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AVIATION AIR POLLUTION STUDIES IN THE EMIRATE OF ABU DHABI

by

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Declaration

I declare that, except where stated, the work presented in this thesis is my own

Signed ……………………………………………………… Sukaina Alwasity

Date ……………………………………………………… 12 October 2012

بسم الله الرحمن الرحيم

IN THE NAME OF ALLAH THE MOST GRACIOUS THE MOST MERCIFUL

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<u>Abstract of Thesis</u>

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Aviation is an integral part of the infrastructure of the modern civilization. Air transport plays an important role in the global economy and has contributed enormously towards global integration. It supports commerce, tourism and private travel. These positive advantages of the aviation industry involve substantial costs to the environment.

Aircraft emit large amounts of air pollutants, degrading air quality. Air pollution in and around airports worldwide is rapidly growing. Abu Dhabi International Airport (ADIA) is no exception. It is planned to undertake expansion and development at Abu Dhabi airport to meet the requirement of fast growing air traffic, which is expected to reach 30 million passengers annually between 2030-2050. The projected growth of air traffic is likely to result in considerable impact on local air quality and climate.

The first aim of this project was to review the available monitoring data and explore what additional measurements would be useful. The second aim was to assess emissions from the various sources on the ground, which will increase with airport development. Thirdly, since CO_2 emissions from aircraft is major issue in relation to climate change, this study also aimed to estimate CO_2 emissions from aircraft, and provide future projections.

Monitoring data from the Abu Dhabi area and monitoring campaigns at the airport have been analysed relating them to characteristics of the surrounding area and airport activities. To obtain higher spatial resolution, diffusion tubes were used although they proved to be of limited use because of extreme meteorological conditions.

Data have been collected from various sources on each of the emission related activities at ADIA. An emission inventory of ADIA activities has been generated using Emission Dispersion Modelling System (EDMS) for different air pollutants such as $NO_{x,}$ PM_{10}, and CO. This included emissions from aircraft and ground support sources. The information gathered produced a basis for projections for future growth and development of ADIA during the coming years.

CO_2 emissions have been assessed based on current aircraft mix and air traffic data at ADIA, combined with International Civil Aviation Organization (ICAO) data. The consequences of projected growth of ADIA for different aircraft types and journeys have been determined.

THIS THESIS IS DEDICATED TO MY FAMILY

MY MOTHER & MY SON FAISAL

FOR THIER

LOVE AND SUPPORT

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ACRONYMS

A/D	Arrival and Departure
ADMS	Atmospheric Dispersion Modelling System in an urban Environment
AERMOD	American Meteorological Society /Environment Protection Agency Regulatory Model Improvement Committees Dispersion Model
AERMET	AERMODs Meteorological Preprocessor
ADIA	Abu Dhabi International Airport
AIR	Aerospace Information Report
APU	Auxiliary Power Unit
ATC	Air Traffic Control
AQEG	Air Quality Expert Group
BAH	Booz Allen Hamilton
CAEP	Committee on Aviation Environmental Protection
CO	Carbon monoxide
CO_2	Carbon dioxide
DEFRA	UK Department of Environment, Food and the Rural Affairs
DETR	UK Department of Environment, Transport and Regions
DORA	Department of Operations Research and Analysis , Civil Aviation Authority
DXB	Dubai International Airport
DWC	Al Maktoum International Airport
EAD	Environment Agency of Abu Dhabi

EC	European Commission
EDMS	US Emissions and Dispersion Modelling System
EI	Emission Inventory
EU	European Union
FAA	Federal Aviation Administration
GA	General Aviation
FEA	Federal Environment Agency
FECC	Food Environmental Control council
FJR	Fujairah International Airport
GA	General Aviation
GCAA	General Civil Aviation Authority
GDP	Gross Domestic Product
GFC	Gas Filter Correlation
GHG	Greenhouse gases
GPU	Ground Power Units
GSE	Ground Support Equipment(inside an airport)
GUI	Graphical Users Interface
HC	Hydrocarbon
HCHO	Formaldehyde
HCN	Health Council of the Netherlands
h	Hours

HKIA	Hong Kong International Airport
HNO_3	Nitric Acid
H_2SO_4	Sulphuric Acid
ICAO	International Civil Aviation Organization
IPCC	International Panel on Climate Change
ISA	International Standard Atmosphere
km	Kilometres
LAQM	Local Air Quality Management
LAX	Los Angeles International Airport
LT	Long Term
LTO	Landing & Take off
MAC	Maximum Allowable Concentration
MOEW	Ministry of Environment and Water
NAAQS	National Ambient Air Quality Standards
NDIR	Non-dispersive Infrared
NMHCs	Non methane Hydrocarbons
nm	Nanometer
NST	National Standard Time
NO	Nitrogen oxide
NO_2	Nitrogen dioxide
NO_X	Nitrogen oxide

O_3	Ozone
Ox	Ozone oxides
PAN	Peroxy-acetyl-nitrate
PM	Particulate matter
$PM_{2.5}$	Particulate matter with aerodynamic diameter of less than 2.5 microns
PM_{10}	Particulate matter with aerodynamic diameter of less than 10 microns
PMT	Photomultiplier tube
PORG	Photochemical Oxidant Review Group
PSS	Photo Stationary State
ppb	Parts per billion
RKT	Ras Al Khaima International Airport
RH	Relative Humidity
r	Correlation coefficient
RO_2	Proxy radical
r^2	Coefficient of determination
S	South
SCADIA	Supervision Committee for the Expansion of the Abu Dhabi International Airport
SD	Summer Day
SHJ	Sharjah International Airport
SN	Summer Night
SO_2	Sulphur dioxide

SPSS	Statistical Package for the Social Sciences
ST	Short Time
TDLAS	Tundyle Diode Laser Absorption Spectroscopy
TEOM	Tapered Elemental Oscillating Microbalance
TEA	Triethanolamine
THC	Total Hydrocarbons
UAE	United Arab Emirates
UHC	Unburned Hydrocarbons
UNFCCC	United Nations Framework on Climate Change
USAF	United States Air Force
US EPA	US Environmental Protection Agency
UV	Ultra Violet
µm	Micrometer
µg	Microgram
VOC	Volatile Organic Matter
W	West
WD	Winter Day
WHO	World Health Organization
WN	Winter Night
Zn	Zinc

CHAPTER 1

INTRODUCTION

Air transport has become integral to economic and social development, facilitating the rapid movement of people and goods around the world, whilst providing employment to a vast number of workers, both skilled and unskilled. Thus, aviation has become an essential part of the world economic system (Somerville, 2003). However, this dynamic and expedient mechanism has cost the environment dearly and now, at the beginning of the twenty-first century, the impact of as few as six decades of polluting aircraft and related emissions, has resulted in catastrophic, irreversible damage in some areas. The effects of the pollutants are being experienced on both a global, regional and local level (Chapman, 2007).

Sixty years ago, the aviation industry was in its infancy, accounting for a small proportion of global transport (Macintosh and Wallace, 2009). It has become an intrinsic part of the world economy, providing 56.6 million jobs throughout its various industries, including 8.3 million in the airline sector (ATAG, 2012) accounting for approximately $2.2 trillion of the $70.16 trillion GWP total in 2011, carrying about three billion passengers per year, with the International Civil Aviation Organisation (ICAO) reporting air passenger traffic up 6.4% in 2011 and expected to rise 4.5% annually going forward to 2030 (IATA,2012) Similarly, aircraft movement is predicted to double from 24.79 million annually in 2010 to 51.71 million per year by 2030 (Airport watch, 2001). Today, over one third of the values of goods that are traded internationally are transported by air, that is, 28 million tonnes of freight and mail each year. When this latest figure was produced in 2007, it was also established that the annual average growth was about 5% and the market is continuing to grow because of the demand for international express traffic and shippers seeking more time-definite deliveries. (Bts, 2010).

In spite of the current economic downturn, the aviation industry is developing in response to the ever-increasing demands for its services. There is, however, a need to balance responsibilities to the business on the one hand and those to the environment on the other. If executed effectively, infrastructure investments will be carried out, thereby enabling aircraft to land and take off with minimum delay and fly the most fuel and carbon efficient trajectories, thereby achieving optimum efficiency in delivering its services, whilst, at the same time, fulfilling its obligations to protecting the environment.

However, it is the very considerable impact of the pollutants emitted by aircraft and related airport activities on air quality that leaves serious concerns for environment (ICAO, 2011). There are damaging effects on those people living in the localities of the airports, suffering from noise and air pollution from the aircraft, the higher traffic levels and activities such as ground transportation, all of which directly affect local air quality and public health.

1.1 Background and definition of the problem.

Airport pollutant emission effects can be felt far away from the source of emission depending upon prevailing the meteorological condition as well as topography of the region. Based upon type of the pollutants the effects can be different on crops, vegetation and human health. Literature on effects of air pollutants on crops and vegetation are well cited (Schenone and G. Lorenzini, 1992; Zheng, et al., 1998; Honour, et al., 2009; Kaliakatsou, et al., 2010). Similarly, air pollutants effects on human health are a major concern worldwide.

It becomes increasingly essential to know the types and amounts of emissions from aircraft and airports from an environmental point of view, especially due to associated health issues (Yu, et al., 2004; Kesgin, 2006). Ozone has been linked with asthma (Wilson, et al., 2005; Peel, et al., 2005; Erbas, et al., 2005; Hernandez-Cadena, et al., 2007) and with reduced development in respiratory peak flow rate in children (Gauderman, et al., 2000). Ozone is also responsible for emphysema, and lung cancer (Kuo, et al., 2006; Nawrot, et al., 2006).

Relations between suspended particulate matter and lung function parameters, respiratory symptoms and mortality have been demonstrated (Dockery, et al., 1993). Investigations have indicated that, depending on particle size, particles are deposited in different regions of the human respiratory system—fine particles penetrate deepest into lung passages.

Lung deposition peaks at 20% for 3 μm particles and 60% for 0.03 μm particles (Swift and Proctor, 1982).

Carbon monoxide exposures are associated with reduced capacity to transfer oxygen, cardiovascular effects, neurobehavioural effects, fibrinolysis effects and perinatal effects (Flachsbart and Mack, 1987; Badman and Jaffe, 1996). Exposure to increased levels of sulphur dioxide (Balmes, et al., 1987), nitrogen oxides (Kagawa, 1985) can cause nose and throat irritation, followed by bronchoconstriction and dyspnoea, especially in asthmatic individuals, are usually experienced after exposure. The details of incidence of health effects due to aircraft emission in continental United States are reported by Ratliff, et al., 2009.

In order to deal with the risk of adverse air pollution effects on environment and to improve public health effective air quality management is required. Several studies have been undertaken over past few decades for local and urban air quality management (Longhurst, et al., 1996, 2006; 2009; Crabbe, et al., 1999; Seika and Metz, 1999; Beattie, et al., 2001). Similarly air pollution abatement strategies have been an emerging area of research (Mediavilla-Sahagún, et al., 2002; Mediavilla-Sahagún and ApSimon, 2003; ApSimon, et al., 2002; Tourlou, et al., 2002; Kazmukova, et al., 2006).

The determination of this study was to evaluate the ambient air quality at Abu Dhabi airport, in the United Arab Emirates (U.A.E). The present airport in Abu Dhabi was opened on the mainland in 1982, close to the main highways linking Abu Dhabi with

Dubai, about 30 km from the city (Figure 2.2). The Abu Dhabi International Airport was built to manage a maximum of five million passengers a year. In the mid-1990s, however, further expansion became necessary and the terminal building was enlarged to accommodate increasing numbers of business and leisure travellers of which a large number are transit passengers between Europe and the Far East (ADIA, 2004).

The fact that certain ADIA facilities - mainly passenger terminal facilities and aircraft parking stands - were no longer capable of meeting demand during peak periods of activity was well known. However, the demands placed on the capacity of other functional sectors of the airport, the future development plans of those sectors, and the land requirements entailed by those plans were not well understood before a master plan study was undertaken(SCAIA,2005). In addition, there were important questions about the ability of the existing airport infrastructure and utilities to support future developments. The master plan study began with an assessment of the existing conditions of the airport in 2004. Traffic data were solicited and received from various departments of the Department of Civil Aviation (DCA). The passenger terminal building was inspected, as were the major utilities and elements of the airport infrastructure. In addition, all major stakeholders at the airport were queried about the adequacy of their existing facilities, their growth projections and their future facility requirements.

ADIA is one of the busiest airports in the country. During 2004, a total of 5.2 million passengers, including 47% transfer, 43% transit and 10% AD (arrivals and departures), were recorded by the Supervision Committee of Abu Dhabi International Airport

(SCADIA, 2005). However, an increase in number of passengers at ADIA has been recorded in subsequent years. ADIA is likely to undergo rapid development and expansion in the near future. The new plan provides a framework for the growth of the airport activity to 30 million passengers per year with additional land reserves for a considerable increment of airport capacity beyond this level. As for the future projection, the 30 million passengers per year are expected to be reached sometime between 2030 and 2050 (SCADIA, 2005). The proposed plan provides a robust platform for the new national carrier, Etihad Airways, to develop ADIA as its base and principal hub, not only for passenger traffic, but also for cargo. The proposed expansion plan includes a new second runway 2,000 metres north of the existing runway. This wide separation is necessary to meet the expected demand for aircraft movement during the peak period for handling 30 million passengers, and allowing fully independent operations for maximum capacity (SCADIA, 2005).

1.2 Purpose of the Study

There is no doubt that area of the airport can be developed: however, there is a need to study the impact of such developments on local communities and on local air quality. In recent years much emphasis has been given to evolving an air quality policy framework for maintaining a healthy environment in conformity with international standards prescribed by the World Health Organization (WHO). Therefore, for suitable air quality management purposes, the principal importance is to integrate air quality related information obtained from different sources such as emission inventories, monitoring and tools such as air quality modelling, in order to lay the foundation for an aviation air quality policy in Abu Dhabi and the UAE in general.

1.3 Aims and Objectives

The Abu Dhabi International Airport body is fully aware of the potential environmental impacts that may arise from the expansion of the airport (SCADIA, 2005). As a result, it has provided funding for this study to carry out air pollution studies around Abu Dhabi Airport, the following aims and objectives of the present study are:

- To establish an emissions inventory for ADIA, especially with respect to NO_x emissions due to the landing and take-off (LTO) cycle of the aircraft,
- To evaluate the air quality status at the airport and surrounding areas by analysing air pollution data and to conduct a NO_2 diffusion tube measurement campaign to find out NO_2 spatial distribution,
- To carry out air pollution modelling to predict the future air quality at ADIA,
- To estimate ADIA's contribution to global warming issues,
- To make recommendations in support of an air quality policy for ADIA.

Figure 1.1 : Major components for suggesting air quality policy for ADIA

1.4 Importance of the study

This study will be first of its kind for the country. Considering that the UAE has 23 airports with paved runway (UAE, 2007), six of them are international and has announced the seventh (GCAA, 2012). The six established airports are:-

- The Abu Dhabi International Airport, established in 1969 in what is now the capital of the UAE. The airport is home to Etihad Airways the national airways of the UAE (ADAC, 2012).

- Al Ain International Airport is located in the emirate of Abu Dhabi, in the city of Al Ain. It was established in 1994 and contains one runway, a single terminal building, five passenger aircraft parking and two parking areas for cargo aircrafts (ADAC, 2012).
- Dubai International Airport, built in 1959 it was the first airport in the UAE (Dubai Airports History, 2012). The airport is located in the south-eastern part of the city. It's now home to Emirates Airlines. The airport will be the 2nd hub for the Australian Qantas Airways. The airport is also home to the budget airline Flydubai (Airport, 2012). According to Airports council International, world airport traffic report (ACI, 2009), Dubai International Airport is the sixth busiest airport worldwide and the first busiest in the Middle East with 40, 901,735 passengers.
- The newly opened Al Maktoum International Airport located on the outskirts of Dubai and will be part of Dubai World Central, which is a commercial logistics scheme. The airport will house six parallel runways 4.5 km in length, three passenger terminals, and sixteen cargo terminals with a 12 million tonne capacity (DWC, 2012).
- Sharjah International Airport opened in 1977 and is located in the emirate of Sharjah and its 15 kilometres away from Dubai. The airport includes one runway and is the base of the budget airlines, Al Arabia Airlines. The airport also has 4 cargo terminals (SHJ, 2012). In 2009 was rated to be the 10th busiest airport in the Middle East with 5, 76,098 passengers according to (ACI, 2009).

