	4	Tolerable
5.	Microwaves	0.32	4	1	4	6	Insignificant
6.	Refrigerator	0.16	3	1	3	7	Insignificant
7.	Paper consumption	1078.21	5	3	15	3	Significant
8.	Ramp vehicles	8006.73	5	4	20	2	Intolerable
9.	Admin vehicles and staff commuting	30.11	3	2	6	5	Tolerable

4.3.2 Risk assessment using Fuzzy logic risk model

(Zadeh, 1965) pioneered the use of fuzzy set theory to replicate the subjective and intellectual thought processes of humans in 1965. Membership functions and a set of criteria transform language concepts to numerical values, allowing probability-based decision-making to be used. It is defined by a set of membership functions with values ranging from 0 to 1. A zero represents an event that has no probability of occurring, a 0.5 represents an event that has a 50% chance of occurring, and a 1 represents an event that will undoubtedly occur. According to (Nieto-Morote & Ruz-Vila, 2011), fuzzy risk evaluation systems follow the following rules: (i) specifying the parameters, (ii) constructing the fuzzy inference, and (iii) defuzzification. Fuzzy logic can describe complicated nonlinear functions, is adaptable and tolerant of inaccurate input, is based on natural language, can be developed using normal control techniques, and is based on natural language (Fouladgar et al., 2012). To achieve constructive risk assessment, a panel of 5 subject experts were invited to assess the likelihood (L) and severity (S) of identified risks influencing carbon emissions. Each participant was questioned individually, allowing them to seek clarity, ask questions, and contribute insights into the major risks under discussion. By integrating the literature review with experience and opinions of experts from diverse areas, this technique ensured a complete and comprehensive risk assessment. After the collection of "L" and "S" values from all experts, the fuzzy logic model was used to calculate the mean risk level for all emission sources. After collection of necessary information, a category was identified for both likelihood and severity using the scale shown in Tables 3.5 and 3.6, where 1 represents the lowest level and 5 represents the most. The risk rating was generated by combining the category information in the two columns or by assigning weights to the categories and calculating the product of the likelihood and impact weights (Susanto & Mulyono, 2018). (Sharma and Goyal, 2019) has outlined the following steps to modelling a fuzzy inference system:

a. The principal determinants or indicators of the dependent variable are independent variables.
b. Fuzzy sets are formed for independent and dependent variables. Rather than numerical numbers, these specify a variable in spoken language. The membership function specifies how realistically each variable is a member of a specified fuzzy set.
c. The fuzzy inference model comprises of in-built rules.
d. Independent variables and inference rules are employed to generate the fuzzy output set for the dependent variable. After defuzzification, a number denotes the fuzzy output set.

The fuzzy logic toolbox in MATLAB was used to create the model for risk assessment in the following phases, which were based on the fuzzy logic approach literature and MathWorks guidelines:

1. Create and declare variables for input and output. Figure 4.16 depicts the link between the inputs, impact, and likelihood, and the output risk level. The experts used the inputs as criteria to rank the severity of each danger.

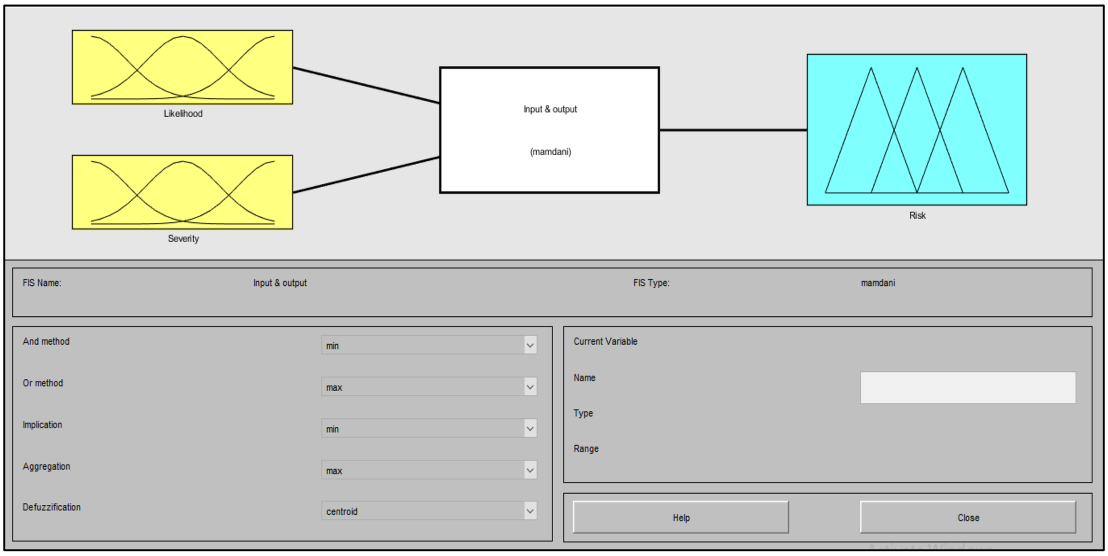

Figure 4.16: Input and output variables

2. The membership function (MF) is a curve that shows how each input point is associated with a membership value between [0] and [1]. Table 3.5 has defined the membership function for input variables. While the membership function for output variables have been defined in Table 3.6.