- Ras Al Khaima International airport opened in 1976 and it is located in the north of the UAE. It is now the base of RAK Airways, budget airlines. It contains one runway, two passenger terminals and one cargo terminal (Airport, 2012).
- Fujairah International Airport, opened in 1987 is now mainly used for cargo and military stop-offs (Airport, 2012).
- The newly announced Ajman International Airport will be the nation's seventh international airport and is currently under development. Ajman International Airport is set to be operational by 2015 and is supposed to serve 1 million passengers annually and handle 400,000 tonnes of cargo (Airport, 2012).

Each airport has ambitious plans to expand its facilities. In contrast, some European airports are facing pressure on their expansion plans due to air quality and other environmental concerns, such as Heathrow airport, with concerns regarding the obligation to comply with the mandatory air quality limit values for NO_2 that were applied from the beginning of 2010 (as set in EU Directive 1999/30/EC).

ADIA is the second busiest airport in the country after Dubai International Airport. In addition it is rated to be the 7^{th} busiest airport in the Middle East market according to world airport traffic report (ACI, 2009). The present study may contribute towards more effective management and control of air pollution around airports in the United Arab Emirates as whole and may provide a foundation and framework for future research.

Based on the literature review given in chapter 2, and chapter 5 the Abu Dhabi Emirate and ADIA Case Study it is observed that no emission inventory has been conducted in Abu Dhabi International Airport (ADIA). Thus, present research have been undertaken to fill the research gap. Further, the study will serve as background emission inventory of

ADIA and that may provide crucial information regarding present status of the airport environment. Based on the existing methodologies, the study will be carried out in the best possible manner. Consequently, based on this study, initiatives may be undertaken for efficient airport air quality management.

The main source of air pollution is the oil and gas industry in Abu Dhabi Emirate, followed by the power and transportation sectors. (ERODA, 2005) Currently, in the Emirate of Abu Dhabi, the Environmental Agency Abu Dhabi (EAD) is conducting an air quality monitoring and management project but ADIA was not included or the areas around the airport, more details are given in chapter 5 , therefore this study fill the gap especially for NO_2 spatial distribution

In December 1995, the UAE acceded to the United Nations Framework Convention on Climate Change and became an official party in March 1996 with a mandate, as a Non Annex 1 Party to the Convention, to submit National Communications (Ministry of Energy, 2006).

A team of UAE scientists and experts specialising in different disciplines were involved in preparing the National Communication in coordination with the Ministry of Energy, but the aviation sector was not included (Ministry of Energy, 2010); therefore the importance of this thesis is to fill the gap by covering the aviation sector in Abu Dhabi Emirate by calculating CO_2 emission from ADIA. More details regarding this issue are given in Chapter 5.

1.5 Discussing the selection criteria for the methodologies adopted in this research

Selection criteria for the methodologies adopted in carrying out present study were decided based on consultation with the following:

I. Research supervisors for academic inputs.

II. Former Department of Civil Aviation and the Abu Dhabi Airport Company (ADIC) for data information.

III. Measurement of ambient air quality at Abu Dhabi Airport was carried out by the SCADIA (Supervision Committee of Abu Dhabi International Airport) for baseline measurements of different pollutants.

A. Emission Inventory

Emission inventory can be defined as an estimation of emissions released by a number of different sources in an area at a specified period of time. Emission inventories are a useful tool in air quality control policies, since they allocate individualization of the major source contributions, and they can be used to assess the implementation of control strategies. They are also used as benchmarking and for trend analysis, (AQEG, 2004).

A number of studies were reviewed to decide which method should be adopted to compile the emission inventory, the details of which are available in chapter 4. Different models for airport emission inventories were reviewed in Chapter 2. LASPORT was developed in 2002 on behalf of the German Airport Association (ADV) for the calculation of airport-related emissions and concentration. It has been used to assess the local air quality at different European airports. ADMS AIRPORT air quality model was designed to model pollutant concentration in airport vicinities. EDMS is used in North America and has the ability to calculate emissions and model pollutant concentrations as well. Based on the existing methodologies, the EDMS Model was chosen because it has the capability to calculate emissions from the different sources at ADIA and it is affordable where other models are much more expensive as reviewed in chapter 2. More details on EDMS input data will be given in chapter 4.

Certain guidance and tools were also used including ICAO guideline methodology (Doc.9889, 2007) providing the latest specification to establish an emission inventory

Emission inventory results were compared with different airports using EDMS, such as San Diego International airport and Denver International airport. Moreover, comparison of NO_x emission results of ADIA with UK airports, and comparison between three different aircraft types in terms of fuel flow and NOx emission factors used in three airports London Heathrow LHR, London Gatwick LGW and ADIA were also conducted in this study.

B. NO_2 Measurement.

NO_2 measurements were carried out using passive diffusion tube methods in order to find out the spatial distribution of NO_2 in the vicinity of ADIA. The decision was made to use the diffusion tube method after reviewing different measurement techniques (available in chapter 2 under the measurement section). This technique has several advantages such as low capital and operating costs, requires no power supply or site calibration (AQEG, 2004). This was carried out by the author who also tried to investigate the limitations found for this technique in the climatic conditions of Abu Dhabi.

C. **Air pollution data sets**

Air pollutant data sets were received from airport authorities of ADIA. Air quality parameters included, O_3, PM_{10}, CO, NO_x and SO_2. The pollutant measurements using standard measurement techniques were carried out for 9 months i.e., from 15 November 2005 to 15th July 2006 by the Supervision Committee for Abu Dhabi International Airport (SCADIA). Details of the measurements techniques are given in chapter 4 for the different parameters.

D. Modelling

AERMOD is basically an advanced Gaussian plume model but is able to treat terrain features, buildings, convective conditions and other complex scenarios. More details in chapter 2. The AERMOD model within EDMS includes a specific airport-related physical process. The trajectory and mixing of the engine jets are parameterized in terms of a plume height and size and these are based on recent lidar studies. The effects of jet momentum and buoyancy are treated with this parameterization. AERMOD uses several different source configurations to represent the emissions including point, area and volume (though not line) sources. The model can produce output concentrations that are "source-apportioned". The model typically works on hourly emissions and meteorological data over a year or more. Output concentrations are available for annual or shorter time averages. It is unfortunate that the EDMS model does not model NO_2 as this is the principal pollutant of concern for this thesis. But the decision was made to choose EDMS-AERMOD following the advice of Abu Dhabi Airport Authority, the funding body for this thesis. This was chosen because the Abu Dhabi Environmental Agency uses AERMOD and they recommended it for all Abu Dhabi Government agencies, other models were reviewed in chapter 2.

E. CO_2 Estimation Inventory for ADIA

The IPCC (2006) provides a three-tiered methodology in the "Greenhouse Gas Inventory Reference Manual" .The first-tier "Tier 1" was used in this study which is based on total amount for aviation fuel consumption to be multiplied by the emission factor. Table (4.5) in Chapter 4 presents ADIA's fuel consumption. Moreover, results generated from Tier 1 were compared with results generated from Tier 3. This depends on the number and type of aircraft operations, the types and efficiency of the aircraft engines and the fuel used, and the flight distance; and was also used in this study. More details on the calculation methodology are given in chapter 2 literature review: and the data input, such as actual traffic data sets, are given in Chapter 4, the methodology. Future scenarios of traffic growth were generated and corresponding CO_2 emission projections were carried out and compared with UK Airports. According to the Airports council international (ACI,2009), London Heathrow (LHR) is the busiest airport in the world with 60 million passenger and Dubai International Airport is the busiest airport in the UAE and the sixth busiest airport in the world with 42 million passenger in 2009. Taking into consideration that this study is the first of its kind in the UAE, therefore, such comparisons would be useful for the environmental aviation policy maker in Abu Dhabi Emirates as well as the UAE in General.

1.6 Overall approach

An airport is a hub of a multitude of interconnected activities including aircraft operations, airside vehicles, power plant, fuel storage and landside vehicles. Air emissions arise from all of these sources. No emission inventory has been conducted before this study for ADIA, as mentioned; therefore data were collected on air traffic movement and the number of land side vehicles in order to prepare a base case emission inventory. The Emissions Dispersion Modelling System (EDMS) was used for civilian airport and military air bases to assess air quality due to the emissions from different airport sources. More details on the above models are given in Chapter 2. EDMS was developed in the US and thus reflects US operations, regulatory status, data formatting and other US standards.

Efforts were made to access the overall quality of ambient air at Abu Dhabi airport during the study period. Meteorological data including wind speed, wind direction and temperature were collected from the study site. Air pollutant data sets were received from the airport authorities of ADIA. Air quality parameters included, O_3, PM_{10}, CO, NO_x and SO_2. The pollutant measurements using standard measurement techniques were carried out for 9 months between 15 November 2005 and 15th July 2006 by the Supervision Committee for Abu Dhabi Airport (SCADIA).

Data sets were subjected to further interpretation of trends of pollutants with respect to diurnal variations as well as seasonal changes with respect to O_3, NO, NO_2 and NO_x. The $NO_{2:}$ NO_x relationships were determined from the measured concentrations of these parameters.

All combustion processes in the air produce NOx. NO_2 and nitric oxide (NO) are both oxides of nitrogen and together are referred to as Nox. It is NO_2 which is subject to health based air quality standards (AQEG, 2004). Details about the impact of NO_2 on human health were mentioned earlier in this Chapter. Therefore, NO_2 measurements were carried out using passive diffusion tube methods in order to find out the spatial distribution of NO_2. This method is based on the principle of passive diffusion of NO_2 molecules on an absorbent, that is, tri-ethanolamine. The observed NO_2 concentrations were compared with the results obtained using a chemi-luminescent based NO_2 monitor. The Emissions Dispersion Modelling System (EDMS) model was used to estimate NO_x levels at different receptor locations in ADIA. (This is one of the limitations of the EDMS model which is discussed in Chapter 4). Observed data sets were compared with the predicted values in order to validate the model results. The EDMS model was further used to predict NO_x levels from airport activities at different receptor locations in ADIA for the future scenarios.

As climate change occurs it becomes increasingly important to monitor and record CO_2 emissions in the atmosphere. The first essential stage towards developing strategies to reduce GHGs emissions, carbon calculators, is used to present an estimate. CO_2 emissions were estimated using actual traffic data sets. Future scenarios of traffic growth were generated and corresponding CO_2 emission projections were carried out in order to help formulate an air quality management policy for ADIA in response to the growth in the air traffic movement.

1.7 Limitation of the study

An emission inventory for the area around the airport, such as the road network, was not available. Similarly, background measurement concentrations were not available from the Abu Dhabi Environmental Agency. Moreover, the Abu Dhabi Air Quality Monitoring network did not include the airport or the surrounding area Khailfa city A and B.

Diffusion tubes are widely used in the UK and in other parts of the world for special distribution of NO_2 concentration, but the extreme hot weather conditions in the UAE demonstrated low concentration or under-estimates of NO_2. The high temperatures which reached up to 49°C resulted in the diffusion tubes becoming dehydrated.

1.8 Content and Structure of the Thesis

Chapter 1 introduces the research theme of the study and describes the aims, objectives, scope of work, and the overall approach. Chapter 2 gives an overview of the relevant literature on air quality and emissions. Chapter 3 is a literature review on international air transport policy.

Chapter 4 describes the materials and methods used for the research. Chapter 5 presents the overall operational characteristics of Abu Dhabi Airport including its location, climate parameters, passenger and cargo load at present and in the near future and proposed expansion or development programme at ADIA. Chapter 6 presents ADIA emission inventory results.

Chapter 7 presents the results of field measurements of air quality parameters representing overall air quality at ADIA. Chapter 8 presents results of the air quality modelling.

Chapter 9 presents the estimates of CO_2 emissions due to various aviation activities at ADIA for the year 2006 and the future scenarios due to forecasted growth in aviation activities. Chapter 10 presents a general discussion. Chapter 11 presents the summary, conclusions and recommendations based on the present study

CHAPTER 2

AMBIENT AIR QUALITY AND AIRPORT EMISSIONS: AN OVERVIEW

This chapter takes a comprehensive view of the factors causing polluting emissions at airports and their effects on ambient air quality. The first part reviews the airport emission sources and possible factors affecting emissions. This is followed by an overview of emission inventory methodologies, examining the details involved in compiling the required information. The inventories of several international airports are studied, namely, Heathrow, Gatwick, Athens, Denver and San Diego. Followed by, monitoring methodologies of specific pollutants .Various types of modelling in use today were also reviewed, the chapter concludes with a review of the aviation CO_2 emission estimation methodologies.

2.1 AVATION EMISSIONS AND AIR QUALITY: GENERAL OVERVIEW

The dramatic growth in air transportation in the decade from 1991 to 2002 (DOT, 2003) resulted in increased concerns regarding the impact of aircraft-related emissions on the environment, in particular, the ambient air quality of the airport both inside and outside airport boundaries.

Airports are estimated to be responsible for about 5% of the total air pollution generated by the entire air transport system, that is, about 30 million tons per year (ACI, 2008). Today, in spite of the on-going effects of the worldwide economic downturn, the airline industry continues to function and develop, albeit in the face of a small but regular annual decline, excluding the Asian and Middle Eastern markets, which are currently thriving. The scale of the global business in the airline industry is enormous and the environmental implications are complex, as recent figures reveal. In 2011 worldwide flights produced 676 million tons of CO_2, just under 2% of the global emissions (ATAG, 2012).

Ambient concentrations of total hydrocarbons, methane, carbon monoxide, non-methane hydrocarbons and airborne particulate lead were investigated in the vicinity of Heathrow Airport, London (Nichols, et al., 1981). It was observed that concentrations of air pollutants measured around Heathrow Airport were not considerably higher than those which might be expected from an urbanised area, and were slightly lower than those measured at a typical central London site.

Environmental assessment techniques were used to estimate the cost of air pollution from aviation at Lyon-Satolas airport for 1987, 1990 and 2015 (Perl, et al., 1997). Economic cost evaluations were done by considering air pollution from ground based sources in Lyon.

Kalivoda and Kudrna, 1997 presented a study on the future development of air traffic and the expected changes and improvements in specific fuel consumption and air pollutant emissions for 2010 and 2020. Stefanou and Haralambopoulos, 1998 used an inventory calculation system for air traffic to determine annual fuel consumption and emissions. They used airline data on routes, hours of flights, density of traffic, fleet mix and ratings of engine manufacturers for an airline company in Greece. They calculated annual environmental loads and showed that significant amounts of pollutants are received in areas around airports.

Dameris, et al., 1998, presented a global three-dimensional dynamic-chemical model to estimate present and future subsonic and supersonic aircraft NO_x emissions on ozone. Grooss, et al., 1998 performed a study investigating the impact of air-traffic-induced NO_x and water vapour emissions on the chemical composition of the global troposphere and stratosphere for 1991 and a future scenario for 2015. Vedantham and Oppenheimer, 1998 give long term scenarios for aviation through the year 2100.

Kesgin, 2006 estimated aircraft landing and take-off (LTO) emissions (HC, CO, NOx, SO_2) at 40 Turkish airports including the biggest airports, i.e. Ataturk International Airport (AIA) in Istanbul, Antalya Airport in Antalya and Esenboga Airport in Ankara in 2001. Total LTO emissions from aircraft at Turkish airports are estimated to be between 7614.34 and 8338.79 t/year. These results are comparable with those from USA airports. Approximately half of these amounts are produced at AIA. To predict future emissions, it is estimated that an increase of 25% in LTO cycles might cause a rise of between 31 and 33% in emissions. The estimations show that a decrease of 2 min in taxiing time results in a decrease of 6% in LTO emissions.

Nonparametric regression of pollutant concentrations on wind direction is an accurate way to determine the direction of nearby sources (Henry, et al., 2002). This method was extended by Yu, et al., 2004 (using two variables: wind direction and wind speed) to identify the impact of two large urban airports (Hong Kong International Airport and Los Angeles International Airport) on local air quality. Based on this, it was found that at Los Angeles International Airport, CO and NO_x were dominated by emissions from ground vehicles going in and out of the airport. However, near Hong Kong International Airport, aircraft were an important contributor to CO and RSP.