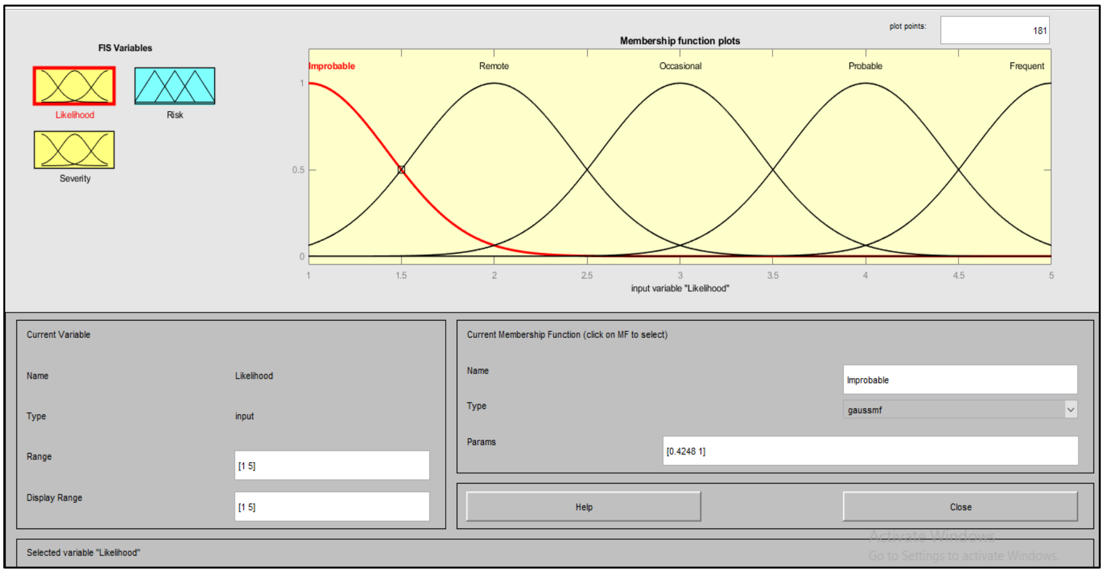

Figure 4.17: Membership functions of first input variable

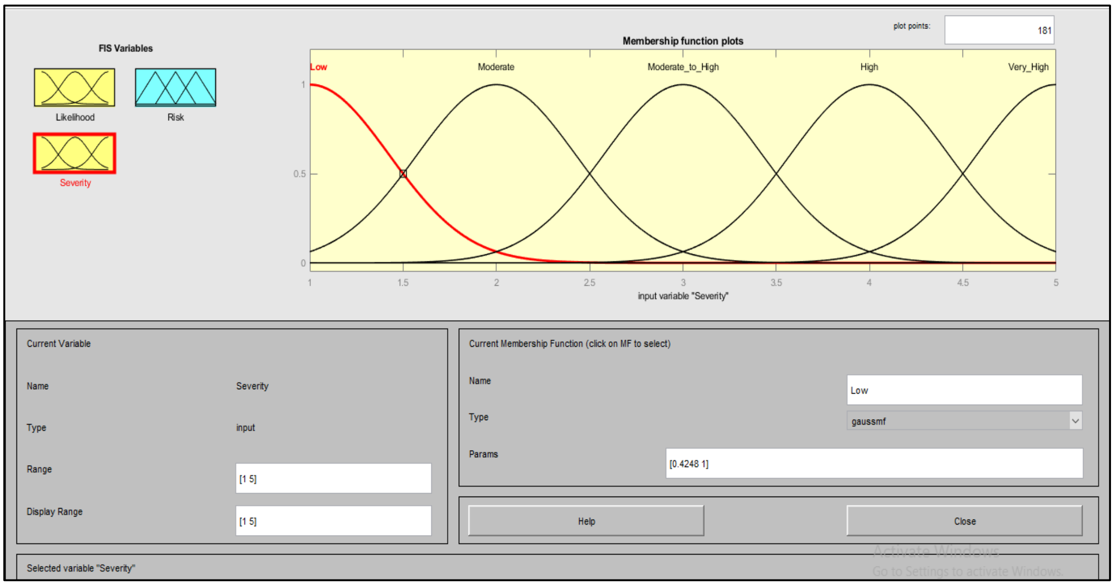

Figure 4.18: Membership functions of second input variable

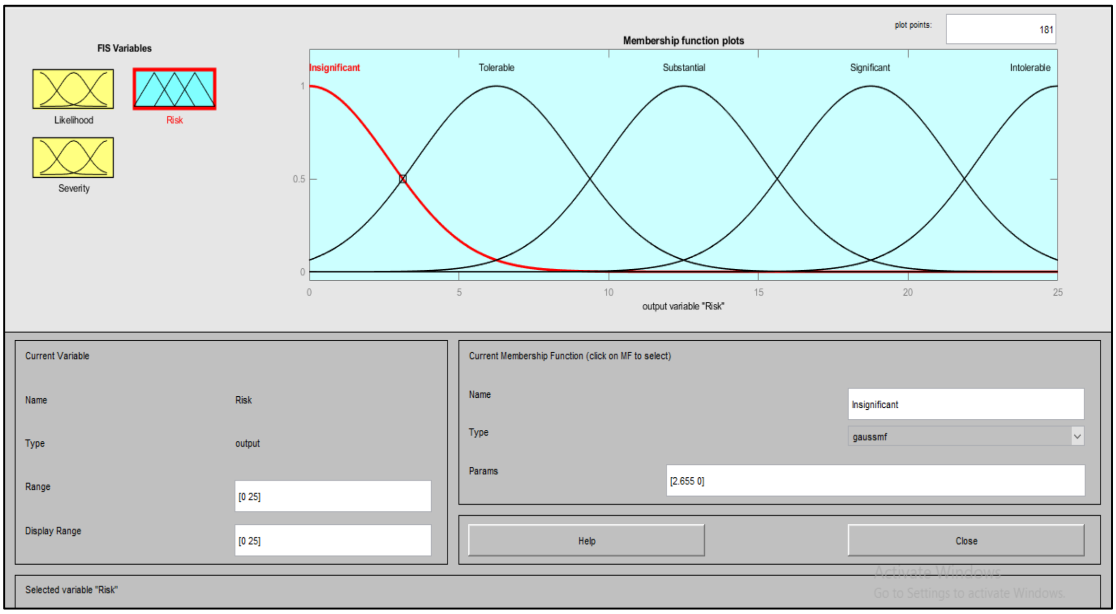

Figure 4.19: Membership functions of output variable

3. Rules are defined to relate input and output variables. This model has 25 rules that are expressed as if-then statements based on the input and output variables using expert opinions. All these rules have been defined in Table 3.7 and schematically depicted in Figure 4.20. A three-dimensional diagram has also helped understand the links between input and output characteristics as it has depicted the mapping of two input parameters (probability and impact) to a single output (risk). This plot is

often referred to as a risk surface and is used for risk assessment (Yazdani-Chamzini, 2014). Figure 4.21 illustrates the control surfaces of the fuzzy inputs of likelihood and severity, as well as the risk of the fuzzy output.

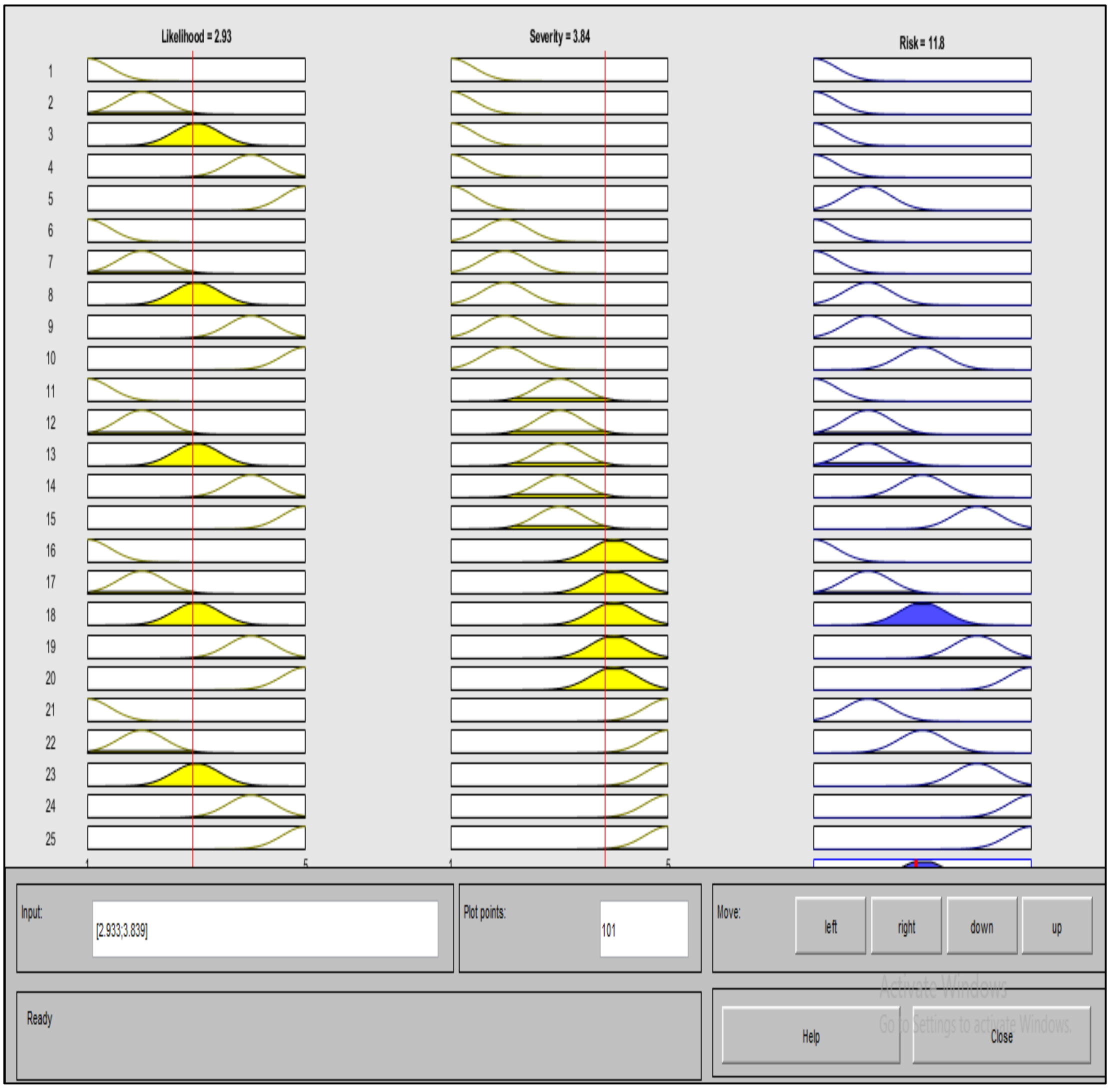

Figure 4.20: Rule viewer

4. Defuzzification is the process of transforming language concepts into fuzzy sets. After the model has completed the defuzzification process to turn the fuzzy values into crisp values, the risk level was calculated based on likelihood and severity for each emission source. The surface view of results can be shown in Figure 4.21.