NO_x and NO_2 concentrations in the ambient air as a contribution from Heathrow airport were detected and quantified and it was shown that aircraft NO_x sources can be detected to at least 2.6 km from the airport, even though the airport contribution at that distance is very small. It was also estimated that approximately 27% of the annual mean NO_x and NO_2 was due to airport operations while at background locations (2–3km downwind of the airport) the airport contribution was less than 15% (Carslaw, et al., 2006).

Pollutant dispersion during an airplane take-off was computed with ADREA-HF, a 3D unsteady Reynolds Averaged Navier-Stokes (RANS) computational fluid dynamics code, using a one-equation turbulence closure model (Koutsourakis, et al., 2006). Modelling revealed that brake release point could be the best place to have measurements, regardless of wind speed and direction. Moreover, NO_x background concentration is expected to be much higher near big airports, where airplanes take off every few minutes. Also, inside the airport, average NO_x values will be much higher along the runway, with peak values at the brake release point.

Graham and Raper, 2006 predicted the transport of aircraft NO_x emissions to ground level in the vicinity of an airport by employing a kinematic approach The simulations predicted mean NO_x concentrations of maximum 3 μg/m^3at the centre of the runway arising as a result of the vortex-mediated transport (as expressed on conversion of all NO to NO_2), with concentrations on the order of 1 μg/m^3 arising 0.5 km laterally from the runway.

A measurement campaign at Zurich Airport, to study the impact of emissions on local air quality, reported that CO concentrations in the vicinity of the terminals were found to be highly dependent on aircraft movement, whereas NO concentrations were dominated by emissions from ground support vehicles (Schürmann, et al., 2007).

Westerdahl, et al., 2008 reported on emitted particles during aircraft ground level operations in Los Angeles International Airport (LAX) in the USA. The results were based on the mode of activity at the airport without indicating airframe or aircraft engine types. They reported that considerable concentration levels of ultrafine particles emitted from aircraft engines can be found as far as 1 km from the end of a runway, in spite of physical and chemical processes, such as dispersion, coagulation and the volatilization of organic species, to reduce the level of ultrafine particles.

An attempt was made (Mazaheri, et al., 2011) to determine the annual particle emissions due to the large aircraft thrust engine operations at Brisbane Airport BNE (domestic and international).

It was found that LTO (landing and take-off) cycles contribute to more than 97% of these annual emissions at BNE in comparison to GRP (ground running procedures) related emissions. In the study, it was further reported that annual particle number, $PM_{2.5}$ and NO_x emissions from large aircraft operations, during LTO cycles and GRP at BNE, were 1.98 x 10^{24}/yr, 1.35 x10^4 kg/yr and 8.13 x 10^5 kg/yr, respectively. Analysis of the LTO cycle contribution to the daily emissions showed that the contribution of the climb out mode is considerably higher than for other individual LTO operational modes. Emissions during aircraft departures were significantly higher than those during arrival operations, due to the higher aircraft engine emission rates during take-off and climb out.

Contributions of commercial aviation emissions during landing and take-off (LTO) cycles from three U.S. airports were studied. These include: Atlanta's Hartsfield-Jackson, Chicago's O'Hare, and Providence's T.F. Green. The fine particulate matter ($PM_{2.5}$) levels were estimated using the Community Multiscale Air Quality model (Arunachalam, et al., 2011). It was followed by calculation of the total population health risks at various distances from each airport and it was indicated that 28-35% of health risks occurring more than 300 km from the airports were due to secondary pollutants (ammonium sulphate and nitrate) and a 108-108 km domain centred on the airport captured most population exposure for primary components of $PM_{2.5}$.

Unal et al. 2005 quantified the impact of aircraft emissions (PM2.5 and ozone) at Hartsfield–Jackson Atlanta International Airport on regional air quality. The $PM_{2.5}$ emissions results were based on Smoke Number (SN) using the ‘‘first order’’ method and

Emissions and Dispersion Modeling System (EDMS) was used for gaseous species. The results suggested that the airport can have a maximum impact of 56 ppb on ozone with a 5 ppb average impact over most of the Atlanta area. $PM_{2.5}$ impacts are also estimated to be quite large with a maximum local impact of 25 μg/m^3. Impacts over most of the Atlanta area were less than 4 μg/m^3. The impacts on ozone and PM2.5 of ground support equipment at the airport are smaller compared to the aircraft impacts, with a maximum impact of 2 ppb for ozone and μg/$m^3$for $PM_{2.5}$.

Farias and ApSimon, 2006 used air dispersion model, ADMS-Urban, to estimate temporal and spatial contributions to NO_x concentrations from aircraft and traffic around Heathrow airport in West London. They concluded that although emissions associated with traffic were smaller than those associated with aircraft, their impact at different locations around the airport, was found to be higher, where people are exposed to air pollution. Further, based on the discrepancies between monitoring data and the model it was suggested that the aircraft contribution is overestimated and the traffic contribution underestimated. Dodson et al. 2009 linked atmospheric dispersion models and related techniques with emissions inventories to model source contributions.

2.2 EMISSION INVENTORY METHODOLOGIES: AN OVERVIEW

An emission inventory can be developed through a variety of methods, for example, by estimating the emission factor, by using emission and dispersion-based model and by direct measurement of some specific pollutants. They are discussed in the following sections.

The main source of airport emissions are aircraft engines, ground service vehicles, airport associated traffic (Cohen et al. 2008), auxiliary power units (APU), ground support equipment inside the airport (GSE), stationary sources, such as fuel farms, power generation and aircraft maintenance, including aircraft engine testing (Draper et al. 1997).

Janic 1999 identified four factors caused by civil aviation that affect air pollution: 1) fuel consumption and energy efficiency, 2) rate of renewal of the aircraft fleet by introducing cleaner aircraft,3) intensity and volume of aircraft,4) type and spatial concentration and distribution of particular pollutants.

Other local issues that play an important role include: local meteorological and topographical conditions, the layout of the airport facilities and the level of congestion at the airport.

The generic equation for emission is given as:

Emission = Emission factor x Activity (Equation 2.1)

Where emission factor is the mass of pollutant released per unit activity and the activity is a defined quantifiable action, e.g., vehicle km travelled or tonnes of fuel burnt. Preparing an emission inventory for an airport can be done using the emissions factors for all types of engines operating in different power settings, different fuel consumption and different times. Draper et al. (1997) and USEPA (1992) indicated that the basic equation representing emissions from aircraft engines, auxiliary power units (APU) ground support equipment inside the airport (GSE), engine testing has the following form:

$$(Emissions)\ pj = (T)k \times (FF)\ jk \times (EF)jk \times (LF)jk \times (N) \qquad (\text{Equation } 2.2)$$

T : time of operation ; FF : fuel flow; EF remission factor; LF: Load factor.

N : number of sources operating; P: pollutant; j : source type; k : mode of operation.

2.3 Airport emission inventory estimation

A. *Estimating aircraft engine emission*

Emissions from aircraft are primarily confined to the process of fuel combustion by aero engines. The magnitude of emissions from an aero engine is largely dependent upon load setting and is identified with engine inefficiency and primarily characterized by the emission of CO and HCs. Higher load settings, such as during take-off and climb out are associated with optimization of engine performance and is generally characterized by the emission of NOx, through the oxidation of atmospheric nitrogen.

The International Civil Aviation Organization (ICAO) and the Committee on Aviation Environmental Protection (CAEP), which is ICAO's technical advisory committee, have defined emissions limits from aircraft engine exhausts. Emissions limits are estimated within 3000ft ceiling of landing and take-off, which is known as the (LTO) cycle, Figure 2.1 represents the LTO cycle defined by ICAO.

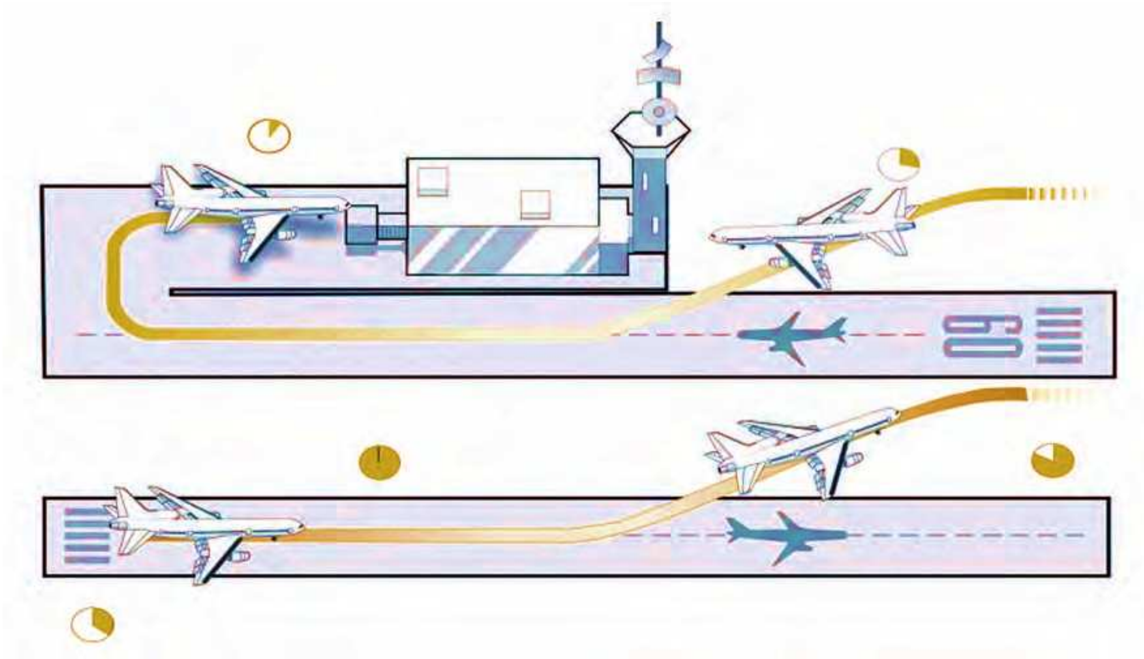


Figure 2.1: The LTO cycle defined by ICAO. *Source: (ICAO, 2010)*

An LTO cycle is subdivided into the following five phases or modes: "Approach" begins when the aircraft descends below the atmospheric mixing zone height and ends when the aircraft touches down on the runway. "Taxi/Idle" includes all time when the aircraft is taxiing between the runway and terminal or hangar/tie down location and includes all ground-based activities incurred during this period. “Taxi-out" is to the runway. "Take-off begins when full power is applied to the aircraft and ends when the aircraft reaches approximately 3,000 feet where the pilot typically powers back for a gradual ascent. “Climb out" begins when the aircraft powers back from take-off mode and ascends above the atmospheric mixing zone height (Draper, et al., 1997).

Data are needed in terms of emission factors, regular fuel consumption rates for aircraft engines, time used up by the aircraft in different modes of the LTO cycle and number of running engines. This set of variables is included in Equation 2.3

$$E_{PJ} = (T)_{jk} \times (EF)p_{jk} \times (NE)_j \qquad \text{(Equation 2.3)}$$

Where,

E_{pj}: total emission of pollutant P, produced by aircraft type j for one LTO cycle

T_{jk}: time in mode for mode k, for aircraft j

EF_{pjk}: fuel flow for mode k, for each engine used on aircraft type j

NE_j: number of engines used on aircraft type j

The emission factor for a particular aircraft engine is selected upon the mode of operation stage of the LTO cycle and the power settings, which are usually assumed as 100% for take-off, 85% for climb out, 30% for approach and 7% for taxi-idle. Moreover, the fuel consumption rate depends on different modes of the LTO cycle, the time in which the aircraft is at a specific stage of the LTO cycle, usually termed “time on mode” and which also depends on meteorological conditions, airport layout and the congestion level on the runway (USEPA, 1992).

B. Aircraft emission factors

The ICAO Engine Exhaust Emissions Data Bank is the major source of data for information about the operation and aircraft engine specifications. It originated as a part of the ICAO engine certification process. ICAO and CAEP describe and amend technical standards for classification of emission pollutants at LTO cycle.

Aircraft performance standards for emissions set up by ICAO were first implemented in l981. These standards relate to the control of fuel venting, smoke, and gaseous emissions (HC, CO, and NOx) from turbojet and turbofan engines proposed for subsonic and supersonic thrust. In addition, these standards were developed to tackle aviation's contribution to air pollution in the vicinity of airports and were modified by 1993 to be more stringent. CAEP, recommended in CAEP/4, further tightening of about 16% in April 1998, on an average for engines newly certified from 31 December 2003. Moreover, all aircraft delivered after 2008 have to meet CAEP/4.

C. Variation from ICAO factors

The ICAO has set limitation on emissions at their sources after finding the best available technology (IPCC, 1999). The difference in technology levels among engine types of whole engine families raises significant issues. The UK DfT has recognized that ICAO emission factors have a number of technical issues describing aircraft operation and performance that may influence actual airport emissions. These technical issues are: ambient conditions, forward speed, engine start, transient emission and emission from future engines.

D. Estimating auxiliary power unit emissions

Auxiliary power units (APUs) are on-board generators that supply electrical power to the aircraft while its engines are shut down. Some pilots start the on-board APU while taxiing to the gate but, for the most part, it is started when the aircraft reaches the gate. The on-board APU is, in effect, a small jet engine and the calculations for the emissions generated by it are similar to that of an aircraft engine operating in one power setting only. The US EPA Procedures for Emission Inventory Preparation has specified APU emission calculation methodology (US EPA, 1992) which is the following:

$$E_{pj} = (T) \times (EF)_j \times (EF)_{pj} \qquad \text{(Equation 2.4)}$$

Where:

E_{pj}: emission of pollutant p produced by the APU model installed on aircraft type j for one LTO cycle

T: operating time

EF_j: fuel flow for each APU used on aircraft type j

EF_{pj}: emission factor for pollutant p for each APU used on aircraft type j.

E. Estimating ground support equipment's

Once the aircraft arrives at a gate, GSE are used to unload baggage and service the lavatory and cabin. At the same time as an aircraft is parked, mobile generators and air conditioning may be in operation to provide electricity and air conditioning unit. Prior to aircraft departure, GSE are present to load baggage, food and fuel. When an aircraft departs from a gate, a tug is possibly used to push or tow the aircraft away from the gate and to the taxiway. Figure 2.2 depicts aircraft and GSE activity at the gate.

Figure 2.2: Aircraft and GSE activity at gate *(Source: EDMS manual)*

A list of the different machinery and their utilities is presented in Table 2.1.

Draper, et al., 1997, indicated the following equation to calculate the pollution emissions from an individual type of equipment for one LTO of a given aircraft type during the period of equipment usage.

$$Epj = (T) \times (LF)_j \times (EF)_{pj} \qquad \text{(Equation 2.5)}$$

Where:

Epj : emissions of pollutant p produced by GSE or AGE type j

T: hours of use equipment type j

LFj: load factor utilized in ground support operations for equipment type j

EFpj: emission factors for pollutant p, specific to a given engine size and fuel type.

Table 2.1: List of ground support equipment used at airport

	Ground support equipment	Description
1	Aircraft Tractors	They are used as push back service, pushing the aircraft back to the gate.
2	Air Conditioning Units	Are used to ventilate and cool stationary aircraft at the terminals.
3	Air Start Units	Or air compressors, these provide large amount of compressed air for starting aircraft main engines.
4	Baggage Tugs	This equipment used at airports to lug baggage between the aircraft and the terminal
5	Belt Loader and Container Loaders	Is a conveyor belt used to move baggage to the aircraft.
6	Bobtail Tractors	Are used to present high-speed transport of cargo and baggage over longer distances within the airport.
7	Lifts for Cargo Moving Equipment	This equipment is used as cargo loaders that allow access to the aircraft for servicing at the terminal and the maintenance base, it includes lifts, forklifts.
8	De-icers	It is a lorry which has a tank, pump, hose and spray gun to transport and spray de/anti-icing fluid on aircraft
9	Ground Power Units	These are generators which provide electrical power to the aircraft when the aircraft's APU and the main engine are not operating.
10	Lavatory service Lorries and Carts	The lorries are self-propelled units equipped with stainless steel tanks, a pump, and a hose used to service aircrafts lavatories
11	Passenger and personal ground Transport	Buses, Cars, Vans, Pickups. Some of these cars and equipment may be assigned to various departments such as administration, emergency response, police department, automotive mechanical maintenance, engineering and constructions.
12	Service Vehicles	specifically modified vehicles to services aircrafts such as fuel and maintenance
13	Others	Comprise small miscellaneous types of equipment generally found at facilities such as compressors, scrubbers, sweepers, and specialized units.