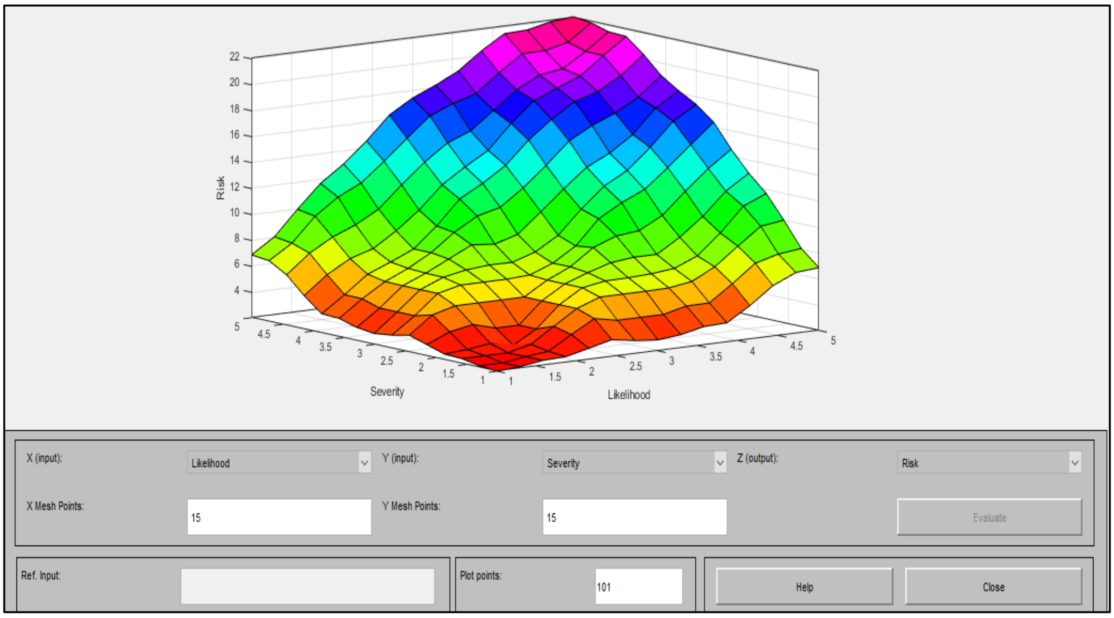

Figure 4.21: Surface viewer

Table 4.12 has outlined the office emissions and their corresponding risk rating and ranking. According to fuzzy model results, emissions from printing devices operation have been ranked first showing the highest risk rating of 4.93. Emissions from ramp vehicles were ranked second and carbon emission from desktop operations was ranked third by the model. On the other hand, carbon footprint emissions emerging from paper consumption along with admin vehicles and staff commuting were ranked fourth and fifth respectively according to model results. Risk factor ranking for emissions resulting from the operation of air conditioners, office lightings, refrigerators and microwaves was sixth, seventh, eighth and ninth respectively by fuzzy inference risk model. With this information, it can be assumed that fuzzy model has helped in risk assessment process by accommodating all uncertainties and ambiguity in data, allowing for a more precise and dynamic evaluation of potential risks.

Table 4.11: Fuzzy risk assessment model

S.	Office emissions	Annual carbon footprint CO_2e (tonnes)	Likelihood (L)	Severity (S)	Risk (R)	Risk rank
1.	Desktops	4.72	3.61	17.80	4.72	3
2.	Printing devices	4.93	5.00	22.10	4.93	1
3.	Office lightings	4.68	1.24	7.62	4.68	7
4.	Air conditioners	4.17	2.25	9.29	4.17	6
5.	Microwaves	3.46	1.05	3.71	3.46	9
6.	Refrigerator	3.92	1.19	4.47	3.92	8
7.	Paper consumption	4.51	3.47	16.40	4.51	4
8.	Ramp vehicles	4.82	4.55	20.70	4.82	2
9.	Admin vehicles and staff commuting	3.65	2.71	10.53	3.65	5

4.4 Comparison of both risk assessments

The fuzzy risk model was employed to assess the existing risks in the present study and the obtained results were compared with those obtained by the conventional risk assessment method. A comparison between the final rankings of the fuzzy proposed model with that of the conventional risk assessment has been provided in Table 4.13. The events with respect to risks were ranked from least to most severe. The results reported in this table show that the printing devices emissions had gained the first rank among the office emission risks using the conventional risk assessment method and fuzzy inference system method. The emissions from ramp vehicle operation ranked second in the conventional risk assessment method and fuzzy risk model. The risk factor for desktop operating emissions was ranked third using the traditional risk assessment method and fuzzy risk model. Similarly, paper consumption was also ranked third by the conventional risk matrix assessment. But this risk factor was ranked fourth by the fuzzy logic risk model. Admin staff vehicles and staff commuting was ranked fifth by both conventional risk assessment and fuzzy risk model. In addition to this, risk factor for air conditioning emissions was ranked sixth and fourth by the fuzzy risk assessment and conventional risk matrix, respectively. The emissions from office lightings operation provided risk factor that was ranked seventh and sixth by the fuzzy risk assessment and conventional risk matrix, respectively. Risk factor for refrigerator operation was ranked eighth using the traditional risk assessment method and fuzzy risk model. In the end, microwaves operation was ranked ninth representing the least risk factor among all. While this risk factor was ranked seventh according to the conventional risk assessment method. Compared with the traditional risk assessment, the ranking of the fuzzy model also seemed to be quite reliable. The fuzzy model has enabled us to consider uncertainty in the environmental risk assessment process and, contrary to the conventional risk matrix method, it requires predefined experts' rules and opinions. The most significantly debated shortcoming of the traditional risk assessment is that various sets of likelihood (L) and severity (S) may generate an identical value for risk index. However, the risk implication may be completely different. This means that the two parameters are assumed to have the same importance. This may result in a bad impact on the results of the risk assessment process; so that, the results may be wrong and invalid. As an illustration, consider two different scenarios having values of 5, 3 and 3, 5 for L and S, respectively. Both these scenarios will have a risk value of 15. However, the risk implication of the two scenarios may be significantly different because the importance weight of the likelihood parameter is significantly different from the severity. This problem may impose a waste of time and finance for organizations.

S. No.	Office emissions	Conventional risk assessment method				Fuzzy logic risk model			
		Likelihood (L)	Severity (S)	Risk (R)	Rank	Likelihood (L)	Severity (S)	Risk (R)	Rank
1.	Desktops operation	5	3	15	3	4.72	3.61	17.8	3
2.	Printing devices operation	5	5	25	1	4.93	5.00	22.1	1
3.	Office lightings operation	5	1	5	6	4.68	1.24	7.62	7
4.	Air conditioners operation	4	2	8	4	4.17	2.25	9.29	6
5.	Microwaves operation	3	1	4	7	3.46	1.05	3.71	9
6.	Refrigerator operation	4	1	3	8	3.92	1.19	4.47	8
7.	Paper consumption	5	3	15	3	4.51	3.47	16.40	4
8.	Ramp vehicles operation	5	4	20	2	4.82	4.55	20.70	2
9.	Admin vehicles and staff commuting	3	2	6	5	3.65	2.71	10.53	5

Table 4.12: Comparison between fuzzy model and conventional risk model

Chapter 5 Conclusions & Recommendations

5.1 Conclusions

All office aspects produced a total carbon footprint of 24642.97 tCO_2e annually with 57.92% from printing device operation and 32.49% from ramp vehicles operation. According to conventional risk model results, the highest (intolerable) risk level associated with carbon emissions were related with the use of printing devices. On the other hand, Fuzzy model results indicated that the highest risk rating associated with emissions is for printing devices, followed by airport ramp vehicles emissions based on its relative importance. The study results have showed that carbon footprint analysis along with the environmental risk assessment can be extremely useful for identifying, assessing, and targeting the high-risk areas in our surrounding environment for ensure environmentally responsible behaviors. It served as the foundation for the current study, which sought to identify the carbon footprint of the organization, its environmental risk factors, and their relationships. However, acquiring precise assessment information on the risk components (i.e., likelihood of occurrence and the severity) is quite difficult and even in many situations impossible. For a quick and simplified risk assessment process, Fuzzy risk assessment model was utilized in this study to handle the uncertainty associated with the process of modelling a complex system, allowing the risk components and their relative importance to be considered in modelling the risks caused by the project in a linguistic rather than precise manner. The Fuzzy risk model's output was used to enhance decision-making in the risk management process. Comparison of risk assessment results from both models have revealed that the Fuzzy risk model results can also provide a reliable method for risk assessment in addition to the traditional risk assessment approach. Moreover, results also concluded that some preventive strategies can be helpful to reduce the carbon footprint emerging from an office environment which include:

a) Reducing energy consumption and promoting sustainability involved a combination of effective measures including energy-efficient devices, implementing paperless initiatives, and alternative modes of transportation.
b) Other effective strategies include recycling, installing motion sensors, conducting energy audits, and switching to renewable energy sources.

c) To foster an eco-friendly workplace, concerted effort towards education & awareness for sustainable environment along with the collaboration of eco-conscious suppliers is required.

5.2 Recommendations

The Fuzzy logic model is an efficient and applicable tool to solve decision making problems under uncertainty. Therefore, applying this model can be developed to assess runway safety by considering factors such as weather conditions, aircraft types, and runway surface conditions. Fuzzy risk model can also be utilized to perform multifactorial analysis, considering various parameters simultaneously to assess risks comprehensively. Fuzzy logic model can also be proved useful for security screening procedures at airports, incorporating variables such as passenger behavior, luggage contents, and threat intelligence.

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