Source: Draper et al., 1997 and ICAO, 2003.

F. Estimating aircraft engine testing emissions

Equation 2.6 conveys the calculation methodology for aircraft testing emissions during the time consumed for the test.

$E_{pj} = (N) \times (TM)_j \times (EF)_j \times (EF)_p$ (Equation 2.6)

Where:

E_{pj}: total emission of pollutant p

N: number of test cycles preformed

TM_j: average test time per test, for engine testing mode j

EF_j: fuel flow rate while in engine testing mode j

EF_p: emission factor in mass of pollutant p emitted per mass of fuel burned.

G. Estimating stationary source emissions from an airport

Generally, airports will own and operate a number of power generation plants that are typically fuelled by petrol or diesel. There are a number of minor sources within the airport locality that emit a wide range of pollutants: these include fire training exercises, aircraft maintenance and fuel storage, which can be a significant source of VOCs at an airport.

H. Estimating landside vehicle emissions

Emission factors for NO_x emissions from combustion sources are usually fuel related, while those from road transport are traffic (specifically speed) related and both are expressed in grams of NO_x emitted per kg fuel consumed or per km travelled. The emissions factors are fuel related e.g. diesel or petrol. Statistical data for the activity can be obtained from census data, energy statistics, traffic surveys and counts, vehicle and transport statistics. Emission factors are specific to each pollutant, road and vehicle and depend on vehicle type and age, fuel type, engine type and size. Other parameters include: the emission regulations which applied when the vehicles were first registered, acceleration, deceleration, steady speed and idling characteristics of the journey, as well as road gradient and vehicle load which affects engine load (NAEI, 2005b). Emission factors used in databases are generated through measurement of emissions of vehicles driven over a range of real world driving cycles. They are then allocated to a range of average speeds and then combined with activity data to get the hot exhaust emissions for each road and vehicle type.

Case studies of UK airports emission inventories based on basic methodology of emissions estimation are discussed in this chapter. The UK total emission estimates from landside vehicles is calculated by using vehicles distribution over the physical airport area based on aircraft arrival statistics for each airport (National Atmospheric Emission Inventory, NAEI 2006).

2.3.1 Heathrow emission inventory

Heathrow Airport is the largest in the UK and EU countries in terms of international passenger numbers. This airport has five terminals and two runways engaged for 15 hours of the day and the airport experiences regular delays (Department for Transport, 2002). Moreover, Heathrow is an important public transport hub, having a large bus station and rail connections to London. The airport is bordered by densely populated areas including housing estates, schools, hospitals, sports grounds and several shopping areas. According to BAA Heathrow, the main source of air pollution coming from Heathrow is chiefly the road vehicles circulating in and around the airport, along with aircraft operations (BAA Heathrow, 2002a).

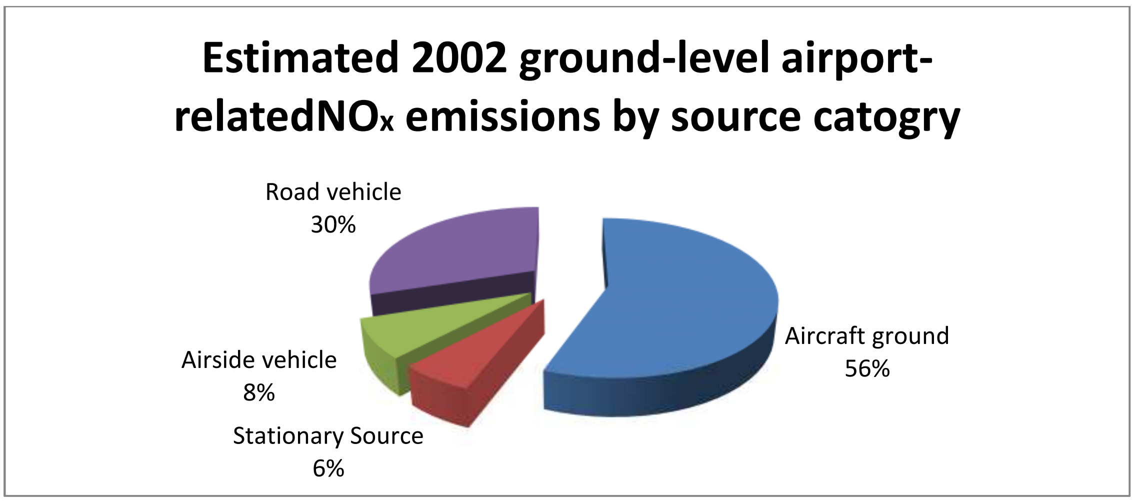


Figure 2.3 Heathrow ground-level airport-related NOx emissions by source category

Source: BAA Heathrow "local air quality action plan 2007-2011"

The Heathrow inventories include emissions from the following source categories: a) aircraft in the landing and take-off (LTO) flight phases up to 1,000m, b) auxiliary power unit (APU) emissions and emissions from engine testing, c) airside vehicles/plant, d) road vehicles on airport landside roads, e) car parks and taxi queues, f) airport heating plant and g) fire-training ground.

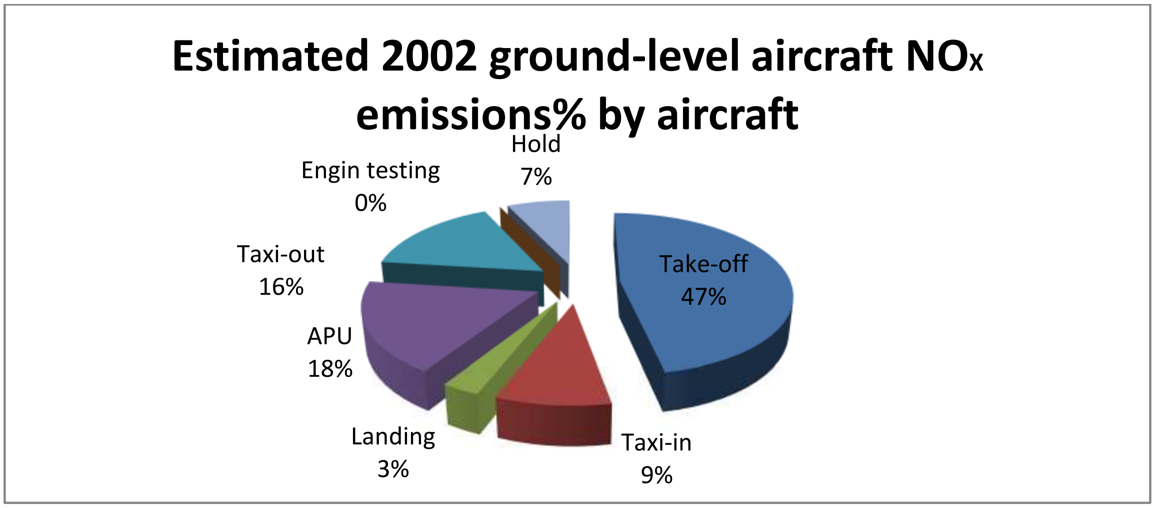


Figure 2.4 Heathrow ground-level airport-related NOx emissions by source category

Source: BAA Heathrow "local air quality action plan 2007-2011"

Based on the emission inventories compiled in Heathrow airport, (BAA Heathrow, 2002a) it was found that aircraft emissions contribute 56% of the total NO_x emissions followed by the landside vehicles (30%), airside vehicles (8%) and stationary sources (6 %) respectively. Further, it was revealed that the dominant source of airport-related emissions from aircraft is during the take-off phase that contributed 47 % of emissions. Other contributors were: APU (Auxiliary Power Units, 18 %), taxi-out (16 %), taxi-in (9 %), hold (7 %) and landing (3 %) respectively. Furthermore, the same study exhibited the estimation of aircraft NOx emissions by aircraft phase; Figure 2.4 presents the results of the study. The DfT has discussed the dominant source of airport-related emissions from aircraft that are the main-engine exhausts during the take-off phase. Consideration is also given to estimation of emissions from auxiliary power units (APUs), brakes and tyres and engine testing.

The emission inventory for London Heathrow airport (LHR) gives a number of postulated future cases, including two-runway cases operating in segregated mode (SM), two-runway cases operating in mixed mode (MM) and three-runway cases (R3). The main input data for this emission inventory is presented in Table 2.2, which is the total movement. Table 2.3 describes the fleet mix for LHR.

Table 2.2 Heathrow input data . *Source: BAA 2002*

Total annual passenger	63.0 mppa
Total annual Movement	**466,554**

Table 2.3Heathrow aircraft fleet mix

Aircraft Code	Aircraft Type	%
319	A319	**10.26**
320	A320	**15.74**
321	A321	**9.47**
343	A349-300	**1.92**
733	A737-300	**3.23**
734	B737-400	**8.58**
735	B737-500	**4.70**
738	B737-800	**1.02**
744	B747-400	**9.61**
752	B757-200	**6.79**
763	B767-300	**2.96**
76B	B767-300ER	**2.95**
772	B777-200	**1.87**
77A	B777-200ER	**5.38**
AB6	A300-600	**1.01**
M81	MD81	**1.02**
M82	MD82	**1.37**
Other		**12.49**
		100

Source: BAA 2002

A breakdown of annual emissions by source category for the aircraft category and the emissions from aircraft on the ground, are shown separately from the emissions from aircraft above the ground because the former are a much more important contributor to ground-level concentrations than the latter. The full spatial distribution of emissions is input to the dispersion modelling, which automatically takes into account that emissions at increasing height have a decreasing influence on ground-level concentrations. For the ground-level emissions, the breakdown enables the contributions from the various LTO flight phases (taxiing, hold etc) to be compared.

Table 2.4: Estimated Heathrow airport-related annual NOx emissions for 2002

Source	NO_X Emissions (tonnes/year)
Aircraft Ground level	
Taxi Out	273
Hold	149
Taking off	653
Landing roll	39
Taxi In	148
APU	385
Engine testing	16
Total ground	**1662**
Initial climb	659
Climb out	13.7
Approach	507
Total elevated	**2483**
Total Aircraft emissions	**4145**
Other sources	
Airside vehicles	**237**
Car park	**27**
Stationary Source	**179**

(Source: BAA 2002)

2.3.1 Gatwick Emission inventory 2002/2003

AEA Technology conducted an emission inventory for Gatwick Airport following the basic methodology of emissions estimation, which was mentioned earlier in this section (Equation 2.1). Modes of the LTO cycle were divided in to eight phases: (1) taxi-out; (2) hold at runway head; (3) take-off roll (from start-of-roll to wheels-off); (4) initial climb (ie, wheels-off to throttle-back, assumed to occur at 450m); (5) climb-out (from 450m to 1000m); (6) approach (from 1000m to touchdown); (7) landing roll (from touchdown); (8) Taxi in (AEA, 2003). The emission factors for aircraft engines used in Gatwick are the ICAO databank which gives certification test results for most of the engines in service.

According to the AEA report the total aircraft of Gatwick airport movements has increased from 233,896 in 1996/7 to 244,989 in 2002, and the total NOx ground -level emission estimate (588 tonnes/year). Table 2.6 provides a break down by source category for NOx emission and is observed that the aircraft emissions are the dominant contributor to total airport-related NO_x emission.

Table 2.5: Estimated Gatwick airport-related annual NOx emissions for 2002/3

Source	NO_X Emissions (tonnes/year)
Aircraft main Engine	**1589.79**
Ground level	**587.69**
Taxi Out	95.56
Hold	40.30
Taking off	68.13
Landing roll	26.75
Taxi In	68.13
APU	134.73
Elevated	**1002.11**
Initial climb	286.52
Climb out	438.57
Approach	277.1
Airside vehicles/ plant	114.31
Airport-related landside road vehicles	199.86
Road network	184.71
LDVs	**111.67**
HDVs	**73.03**
Public Car Parks	7.01
Staff Car parks	6.75
Taxi	1.40
Stationary Sources	21.43*
Heating Plant	21.33
Fire training	0.20*
Total Airport – related	**1925.39**
Non airport	
Net Work non – airport road vehicles	646.31
LDVs	313.64
HDVs	332.68

Source: AEA 2003

2.3.3 Athens International Airport (AIA)

Athens airport emissions inventory was based (Theophanides and Anastassopoulou, 2009) on EDMS as required by the Environmental Protection Agency (EPA). The programme incorporates the EPA's NONROAD and MOBILE6 models for contributions from ground support equipment (GSE), buses and cars. Those authors assumed a reduced number of taxi paths and gates that represented the majority of traffic flow. They found that 75 tonnes VOCs (a tonne is a metric ton or 1000 kg) and approximately 360 tonnes NO_x per year per 100,000 aircraft movements came from the airport activity. The NO_x results produced from EDMS were within 10% of the values published by AIA (~390 tonnes NO_x per year per 100,000 aircraft movements). These results were compared with other airport such as Zurich International Airport, Gatwick International Airport, Atlanta International Airport, Dulles international Airport and Chicago International Airport (Theophanides and Anastassopoulou, 2009).

2.3.4 Bay Area Airports

A study conducted by ISF consulting on behalf of Sun Francisco bay area Metropolitan transport commission in order to assess the impacts of the Bay Area Airports on the region's air quality(ISF, 2010), emission inventories were established for each of the major airports (San Francisco International (SFO), Oakland International (OAK), and Norman Y. Mineta San Jose International (SJC)) for each current baseline and future scenarios (ISF, 2010) .The general approach in developing the Bay Area Aircraft Emission Inventory was to develop an airport specific emission inventory for each of the three major airports in the region (SFO, OAK, SJC) using the latest version of FAA's EDMS 5.1.1 tool. These airport emissions are a small fraction of the total Bay Area emissions. Airport related NOx emissions compose 4.0% of the total Bay Area NOx emissions, followed by VOC at 2.7%, CO_2 at 2.6% and CO at 2.1%. The GSE CO emissions contribute the largest percentage to the total airport emissions ranging from 35.6% at OAK to 52.8% at SFO; GSE NOx percentage ranges from 11% at SFO to 16.8% at SJC; and VOC percentages range from11% at SFO to 16.8% at SJC, with GSE CO_2 emissions much smaller at just about 2% at each airport. All three of the Bay Area Airports have long-term objectives to electrify GSE. These efforts represent a significant reduction in future GSE emissions of CO, VOC and NOx. Thus the analysis has assumed that by 2035 all ground support equipment (GSE) at the three Bay Area Airports will be electrified resulting in no on-airport emissions from GSE (ISF, 2010).

2.3.5 Denver International airport

The development of the airport pollutant emissions inventory was conducted using the Emissions and Dispersion Modelling System (EDMS 4.2) for Denver International Airport. The pollutants assessed in the airport emissions inventories include carbon monoxide; ozone precursors: volatile organic compounds (VOC) and oxides of nitrogen (NO_x); and PM_{10} (Ricondo & Associates, 2005).

NO_X emission for Denver International airport presented in Table (2.6) for the year 2001, 2009, 2010.2013,2020, and 2030.

Table 2.6 NO_X (tonnes\year) Emission estimation for Denver International airport

	2001	**2009**	**2010**	**2013**	**2015**	**2020**	**2030**
Aircraft	2,322,43	2,899,20	2,979,45	2,979.45	3,379,03	4,129,90	4,512.77
Airport Equipment	771,23	637,36	732,76	637,37	528.84	530,20	569,00
fire fighting training	0.08	0.16	0.17	0.16	0.17	0.22	0.22
Minor point sources	41	52,94	54.52	54.52	61.72	78.10	86.03

Source: (Ricondo & Associates, 2005)

2.4 Estimation and measurement of specific pollutants

2.4.1 Nitrogen dioxide measurements methods

Air pollutants are monitored for research, information, policy and statutory purposes. Nitrogen dioxide concentrations in the atmosphere can be measured using chemiluminescent analysers, diffusion tube samplers, electrochemical sensors, thick film sensors or differential optical absorption spectroscopy (DOAS). An overview of the different techniques can be found AQEG (2004). A summary of these different techniques and their advantages and disadvantages is given in Table 2.7. On the other hand, there is the MESSAGE devise figure (2.5) which was used in the Mobile Environmental Sensing System Across Grid Environment project during (2006-2009) (Cambridge, 2009). This project was carried by Cambridge University, Imperial University, DUVAS Technology and Cambridge City Council, the project team concluded that this device has some advantages such as it is portable and relatively low cost and give good spatial information. On the other hand, the study indicated that the resolution was not good as the chemilumiescnce technique.

Figure 2.5 the message device. ***Source:*** ***http://www.sensaris.com/wp-content/uploads/old/2011/09/Cambridge-Message.pdf***

An overview of the chemiluminescent analyser and diffusion samplers is given below.

A. Chemiluminescent analyser

Chemiluminescence is defined as the emission of light (luminescence) without emission of heat as the product of a chemical reaction (AQEG, 2004). In other words, chemiluminescence describes the process of fluorescence resulting from a chemical sampler, it has a lower detection limit of 1 μg/m^3 and it presents real-time data with short time resolution (< l hr).

It depends on the principle that NO and O_3 react to generate a quality luminescence with intensity, linearly proportional to the NO concentration. Infrared light emission results when electronically excited NO_2 molecules decay to lower energy states. Specifically,

$NO + O_3\text{-}NO_2 + O_2 + h\nu$

Nitrogen dioxide (NO_2) must first be transformed into NO before it can be measured using the chemiluminescent reaction. NO_2 is transformed to NO by molybdenum NO_2 to NO converter heated to about 325 °C (AQEG, 2004).

Technique	Advantages	Disadvantages
Chemiluminescence	The reference method specified in the EU First Daughter Directive. Lower detection limit of ~ 1 µg m-3. Provides real-time data with short time resolution (<1hr) that can be used for public information	Relatively high capital cost.
Diffusion tubes	Low capital and operating costs. Possible to carry out surveys over wide geographical areas to provide information of the spatial distribution of NO_2 concentrations. Require no power supply, and minimal training of site staff. Site calibrations are not required. Lower detection limit of ~2-3 µg m-3for a 4 week exposure period.	Only provide concentrations averaged over the exposure period (typically 4 weeks).Accuracy of the method, and bias relative to the reference sampler, is dependent upon the method of tube preparation and the laboratory completing the analysis. Results need to be 'bias-corrected' before comparison with limit values and objective
Electrochemical Sensors	Portable samplers that can be easily deployed in the field.	Lower detection limit of some samplers (~200 µg m-3) makes then unsuitable for ambient monitoring.
Thick-film sensors	Portable samplers that can be simply deployed in the field. Possible to measure a number of pollutants simultaneously. Offers real-time data with short time resolution (<1 hr) that can be used for public information. Lower detection limit of ~4 µg m3.	At this time, the sensor for NO_2 has not been commercially released. Only measurements of NOx may currently be carried

DOAS	Concentration integrated over the length of the light path. Gives an ‘average’ concentration that can be beneficial to evaluate public exposure. Possible to measure a number of pollutants simultaneously. No inlet manifold required. Offers real-time data with short time resolution (<1 hr) that can be used for public information. Lower detection limit of ~ 1 µg m-	The integrated measurement cannot be directly compared with the EU limit values or the air quality objectives (which are set for a single point measurement).Relatively high capital cost. Weather conditions, such as fog or snow, can affect the Instrument performance.

Table 2.7 Summary of advantages and disadvantages of NO_2 measurement

Source: AQEG 2004

B. Passive diffusion tube measurement

Diffusion tubes are widely used to carry out surveys over wide geographical areas to provide information on the spatial distribution of specific air pollutants (Kirby, et. al., 2001). Measurement using passive diffusion tubes provides an average concentration over the total exposure period. A diffusion tube sampler consists of an acrylic tube that can be sealed at both ends. This technique is based upon Fick's Law as given below:

$$F = D\frac{\delta C}{\delta Z}$$

Where F is the molar flux (mol cm^{-2} s^{-1}),

D is the diffusion coefficient (cm^2 s^{-1}),

C is the concentration (mol cm^{-3}),

Z is the diffusion path coordinate (cm).

This is the principle of passive diffusion of NO_2 molecules on an absorbent triethanolamine. During sampling, one of the ends of the tube is open and the other contains the absorbent. The gas molecules diffuse from the area of high concentration (open end) towards the area of low concentration (absorbent). The law states that the one-way flow of gas is proportional to the concentration gradient in the tube. The quantity of nitrogen dioxide absorbed is proportional to its concentration in the environment. The closed end of the tube has stainless steel grids covered with triethanolamine. The tubes must be prepared in a clean atmosphere in order to minimize contamination by atmospheric nitrogen dioxide. The open end is then sealed. The tubes are stored in sealed containers before exposure. (AQEG, 2004)

The tube is then placed vertically (open end downwards) after exposure. It tube is sealed again and taken to the laboratory for analysis. The sampling can last up to two weeks. The trapping method is very selective; however PAN can interfere. The disturbance caused by this type of pollutant is negligible because of its formation in areas that are far from the sources of the precursor pollutants (VOCs NOx). In the laboratory, all the NO_2 absorbed in the form of nitrite is extracted from each tube. Before analysis, a dinitrogen complex must be formed through a chemical reaction. The quantity of this dinitrogen compound is analysed by molecular absorption spectrometry at a wave length of 540 nm. The spectrometer is calibrated on standard nitrite solutions. The total quantity of NO_2 absorbed can then be determined. (AQEG, 2004)

This technology is useful for carrying out large-scale spatial surveys of NO_2 over time periods ranging from weeks, months or a year (Bush et al., 2001; Stevenson et al., 2000). It does not require maintenance or a power supply at the sampling site (AQEG, 2004). Studies in Sweden, Krochmal and Kalina, (1997) have shown that there is good agreement between diffusion tubes measurements and automated ones with high precision.

The factors affecting the performance of diffusion tubes are also important for research, in order to ensure the accuracy of the measurements. Nevertheless, several studies have indicated that diffusion tubes tend to over-estimate or under - estimate NO_2 concentrations (Heal, et al., 1999; Kirby, et al., 2001), since climatic variability such as high wind speed may influence the performance of the diffusion tube sampler in the field.

There are several factors affecting the performance of diffusion tubes, such as exposure setting, location and duration (AQEG, 2004). It is significant that the performance of diffusion tube sampling has been tested widely in examined in many studies in European climatic conditions Kasper-Giebl and Puxbaum (1999), Ferm and Svanberg (1998), as they were never tested for the hot arid environment of UAE, where ambient temperature remains above 45°C in summer with high UV sunlight.

Numerous studies have been conducted using passive sampler techniques to measure NO_2 concentrations. The description of some earlier studies using diffusion tubes is given in Table 2.8.

Table 2.8: Nitrogen Dioxide diffusion tubes Measurements methods

Author	Study	Remarks
Palmes, et al., (1976)	Personal sampler for nitrogen dioxide.	The sampler depends on the transfer of NO_2 by diffusion to a triethanolamine-coated collector at the sealed end of a tube; the open end of the tube is exposed to the test environment. The devices are accurate, light, simple to use and have very good shelf life before and after sampling
Atkins, et al., (1987	The measurement of nitrogen dioxide in the outdoor environment using passive diffusion tube sampler	The sensitivity of two types of Palmes diffusion tubes for NO_2 have been evaluated in this study. This was under field conditions by exposing the two types of Palmes diffusion tube simultaneously carried out at the Bockenheim (Frankfurt) air monitoring station, where NO_2 is continuously monitored by a chemiluminescent NO_2 analyser. Results obtained indicated that:- The Passive Sampling tube with a 8.20 cm in length is more sensitive and reliable, based on obtained accuracy values of 1.40-15.00%. The accuracy of the diffusion tube with length 7.47 cm varied from 10.70-36.80% of the actual value (continuous monitor).
Hedley, et al. (1994)	An evaluation of integrating techniques for measuring atmospheric nitrogen dioxide	This study is to evaluate two integrating techniques for measuring ambient NO_2. Both techniques involved quantitative collection of NO_2 in a reagent-coated cartridge, specifically triethanolamine (TEA)-coated silica gel and diphenylamine (DPA)-coated Florisil, The evaluation consisted of laboratory and field studies. The results shows the following: - The laboratory studies of the TEA method showed collection and reaction efficiencies of 100 and 90%, respectively. A positive interference occurred when O_3 and NO were passed through the cartridge at the same time. PAN was found to generate a 67% positive interference. The

		ambient concentrations determined using the TEA method were approximately a factor of two higher than those determined using TDLAS. For the DPA method the collection and reaction efficiencies were determined to be 100 and 64%, respectively. O3 produced a negative interference by reacting with the NO_2-DPA products. PAN produced a 42% positive interference
Heal and Cape (1997)	There appears to be no simple method for retrospectively correcting NO_2 measurement data obtained using diffusion tubes since the overestimate is not simply related to the average NO/NO_2 or NO/O_3 ratios, but a numerical evaluation of chemical interferences in the measurement of ambient nitrogen dioxide	The study demonstrates the following findings: - A one-dimensional model of the sampler supporting diffusive transport and chemical reaction has shown that NO_2 concentrations are steadily overestimated as a result of chemical reactions in the tube, influenced by the reaction of NO with O_3 to give NO_2 The contribution of PAN and other potential interferons is shown to be small for UK conditions. The degree of overestimation depends on the direct NO/NO_2 ratio and on the relative concentrations of NO and O_3. The model illustrates that diffusion tubes effectively measure NOx rather than NO_2 concentrations; although in practice the difference between NO_2 and NO concentrations is likely to be within the measurement uncertainty. Passive diffusion samplers may give reliable concentration data for NO in rural air; they cannot be used with confidence in polluted urban air to estimate NO_2 concentrations.
Heal, et al., (1999)	Overestimation of urban nitrogen dioxide by passive diffusion tubes: A comparative exposure and model study	This study was carried out in Edinburgh, UK. Acrylic, foil-wrapped and quartz tubes were exposed in parallel for 1-week and 4-week periods at three urban sites equipped with continuous analysers for NO, NO_x and O_3. Hourly NO_2, NO and O_3 data for 20 1-week exposures were used as input to a numerical model of diffusion tube operation incorporating chemical reaction between co-diffusing NO and O_3 within the tube. The paper concluded that: -

		Standard acrylic passive diffusion tubes considerably overestimated NO_2 concentrations relative to chemiluminescence analysers, by an average of 27% over all sites for 1-week exposures, no major difference was observed between standard and foil-wrapped acrylic tubes (both UV blocking). The 4-week exposures yielded steadily lower NO_2 concentration than average NO_2 from four sequential 1-week exposures over the same period. The reduction in the apparent NO_2 sampling rate with time most likely arises from in situ photolysis of trapped $NO_{2.}$ The mean calculated overestimation of 22% for NO_2 from the PDT model simulations is close to the average difference between acrylic PDT and analyser NO_2 concentrations (24% for the same exposure periods), showing that within-tube chemistry can account for observed discrepancies in NO_2 measurement between the two techniques. PDT NO_2 concentrations were correlated with both analyser NO_2 and NO_x suggesting that acrylic PDTs retain a qualitative measure of NO_2 and NO variation at a particular urban location
Bush, et al., (2000)	Validation of nitrogen dioxide diffusion tube methodology in the UK.	Measurement of NO_2 concentration using six different diffusion tube exposure procedures were made and compared with continuous monitoring data, the study was designed to investigate, any difference between 2 and 4 weeks exposure period. The potential effect of light and wind turbulence on diffusion tubes measurement. The maximum exposure period for comparison with chemiluminescent analysers this paper concluded the: - The overall difference between diffusion tube measurement and chemiluminescent measurement of NO_2 was well within the estimated uncertainty associated with continuous monitors. Major correlations were found between all diffusion tube exposure types and corresponding chemiluminescent measurements data.

Stevenson, et al., (2000)	Five years of nitrogen dioxide measurement with diffusion tube samplers at over 1000 sites in the UK.	This paper demonstrate: - How diffusion tubes can be utilized in large numbers to determine a wide spatial distribution of nitrogen dioxide throughout a country the size of the UK. The need for careful quality control in relation to the organization of the survey (site location, survey, timetable) The harmonization of analysis undertaken by different laboratories
Heal, et al., (2000)	Systematic biases in measurement of urban nitrogen dioxide using passive diffusion samplers	Passive diffusion tubes were deployed in the centre of the city of Cambridge, UK results were compared with chemiluminescence analyser which provided hourly NO and NO_x and continuous O_3 analyser The paper concludes: - Samplers basically overestimate NO_2 by 10-50% because of reaction in the tube between co-diffusion of NO and O_3. Cumulative NO_2 sampled by passive sampler decreases proportionately as exposure time increases.

Source: collected by the author from the different studies

2.5. Modelling air pollution around airports

Air Quality Modelling produces the ambient concentrations of contaminants in the atmosphere without actually measuring them. Generally, for regulatory work, a modelling approach is an acceptable alternative to determine the resulting concentrations of a pollutant at various locations around the source, because the cost of setting up monitoring stations at all desired locations around a source is very high. Dispersion modelling uses the source characteristics and the meteorological conditions in order to estimate the atmospheric dispersion of the pollutant and the resulting concentrations at various locations. The results from the dispersion modelling are also used in the preparation of health risk assessments. In addition, they are used to support laws and regulations that are designed to protect air quality.

2.5.1. Meteorology

At any given location, NO_2 concentration is determined by a number of variables: the NOx emissions source, the rate at which these emissions are dispersed and the area over that they are transported. Meteorology of winds, turbulence mixing and dilution, play a significant role in controlling dispersion and accumulation of NO_2. The pollutant emitted into the atmosphere is generally transported, dispersed and deposited in the lower part of the atmosphere.

The boundary layer can be subdivided into four separate component layers: the surface layer, the mixing layer, the stable layer, and the residual layer. The surface layer is the sub layer closest to the earth where turbulent stresses are relatively constant. Between the surface layer and the earth's surface is a very thin layer dominated by turbulent motion. Above the surface layer is either the mixed layer or the stable layer, depending on the temperature structure of the boundary layer. During the daytime surface heating leads to convective motion in the boundary layer. Heat transfer from the surface to form rising warm air. Radiative cooling from clouds forms sinking cooler air. Convective motion also leads to significant turbulence that mixes the air within this layer. As a result of the convective motion, significant mixing of the air occurs; this sub layer is called the convective layer or mixed layer. Above the mixed layer is a stable layer that prevents the continued upward motion of thermals. This stable layer also restricts turbulence, preventing frictional influences from reaching above the boundary layer. During the day, the mixed layer reaches heights over 1 km and makes up the entire layer of the boundary layer above the surface layer. However, the mixed layer vanishes with the sun as the thermally driven convection ceases. After sunset, convective motion decreases considerably. However, the earth's surface still affects the air, and a stable boundary layer forms (also called the nocturnal boundary layer). This boundary layer by light winds and more sporadic turbulence than in the mixed layer.

The structure of the atmospheric boundary layer can be:

Unstable/convective - characterized by light winds and strong surface heating and consequently strong vertical mixing:

ii) Neutral - characterized by high winds and/ or weak surface heating or cooling:

iii) Stable - characterized by night time conditions of light winds, clear skies and negative surface heat flux (cooling).

The boundary layer is mostly governed by the three following factors:

The heat flux in the atmosphere surface, this is determined by such factors as the solar radiation reaching the surface, the absorption and release of latent heat by water vapour near the surface, especially around vegetation and over water sources, and heat absorbed or released. The temporal and special variations in the heat flux are also important in determining the structure of the boundary layer.

The roughness and change in elevation of the earth's surface. The effect caused by many obstacles such as buildings, the roughness element obstructing and hence decelerating the air flow:

The airflow at the top of the boundary layer, free from the influence of general roughness, is usually referred to as geotropic wind determined by large scale pressure gradient.

The urban boundary layer is more complex than that of the rural areas as the roughness of the sub layer is vertically much larger, due to taller buildings and occupies the first tens of meters above surface. The urban canopy layer that is a part of the rough sub layer is composed of individual street canyons (AQEG, 2004).

Though meteorology is important in urban pollution prediction, the results of such assessments are validated against measured concentrations and not meteorological variables.

2.5.2 Chemical Processes.

NO_2 is a chemical compound that is emitted as a primary pollutant from combustion processes and is generated in the atmosphere as a secondary pollutant. One of the main mechanisms of generation of NO_2 on the urban scale is by reaction of NO with O_3. In spite of the complexity associated with the chemical reactions and mechanisms involved in the generation of NO_2, an approach to characterise concentrations of coexisting NO, NO_2 and O_3 compounds into the atmosphere is widely used. This approach relies on the assumption of the existence of the photostationary state (PSS) among these chemicals compounds. A PSS condition comprises a situation of chemical equilibrium with steady state conditions in a sunlit atmosphere, using an average photolysis rate that leads to increase in proportion of NO_2 as NO_x increases AQEG (2004).

2.5.3 Type of Models

A model inter-comparison study was conducted in collaboration with UK DfT for Heathrow Airport "Project for the Sustainable Development of Heathrow Airport " (PSDH, 2006) the models used were the empirical models, LASPORT which is Lagrangian model and has been specially developed for the dispersion modelling of airport sources. ADMS and EDMS which both are Gaussian type model. In this section a review of the EDMS will be given since it is the model used in this research with highlight on empirical modelling which can be used along with EDMS to determine the NO_2 concentration.

Britter, et al., (2005) who took part of the study mentioned above provided a brief summary of the model, including comments on the scientific foundation, an outline of the input data used and the method of model implementation. The modelling approach implemented was to model the airport itself and a reduced network of roads in the vicinity of the airport. This approach requires the specification of background concentrations of the air flow entering the modelled region. Meteorological data were obtained from the meteorological station on-site. The predicted concentrations were compared with monitored data, both as annual averages and as hourly time series. The pollutants that were investigated are NO_x, NO_2 and PM_{10}, using the Emission and Dispersion Modelling System (EDMS, version 4.3). In addition, 10 monitoring stations were used in comparison with model results (aircraft concentration only), as annual and hourly averages Britter, et al., (2005).Heathrow Emission Inventory 2002 has been used as base of the study, but emissions estimation from aircraft and aircraft operations using the EDMS internal database were conducted. However the author has highlighted that they had to modify some aircraft configurations to produce emissions consistent with the Heathrow Emission inventory 2002. In addition, other inputs were used as meteorological data and topography of the area and the emission locations, such as the LTO cycle, includes runways and taxiways, gates, car parks, airport close road network, buildings, engine testing and other stationary sources Britter, et al., (2005). Moreover, an empirical model is used to estimate the NO_2 concentration because EDMS does not have the ability to model $NO_{2.}$ .According to the study, the annual average results are satisfactory between the modelled and monitored concentrations with the differences between them lying in range of 5 - 12 % and 24 % for estimated and monitored NO_x and NO_2, respectively. The total NO_x predictions were quite similar for all the models. The authors recommended, in order having a better usage of EDMS, the model needs more computer running times to get more model features.

On the other hand, empirical estimations of NO_2 concentration is widely cited Stedman et al. (2001, 1998), Carslaw et al. (2001), Laxen & Wilson (2002), Jenkin (2004a) Jenkin (2004b) and Clapp & Jenkin (2001). They were established to address the relationship between hourly mean NO_2 and NO_X and between annual mean NO_2 and NO_X concentrations. Empirical models founded on air quality data and some assumptions such as correlations between meteorological variables and pollutant concentrations. The chemistry is based on the NO_2-NO_X relationships and transport and dispersion are described using regression analysis. Furthermore, estimation of ambient concentration of NO_2, NO and O_3 was examined by (Jenkins, 2004). Using this method for predicting NO_2 offers a better way of treating the NOx to NO_2 relationship by representative expressions which account for the chemical coupling of O_3, NO and NO_2 within the atmosphere (DEFRA, 2005). These estimations are suitable for extrapolations in spatial and temporal terms.

2.6 Introduction to estimation of CO_2 emission from Aviation Activities.

The Intergovernmental Panel on Climate Change (IPCC) published its report in 1991, Aviation and the Global Atmosphere; it was the first comprehensive assessment of aviation's impact on climate change.

The IPCC determined that aviation emissions presently account for approximately 2 percent of global human- generated carbon-dioxide emissions. The 2 % estimate consists of emissions from all global aviation, both commercial and military.(IPCC,1999)

Emissions from aircraft include greenhouse gases like carbon dioxide (CO_2) and water vapour (H_2O). Furthermore, aircraft emit (NO_x) into the troposphere and lower stratosphere, where they influence (O_3) and (CH_4) concentrations via chemical processes. Emissions from aviation come from combustion of jet fuel (jet kerosene). Jet kerosene based fuels, like JET A-l, are utilized by most commercial aircraft. Major products from the combustion are carbon dioxide 70% CO_2, and little less than 30% H_2O, 1% each of NOx, CO, SOx, NMVOC, particulates (IPCC, 2006). In an ideal combustion of 1 kg of such fuel results in 3.156 kg CO_2 and 1.237 kg H_2O. However, aircraft consumption considerably depends upon the distance travelled. Theoretically, the absolute fuel consumption is higher in total when the flight distance is greater. On short haul flights, the relative consumption per 100 km travelled is higher than the medium haul flight, this is due to the fact that take-off and initial climb require a great deal of energy and have a greater effect on short haul flights. Long haul flights also consume more fuel per 100 kilometres than medium haul flights due to the significant portion of the flight; the aircraft has to carry fuel which is only used at the end of the flight. Several other factors, which influence the fuel consumption per passenger during aviation transportation, are discussed in the subsequent section.

2.6.1 Factors affecting the fuel consumption during flight.

A. Flight Distance

Fuel consumed is proportional to the force of resistance that must be countered by the force of the engine's propulsion which is proportional to the haul. Throughout the landing/take-off (LTO) cycle, the engine is at full thrust and maximum fuel is consumed during this phase. On the other hand, during the cruise phase the rate of fuel use decreases (IPCC, 1999).

B. Flight Occupancy rate

A flight that is at full load burns less fuel per passenger than a flight that has less than its full load. Therefore, with full occupancy, an aircraft will fly at maximum efficiency. The flight occupancy may be an important factor for calculating the overall CO_2 emission load during emission inventory studies.

C. Seat Class

In aircraft, seat type is an important feature and generally, first and business class seats are larger and take up more space. Consequently, a passenger travelling in business or first class is responsible for more emissions because they have effectively excluded additional people from travelling on the same flight (IPCC, 1999).

D. Aircraft Type

The type of aircraft has direct effect on the emission inventory. The type of engine and other characteristics of aircraft engine, influence the emissions through the flight. In general, older aircraft are less efficient than newer models. Most calculation methodologies use an average based upon all planes or any typical commercial plane (IPCC, 1999). The European Environmental Agency (EEA, 2006) completed an emissions inventory of all aircraft operating in the EU, including the amount of fuel used and emissions per stage length. Using fuel consumption data for different stage lengths, four categories of aircraft are compared for their fuel burn and standardized for the number of seats on each aircraft. The representative aircraft and seat numbers from each of the categories are as follows; turboprop (Saab 2000, 52 seats), regional jet (BAel46, 100 seats), narrow body (Boeing 737-400, 137 seats), wide body (Boeing 747-400, 366 seats) and Boeing 2008, Airliners, 2008.

The regional jet and the wide body jet have a constantly higher fuel burn per seat than the turboprop and the narrow body aircraft. For short stage lengths below 1000 km, turboprops have the smallest number of kilograms of fuel burned per seat. At 1100 km, the narrow body aircraft turned out to be the aircraft with the smallest amount of fuel burn per seat. As a result, an aircraft size is matched to certain routes based upon the most efficient use of that aircraft size over a certain stage length. Since fleets (airlines) have different ranges, operating speeds and fuel burn rates, matching fleet to routes could help minimize fuel burn.

E. **Taxiing time**

Taxiing time is the time spent by aircraft to access the terminal area from the runways. From an environmental point of view, improved taxiways reduce emissions at the airport by providing quicker and more direct taxi routes with fewer stops, turns and runway crossings. Aircraft engines produce more CO_2 emissions per unit of fuel while taxiing than other phases of airport operation.

F. Transported Cargo

Most airlines transport both passenger and cargo in passenger aircraft in order to make the most effective use of the aircraft. Therefore, when calculating the fuel consumption in flight the transported cargo should be counted, otherwise the fuel consumption per passenger would tend to be high.

2.6.2 Aviation CO_2 estimation methodologies

The CO_2 from an aircraft is attributed to different modes of the flight with each using fuel at different rates. Emissions occur during the two flight phases (Figure 2.4) which can be considered for emissions calculations: The Landing and Take-Off cycle (LTO) which includes all activities near the airport that take place below the altitude of 3000 ft (1000 m). The Climb, Cruise and Descent cycle (CCD), which is defined as all activities that take place at altitudes above 3000 ft (1000 m).

This division into two flight phases (those above and below 3000 ft) follows the IPCC Tier 2 methodology. Rypdal (2000) analysed the tiered methodology in the Greenhouse Gas Inventory Reference Manual (IPCC, 1996). The main finding was the difficulty and the uncertainty which lies in the distribution of fuel between domestic and international use.

2.6.2.1 The IPCC three-tiered methodology

The IPCC (2006) provides a three-tiered methodology in the "Greenhouse Gas Inventory Reference Manual" as described below: -

Tier 1, the first-tier "Tier 1" is based on total number for aviation fuel consumption to be multiplied with emission factor.

Tier 2, two flying phases are estimated separately; the LTO emission which is based on statistics on the number of LTOs and default emission factor per LTO per aircraft type. This methodology gives all emission factors per LTO.

Cruise phase = total fuel - fuel use in LTO which is then multiplied by the emission factor to obtain the emission.

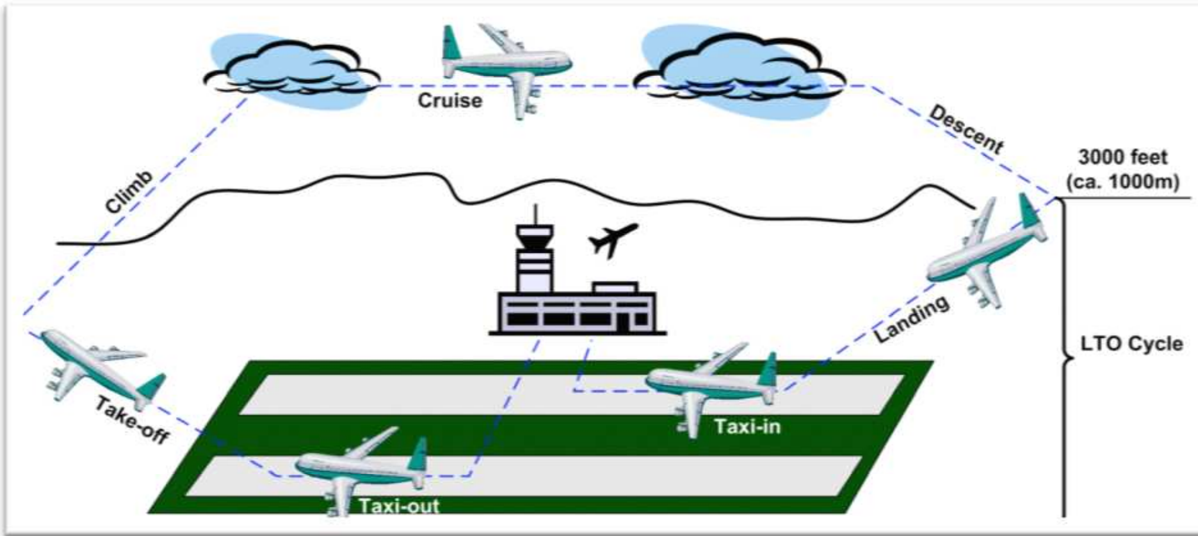


Figure 2.6: The two flight phases of an Aircraft (*Source: Rypdal, 2000*)

The IPCC guidelines provide a further split of Tier 2 into Tier 2a and Tier 2b methods. The IPCC Good Practice Guidance (IPCC, 2000) presents a decision tree to help inventory compilers choose the highest possible Tier to use based on the data available to them. Figure 2.7 presents the methodology decision tree for aircraft.

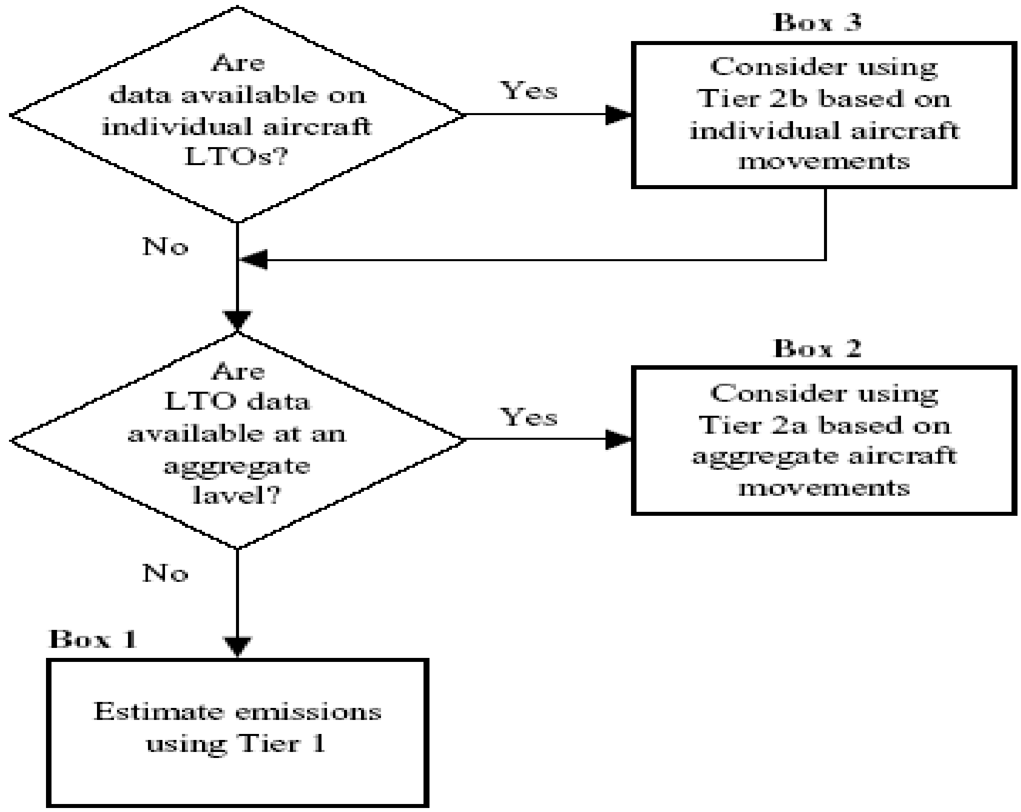


Figure 2.7: The methodology decision tree for aircraft. Source IPCC Good Practice Guidance *(IPCC, 2000)*

In Tiers 1 and 2, it is assumed that the fuel sold is equal to the fuel used. Moreover, the fuel used in the cruise phase is estimated as a residual: total fuel use (sold) minus fuel used in the LTO phase of the flight. Fuel use is estimated for domestic and international aviation separately. **Tier 2** method is preferable instead of Tier 1 if the LTO data are available for individual aircraft. The accuracy of these two methodologies relies greatly on the quality of fuel statistics or fuel consumption data. **Tier 3,** depends on the number and type of aircraft operations, the types and efficiency of the aircraft engines, the fuel used and the flight distance. Consequently, these methodologies are bottom-up, flight-based, rather than top-down calculation-based on the fuel consumed as in Tiers 1 and 2. The choice of methodology usually depends on the data available, such as the type of fuel and the relative importance of aircraft emissions. The European Environmental Agency (EEA) distinguishes Tier 3 method into two categories: Tier 3A which takes into account cruise emissions for different flight distances and Tier 3B which is the calculation of fuel burnt and emissions throughout the full 4-D trajectory of each flight phase, using aircraft and engine-specific. It also requires data such as latitude, longitude, altitude, and time (EEA, 2009). The reasons for undertaking higher tier methodologies are that they give the possibility to obtain time series reflecting changes in technology, verify the estimates, report emissions from cruise and LTO separately. Tier 2 is used as an alternative of Tier 3 if LTO and aircraft type data are available. But no information is available on cruise distance (Lee, et al., 2005). In Tier 3, the aircraft details must be available, that include the information on distance. Emission factors can be obtained from the EMEP/EEA Guidebook website, the methodology is listed in spread sheets for each aircraft type and contain fuel consumption (kg), emission and emission factors(g/kg fuel) for each phase of the flight. To calculate the fuel used during the flight, the sum of fuel used for LTO is taken, plus the fuel used in the cruise phase. The spread sheets also include a table of pollutants emitted such as CO, HC, NO_x. Moreover, if the fuel statistics are not reliable, a bottom-up approach or Tier 3 will provide much higher accuracy.

2.6.2.2 International Civil Aviation Organization (ICAO) methodology

ICAO methodology utilizes a distance based approach to estimate an individual aviation emission, using data available on a range of aircraft types; in another words, it follows the Tier 3 a methodology. The calculation is based on the great circle distance between the airport of origin and the destination airport. In order to calculate the average fuel consumption for the journey, the passenger load factor and passenger to cargo ratio are obtained from traffic and operational data collected by ICAO and applied to obtain the proportion of total fuel used per passenger. This is then divided by the total number of economy class passengers. The result is then multiplied by 3.157 to obtain the amount CO_2 footprint to each passenger travelling.

CO_2 per passenger = 3.157 x (total fuel x passenger-to-freight factor) / (Number of Y-seat x passenger load factor)

Where, Passenger - to- freight factor = is the ratio calculated from ICAO statistical data based Number of Y-seats = the total number of economy equivalent seats available on all the flights serving the given city pair.

Passenger load factor = the ratio calculated from ICAO statistical data base based on number of passengers transported and the number of seats available in a given route group.

Moreover, the load factor and passenger to the cargo factor in the ICAO methodology are based on revenue mass basis using historic freight and mail number specified to the city pair which is being considered. In another words, it is based on the assumption that the average flight allocation for an average passenger mass with baggage is assumed as 100 kg, plus a 50 kg added on, to account on board infrastructures associated with passenger use, such as weight of seats, and other equipment that passengers use in a normal flight. Therefore, the total mass then is calculated as:

((Total No. of Passengers x 100 kg) + (No. of seats x 50 Kg))/1000(tonnes) = Freight (tonnes) +Mail (tonnes)

By using the historical traffic data, it is then possible to calculate the total mass using the above formula. However, there are some limitations of ICAO methodology, such as the cabin class factor being very simplified and divided to two classes only i.e. premium and economy, and the fuel consumption for each aircraft varies from one aircraft to another even if they are the same type, depending on the age of aircraft; but the ICAO, using the CORTNAIR as data source, does not include the age of the aircraft.

2.6.2.3 Global emission inventory models

There are models that calculate aircraft emissions globally such as SAGA, which was developed by the United State Federal Aviation Administration (FAA) and applies the Tier 3B methodology (Kim, et al., 2007) and the AERO2K, which was developed by the European Commission (EC) and applies the Tier 3B methodology, using data from radar traced flight data from North America and Europe showing actual latitude, longitude and flight path (Eyers, et al., 2004). Moreover, a carbon calculator methodology developed by Sabre Holdings was introduced by Jardine (2009). Sabre is a computer reservations system which also applies the Tier 3B methodology (GDS) used by airlines, railways, hotels, travel agents and other travel companies. The Sabre database contains information about all flights including the data of travel, airline departure points and destinations and flights (model and seating configuration). The model uses SAGA model to give fuel burn for a large number of aircraft.

2.6.2.4 ICAO aviation data

The ICAO presented a paper in 2008 (GIACC/l-SD/3), *(Review of aviation emission-related activities within ICAO and internationally)* which relates to data on aviation fuel burn and other sources such as CAEP. ICAO receives annual data which it uses to analyse differences in the financial operations of international airlines throughout the world, using data on fuel and aircraft type. Therefore, CO_2 estimation is possible and could be broken down to region, country, airline and aircraft type. The paper highlights that the scheduled operation could be subject to flight cancellation, but at the same time it considers that the ICAO data are exceptional in terms of the world coverage. In addition, the results were compared with data from other models such as FAA's AEDT, SAGA or EUROCONTROL's AEM and ICAO data were performing around 4%. ICAO regions global estimates included both Annex 1 and Annex 2 countries and the top 10 countries in airlines that have the highest aviation fuel consumption. Table 2.6 presents the ICAO results for the fuel consumption by top 20 countries of departure. The UAE is 11th worldwide; this may be due to Dubai airport being the busiest in the country and the region. On the other hand, according to the ICAO data the UAE is third in the top ten list of fuel consumption by cargo service. Table 2.10 presents ICAO cargo results.

Table 2.9 Fuel consumption (in million litters) by top twenty countries of departure

	Country of departure	**Fuel**
1	United states	**74 584**
2	China	**18 282**
3	United Kingdom	**11 804**
4	Japan	**11 678**
5	Germany	**8 611**
6	France	**6 715**
7	Australia	**5 354**
8	Canada	**5 121**
9	Spain	**4 953**
10	Russia	**4 635**
11	United Arab Emirates	**4 038**
12	Korea	**4 037**
13	Netherland	**3 983**
14	Italy	**3 974**
15	Thailand	**3 966**
16	Singapore	**3 889**
17	Brazil	**3 642**
18	India	**3 556**
19	Mexico	**3 054**
20	Malaysia	**2 374**

Source: ICAO based on OAG timetable.

Fuel consumption expressed in million litters.

Table 2.10: Fuel Consumption for the top ten by cargo service (by country of departure)

SN	Cargo services	Fuel
1	United States	7 750
2	China	2 956
3	United Arab Emirates	1 611
4	Korea	1 111
5	Japan	994
6	Germany	812
7	Netherlands	725
8	France	605
9	India	481
10	Luxembourg	457

Source: ICAO based on OAG timetable

Fuel consumption expressed in million litters

2.6.2.5 CO_2 emission estimation from UK aviation

An emission calculator methodology was developed by DEFRA for all UK sectors, with regard to aviation. DEFRA presented factors for domestic and international flights on several routes using the default average factor for CO_2 emissions, average flight distance and load factors. This methodology was revised to achieve greater accuracy (DEFRA 2009). It used a wide variety of aircraft to calculate emission factors for domestic and international flights with freight transported on passenger planes being taken into account. In addition aircraft specific fuel consumption and emission factors are obtained from EMEP/CORTNAIR Atmospheric Emission Inventory Guidebook (2006).

In the South East and East of England Regional Air Services Study (SERAS) (DfT, 2003), the UK used the Tier 3A and formed estimates based on the assumptions that aircraft use "great circle" routes. In order to avoid recalculating the fuel burn data, SERAS followed an approach in order to reflect differences in average aircraft age and engine technology by including only known aircraft types and performance data. More disaggregated fuel burn data were multiplied by ATM data by destination and aircraft size to give forecasts of total aviation fuel usage. Aircraft fuel usage in tonnes is multiplied by 3.1511 to give CO_2 emissions. SERAS estimates were depending at on the assumption that UK's share of international flights is one-half of the total traffic. The model used fuel burn data for representative aircraft 'types' for domestic, short-haul and long-haul services. This methodology used passenger and freight aircraft movement forecasts which were split by six seat band classes (less than 70 seats, 71-150 seats, 151-250 seats, 251-350 seats, 351-500 seats, and more than 500 seats). Representative aircraft are chosen for each seat band class and aggregated into 15 destination regions (10 international and 5 domestic). Surface access related CO_2 emissions were calculated by multiplying total vehicle km by an average emission rate of 147 grams per km.

In addition, Pejovic, et al., (2008) indicated that SERAS estimates for international aviation in 2000 were about 25% lower (26.1 Mt of CO_2) than the estimates resulting from the improved National Environment Technology Centre NETCEN methodology (32.2 Mt of CO_2).

Watterson, et al., (2004) described another example of Tier 3A application which is the improved model of NETCEN The previous NETCEN model was similar to IPCC Tier 2 (CORINAIR 'Simple') in that it uses fleet-averaged emission factors based on fuel uplifted at all UK airports for the non-LTO flight stages. More detailed information is given for the LTO cycle. The new NETCEN improved method includes emissions per LTO cycle based on detailed airport studies and engine-specific emission factors from the ICAO database. For the cruise phase, fuel consumption and emissions are estimated using distances (GDC) travelled from each airport for a set of representative aircraft. Emissions from additional sources (such as aircraft auxiliary power units) are also included. In addition, in order to avoid double counting of cruise emissions, the entire cruise emissions have been allocated with the departure airport. Moreover, Pejovic, et al., (2007) estimated that the UK total CO_2 emission from aviation for the year 2004 was 34.7Mt. This study was conducted using the Recognized Air Traffic Control Mathematical Simulator (RAMS Plus) and the Advanced Emission Model (AEM III). The RAMS Plus, simulates the four phases of the flight and this gives the fuel burn of each element of the journey, though the ground support equipment and the ground movements are not included in the model which provides a territorial approach only. Each kg of aircraft kerosene was assumed to result in the emission of 3.1kg CO_2. The paper describes the AEM III which simulate the four phase of the flight and this gives the fuel burn of each element of the journey.

This method employs the ICAO Engine Exhaust Emission Data bank (05/2003) and it also uses the BAD A (v3.6), the Eurocontrol Base of aircraft, an improved version of (EEC-BM2). This study indicated that the total international air traffic emissions, calculated in this study (31.8Mt), were higher than those given by NETCEN for 2000 (30.2 Mt), but compatible with their figure for 2004 (33.1 Mt). Moreover, by using real traffic profiles and applying different fuel burn rates to the different modes of flight, it is possible to calculate a CO_2 emissions inventory comparable to other estimates. Also, this methodology can disaggregate the emissions into aircraft groups and route profiles; it presents a significant tool for analysis of various policy effects. (Pejovic, et.al, 2008)

In order to support the 2003 Aviation White Paper, a series of emissions forecasts were formed by the Department for Transport. These were published in a supporting document called 'Aviation and global warming' (DfT, 2004). The Department's high-range forecast (which excludes improvements in technological efficiency) suggests that aviation emissions would grow to 29.1 Mt by, 2050, which would represent a more than six-fold increase from 1990 emissions levels. There is also a low-range forecast, which incorporates the effects of 'economic instruments', and which suggests that emissions would only grow to 15.7 Mt by 2050. Another study was conducted by the Tyndall Centre for Climate Change Research (2005). It examined how the UK could meet its target of a 60% reduction in carbon emissions by 2050. In the CO_2 emissions from aviation scenario, assumptions were based on future passenger growth rates and fuel efficiency improvements.

The Final report to DEFRA’s Global Atmosphere Division, *"Allocation of international aviation emissions from scheduled air traffic"* by Owen and Lee (2006) measured the effects of a range of different ways of allocating international aviation emissions to different countries. In this study a comprehensive model of air fleet characteristics (the FAST model) was used to revise the impacts of different aviation growth scenarios. A forecast up to 2020, of revenue passenger kilometres produced by the International Civil Aviation Organization's Forecasting and Economic Support Group for the sixth meeting of ICAO's Committee on Aviation Environmental Protection, was used to develop two different forecasts. From 2020 onwards the forecast would be based on updated versions of scenarios used by the IPCC. The revision involved converting these forecasts of passenger demand into global emissions, using the air fleet model, and then using different methods for allocating emissions to different countries (Owen, et al., 2006).

The European Environmental Agency (EEA) (2006) performed an emissions inventory of all aircraft operating in the EU, including the amount of fuel used and emissions per stage length. Using these fuel use data for different stage lengths, four categories of aircraft are compared for their fuel burn, normalized for the number of seats on each aircraft. The representative aircraft and seat numbers from each of the categories were as follows: turboprop (Saab 2000, 52 seats), regional jet (BAel46, 100 seats), narrow body (Boeing 737-400, 137 seats), and wide body (Boeing 747-400, 366 seats) (Boeing, 2008; Airliners, 2008). The regional jet and the wide body was consistently higher than the turboprop and the narrow body aircraft in terms of fuel burn per seat. For short stage lengths below 1000 km, turboprops have the fewest kilograms of fuel burned per seat. At 1100 km, the narrow body aircraft becomes the aircraft with the smallest amount of fuel burn per seat. Table 3.8 describes the detail of methodologies adopted for CO_2 calculation for flights.

CHAPTER 3

REQULATORY ACTS, AVIATION POLICIES/GUIDELINES AND POLLUTION REDUCTION PROSPECTS

3.1 Regulatory acts and guidelines

Each country outlines policies and principles to regulate air pollution, in order to maintain its population's wellbeing. One of the fundamental tasks after setting the legislated concentration guidelines is to work out whether the guidelines are being exceeded and, if so, how frequently. Some air quality legislation adopted in different countries is discussed briefly and a summary table showing different laws and regulation related to air pollution is shown in Table 3.1.

Country/ Organization	**Pollutant (Averaging period)**	**SO_2**			**NO_2**			**CO**		**O_3**			**PM_{10}**	
		1 hr	24 hr	Annual	1 hr	24 hr	Annual	1 hr	8 hr	1 hr	8 hr	24 hr	24 hr	Annual
WHO[1]	WHO Guidelines	-	125 µg/m^3	-	200 µg/m^3	-	40 µg/m^3	30 µg/m^3	10 µg/m^3	-	100 µg/m^3	-	50 µg/m^3	20 µg/m^3
EU[2]	Air Quality Framework Directive	350 µg/m^3	125 µg/m^3	20 µg/m^3	200 µg/m^3	-	40 µg/m^3	-	10 µg/m^3	-	120 µg/m^3	-	50 µg/m^3	40 µg/m^3
Australia[3]	National Environmental Protection Measure for Ambient Air Quality	-	80 ppb	-	-	-	30 ppb	-	9 ppm	-	80 ppb	-	25 µg/m^3	-

Canada[4]	National Ambient Air Quality Objectives	-	115 ppb	-	-	-	53 ppb	-	13 ppm	-	65 ppb	50 ppb	30 µg/m^3	-
India[5]	G.S.R.6(E), [21/12/1983] - The Air (Prevention	-	80 µg/m^3	50 µg/m^3	-	80 µg/m^3	40 µg/m^3	4 mg/m^3	2 mg/m^3	180 µg/m^3	100 µg/m^3	-	100 µg/m^3	60 µg/m^3
Japan[6]	Ministry of the Environment Environmental Quality Standards	0.1 ppm	-	-	0.04-0.06 ppm	-	-	10 ppm	20 ppm	-	-	-	-	-
South[7] **Africa**	SANS1929 Guidelines	350 µg/m^3	125 µg/m^3	50 µg/m^3	200 µg/m^3	-	40 µg/m^3	30 µg/m^3	10 µg/m^3	200 µg/m^3	120 µg/m^3	-	75 µg/m^3	40 µg/m^3
USA[8]	NAAQS	75	-	80	-	-	53 ppb	40	9 ppm	-	0.075	-	150	-

		ppb									ppm		µg/m 3	
UK[9]	National Air Quality and European Directive	350 µg/m^3	125 µg/m^3	-	200 µg/m^3	-	40 µg/m^3	-	10 µg/m^3	-	100 µg/m^3	-	50 µg/m^3	40 µg/m^3
UAE[10]	FEA	350 µg/m^3	150 µg/m^3	60 µg/m^3	400 µg/m^3	150 µg/m^3	-	30000 µg/m^3	10000 µg/m^3	200 µg/m^3	120 µg/m^3	-	70 µg/m^3	-

Table 3.1 Air quality standards and guidelines values in UAE and different countries around the world

Source:-

1. http://whqlibdoc.who.int/hq/2006/WHO_SDE_PHE_OEH_06.02_eng.pdf
2. http://ec.europa.eu/environment/air/quality/standards.htm
3. http://www.davidsuzuki.org/publications/downloads/2006/DSF-HEHC-Air-Web2r.pdf
4. http://www2.dmu.dk/AtmosphericEnvironment/Expost/database/docs/AQ_limit_values.pdf
5. http://cpcb.nic.in/National_Ambient_Air_Quality_Standards.php
6. http://www.env.go.jp/en/air/aq/aq.html
7. Naiker et al. 2012
8. http://www.epa.gov/air/criteria.html
9. http://www.legislation.gov.uk/uksi/2010/1001/pdfs/uksi_20101001_en.pdf

10 http://www2.dmu.dk/AtmosphericEnvironment/Expost/database/docs/AQ_limit_values.pdf

3.2 Aviation pollution control policies

Environmental policy intervention in air transport is a prerequisite for sustainable growth of the airport industry. There are a number of initiatives underway to achieve significant emissions reductions in the next few years. FAA, EPA, ICAO and many other groups have been working to identify and elucidate the environmental issues for some time, while NASA has been directing a research program aimed at significantly cutting emissions from aircraft engines. Usually, environmental guidelines in the aviation sector have been command-and-control (CAC) regulations, such as engine standards and restrictions on flight movements (Carlsson and Hammar, 2002). Recently, there has been an increasing concern in incentive-based (IB) environmental regulations such as fuel charges, emission charges and tradable emission permits (TEP).

3.2.1 International Civil Aviation Organization (ICAO) Policies

ICAO developed a series of standards, policies and guidance material for the application of integrated measures to address aircraft noise and engine emissions embracing technological improvement is to protect the environment from the harmful effects of aviation related activities. The Organisation has three main aims, which were adopted in 2004. First, limit or reduce the number of people affected by significant aircraft noise; second, limit or reduce the impact of aviation emissions on local air quality; and finally, limit or reduce the impact of aviation greenhouse gas emissions on the global climate. (ICAO, 2007)

Since the 1970s, the efficiency of aviation-related activities has improved by up to 70%. This is partly due to the significant efforts of the ICAO in reducing aviation-related environmental pollution, through the implementation of strategies and guidelines. Activities carried out by the ICAO in pursuit of this aim include the following: implementing new technologies, efficient planning with regard to the use of land, airspace, airports, and market-based options, and the imposition of limit values on aviation-related noise levels and emissions.

Most environmental strategies are undertaken through the ICAO Council's Committee on Aviation Environmental Protection (CAEP), which consists of Members and Observers from States, intergovernmental and non-governmental organizations representing aviation industry and environmental interests. "ICAO keeps close relations with other UN policy-making bodies that have expressed an interest in civil aviation, notably with the Conference of the Parties to the United Nations Framework Convention on Climate Change, to which it provides regular statements on its emission-related activities (ICAO, 2011).[1]

In the past, ICAO's policy-making on the environmental impact of aircraft engine emissions focused primarily on the ground level effects. In recent years, the scope has been expanded to include the global impact of aircraft engine emissions. In 2007, the ICAO Assembly requested the Council to continue studying policy options to limit or reduce the environmental impact of aircraft engine emissions and to develop concrete proposals and provide advice as soon as possible to the Conference of the Parties to the UNFCCC. It called for special emphasis to be placed on the use of technical solutions, while continuing consideration of market-based measures and taking into

[1] http://www.icao.int/environmental-protection/Pages/default.aspx

account potential implications for developing as well as developed countries (ICAO, 2007).

The ICAO is working on initiatives to improve local air quality, as well as proposing mitigation measures (ICAO, 2007). In 2001, the ICAO Assembly requested the Council to continue to develop guidance for States on the application of market-based measures aimed at reducing, or limiting, the environmental impact of aircraft engine emissions, particularly with respect to mitigating the impact of aviation on climate change. One of the principal developments was an emissions trading system, a system whereby the total amount of emissions is capped and allowances, in the form of permits to emit CO_2, can be bought and sold to meet emission reduction objectives. The system could assist as a cost-effective measure to limit or reduce CO_2 emitted by civil aviation in the long term, provided that it is open to all economic sectors. The Assembly therefore recognized the development of an open emissions trading system for international aviation (ICAO, 2007).

The Assembly made a series of requests to the Council with regard to the urgent development of this ‘open emissions trading system’. First, the Council was asked to formulate parameters for the system. The Assembly specifically requested that they prioritise the establishment of the legal framework and the structure underlying such a system and the place of the aviation industry in such a system. This framework was to embrace an adaptable approach that complied with that of the UNFCCC. At the same time, it was to contain recommendations on vital issues such as compliance, observation, and reporting. Further, the Council was asked to advance activities by formulating parameters for such approaches, if necessary developing a voluntary agreement on a provisional basis. These parameters were to be based on the observation, measurement, and confirmation of alterations in the volume of emissions. Further, the Assembly acknowledged that the early members in such activities must profit from them, and could not later be penalised for their initiative (ICAO, 2007).

The ICAO Council passed a resolution in December 1996, outlining a strategy detailing a series of charges based on aviation-related emissions. However, the Council decided that introducing a worldwide levy on emissions, which all countries would have to enforce, would not be viable at that point in time, due to countries diverse perspectives on the issues and the difficulties inherent in the planning and enforcement of such a strategy. As such, the Council firmly advocated that any levy imposed by states on emissions should be a charge, not a tax. Further, they recommended that any income generated should be used primarily to reduce the effects of aviation-related emissions on the environment. The amount of the levy or charge should be calculated with this aim in mind, in order that the income can be correctly recognised and credited to aviation (ICAO, 2007).

Aircraft are required to meet the engine certification standards (contained in Annex 16) adopted by the Council of the ICAO. These were initially designed to respond to concerns regarding air quality in the vicinity of airports. As a consequence, they establish limits for emissions of oxides of nitrogen (NO_x), carbon monoxide, unburned hydrocarbons, for a reference landing and take-off (LTO) cycle below 915 metres of altitude (3000 ft). There are also provisions regarding smoke and vented fuel. While these standards are established on an aircraft's LTO cycle, they also help to limit emissions at altitude. (ICAO, 2007)

The ICAO Council sets out essential criteria that must be met by airplanes (contained in Annex 16) in order for them to receive engine certification. Initially, these criteria were formulated to deal with concerns over air pollution caused by aviation-activity surrounding airports. As such, maximum emission levels were set for the following substances: unburned hydrocarbons, carbon monoxide, and nitrogen. This limits applied where there was an LTO cycle of not higher than 915 meters, or 3000 feet. In addition the criteria include limitations with regard to smoke fuel released when aircraft are airborne (ICAO, 2007).

The limitations set on NO_x are vital, as this gas is a greenhouse gas at certain heights and contributes towards ozone. Limitations on NO_x emissions were introduced in 1981 and became progressively more rigorous in 1993, 1999, and 2005. From 31st December 2013, these limitations will be improved by 15%, pursuant to CAEP/8 meeting in February 2010. Further, by that date there will also be a reduction in engine manufacturing, in line with the existing standard. CAEP/8 noted that research into non-volatile particulate matter (PM) is more highly developed than research into volatile PM. As such, a decision was made to prioritise non-volatile PM emissions. By 2013, there will be an obligation to obtain certification, which by 2016; a certification standard will be in existence (ICAO, 2010).

Moreover, the optimum scenario in the case of CO_2 reductions relies on advanced aircraft technology and advanced operational improvement relating to the NextGen and SESAR initiatives. It includes an optimistic fuel burn improvement of 15% per annum for all aircraft brought into the fleet between 2016 and 2026. Alongside this, advanced operational improvements would take place across fleets, in all regions and the recommendations for improvements extend beyond those set by the industry (ICAO, 2010).

3.2.2 IPCC policy with regard to aviation-related CO_2 emissions.

CO_2 emissions have an international impact. As such, the control of these emissions creates difficulties with regard to policy. In 2007, IPCC AR4 presented up-to-date research with regard to aviation emissions (IPCC, 2007) the results of this research indicate the following:

- As a result of increasing research and understanding, approximations of the environmental impact of contrails, the white trail of exhaust left in the wake of aircraft, has been reduced. In 2005, aviation contributed approximately 3% of the radiative forcing caused by the actions of the global population;
- It is estimated that 2% of greenhouse emissions globally were the result of aircraft CO_2 emissions;
- It is anticipated that the volume of aviation-related CO_2 emissions will increase by approximately 3-4% annually,
- It is possible that aircraft-related CO_2 emissions could be reduced by improving the effectiveness of fuel. Nevertheless, it is predicted that this will be insufficient to counterbalance the increase in levels of aviation-related CO_2.

IPCC suggests a range of options to reduce the impact of aviation emissions (IPCC, 2007), including changes in aircraft and engine technology, fuel, operational practices, and regulatory and economic measures.

A number of suggestions have been put forward by IPCC to mitigate the effect of these emissions. For example, these suggestions include technological modifications, a reconsideration of fuel sources, a reformulation of operational processes, changes in the regulation of the industry, and financial restructuring.

A. Aircraft and Engine Technology Options

Compared with the standards in the 1970s, subsonic aircraft that are currently being manufactured are approximately 70% more effective in terms of fuel per passenger-kilometre. A decrease in emissions could be facilitated by further development of the effectiveness of fuel and in the design of aircraft. By 2015, it is predicted that fuel will be 20% more effective. By 2050, it is estimated that fuel will be 40-50% more effective (IPCC, 2007).

B. Fuel Options

For transatlantic and long-distance flights, fuel with high energy density is vital. Alternative fuels, such as hydrogen, have begun to emerge (IPCC, 2007). Advocates of hydrogen highlight its potential to entirely do away with CO_2 emissions. However, it must also be noted that the use of hydrogen would augment levels of vaporised H_2O. In any case, the other options with regard to fuel, including hydrogen, have not undergone sufficient research; the effect of the manufacturing and employment of such fuels on the environment as a whole and on sustainability remains unknown (IPCC, 2007).

C. Operational Options

Potentially, an 8-18% decrease in the use of fuel could be achieved through the development of operational processes, in particular air traffic management (ATM) (IPCC, 2007). A significant proportion of these decreases, between 6% and 12%, will be achieved by 2030. Other alternatives, with regard to operations, focus on decreasing the fuel per passenger-kilometre. Optimising operational procedures could decrease the level of fuel utilised, as well as resulting in a 2-6% decrease in missions. Factors that could contribute towards this optimisation include a shorter taxi on take-off, weight reduction by excluding non-essential items, perfecting aircraft speed, reducing ventilation and heating so as to regulate the expenditure of auxiliary power, and boosting load factors.

D. Regulatory, Economic and Other Options

ICAO has begun work to assess the need for standards for aircraft emissions at cruise altitude to complement existing LTO standards for NOx and other emissions. (ICAO, 2010) .Technological development and effectiveness may be advanced through the use of market-based strategies, including charges and taxes on emissions. Further, such environmental levies could decrease the call for transportation via aviation. However, there is a lack of research with regard to many of these changes; their potential impact is unknown. While the US has utilised cap-and-trade with regard to sulphur dioxide (SO_2) and Canada has utilised the approach with regard to ozone-depleting materials, it has yet to be fully investigated in the aviation field. However, it is included in the Kyoto Protocol and is applicable to Annex B states (IPCC, 2007).

Sectors other than aviation have utilised voluntary agreements to encourage a decrease in the utilisation of greenhouse gases and the development of sinks. At present, an investigation into voluntary agreements is under way, to determine their efficacy in terms of decreasing aviation-related emissions. Further, certain grants and financial inducements have a harmful influence on the environment; eliminating these incentives should be considered. Scientific studies are vital in this context. In addition, encouraging ground transportation has the potential to reduce the negative impact of aviation on the environment. In particular, ground transportation could be used in place of short, high-volume routes; fast trains could be substituted for up to 10% of these flights. The impact of such a substitution is at yet uncertain; further research is required, particularly with regard to the interaction between the numerous environmental impacts, such as atmospheric, air and noise pollution (IPCC, 2007).

3.2.3 US Environmental Protection Agency (EPA) Policies

"Aircraft opertation" is a term denoting take-off or landing. There has been a significant increase of approximately 105% in the quantity of aircraft operations in the US between 1976 (15 million) and 2000 (30 million). The EPA is permitted to propogate limit values with regard to aviation emissions. In fact, Section 231 of the Clean Air Act Amendments 1990 obliges the EPA to set standards with regarad to aviation emissions; ICAO policies have typically been accepted. However, this permission is limited; the federal government has authority over limit values in many situations. In 1998, a multi-stakeholder forum was held by the EPA and the Federal Aviation Administration (FAA) to investigate this increase. It investigated a potential voluntary agreement within the US with regard to setting limit values on aviation-related NOx emissions.

The US EPA carried out a study on aviation emissions in US airports in 1990, using a population of 10 airports. Their results indicated that under 1% of regional SO_x and 2-3% of regional NOx emissions are produced by US airports (Jamin et.al, 2004),(US

EPA, 1999). However, it is predicted that these proportions will grow over the coming years, as the frequency of commercial flying increases. The EPA suggests that this increase will be particularly evident in Atlanta and Charlotte. It is estimated that by 2010, the NOx emissions produced by airports in these regions will grow to 8%, and HC emissions from airports will grow to 2.5% in Atlanta and 5.1% in Charlotte.

Previously regulatory attempts to enhance US air quality utilised limitations on emission that were based on command-and-control regulations. This policy resulted in significant decreases in emissions from a range of pollutants such as cars, waste incinderators and coatings. In 1997, the EPA aligned US policies in the area with ICAO policies; these policies are still in force to date. Further, the EPA adopted policies with regard to on-road and off-road engines (Jamin et.al, 2004). In 1996, policies with regard to diesel Ground Service Equipment (GSE) were put in place. Similar policies were adopted with regard to oil GSEs between 2004 and 2007.

A. Limitation on Airport Activity

Certain authorities have enforced restrictions on specified actions in airports, such as the volume of aircraft operations. Such restrictions are in force in numerous airports, including O'Hare in Chicago, National in Washington, and Kennedy and LaGuardia in New York. The aim of these restrictions is to lessen overcrowding. Restrictions on the volume of aircraft operations can only be enforced by the FAA. Furthermore, the FAA has the power to enforce such restrictions only on the basis of safety. While such restrictions may have a positive impact on emissions at that particular airport, this may be counterbalanced to some extent by a corresponding increase in emissions from increased activity in neighbouring airports. Further, in order to encourage theuse of aircraft with a lower volume of emissions, the differing volumes of emissions on all aircraft must be taken into account when formulating restrictions on airport activity.

B. Cap-and-Trade Programs

Recently, there has been a move away from an exclusive focus on "command-and-control" strategies, with market-based strategies, such as emissions trading being utilised instead. As has already been noted, emissions trading, or the "cap-and-trade" strategy, place a limit on emissions; licences permitting a set level of emissions are issued. However, this system allows recipients to purchase and sell these licences in order to achieve the aim of decreasing emissions. Where an entity has a low-cost method of decreasing their emissions, they will they sell their remaining allowance, whereas those entities for whom decreasing emissions is expensive will be more inclined to purchase an increased allowance. One benefit of this system is that there is certain to be an environmental gain, as no matter how often allowances are purchased and sold, the overall level of emissions remains capped. Further, as entities now have a choice as to whether to purchase allowance or to spend money on reducing emissions, the total expenditure on reducing emissions will be lower, as each entity will use the method that is the most cost efficient for them. Despite this, it is impossible to accurately gauge overall expenditure on emissions reduction, because this figure is based on the cost of decreasing emissions, which is set by the market.

C. Fee-Based Strategies

Strategies based on fees utilise the market to encourage low-cost improvements, in a similar manner to emissions trading. Fee-based strategies differ from emissions trading in one important aspect; the total volume of emissions cannot be predicted in advance when utilising a fee-based strategy, as this volume is dependent on the comparative price of decreasing emissions and paying the fee. Where it is less expensive to reduce emissions than it is to pay the fee imposed, entities will take steps to reduce emissions. However, where these steps cost more than paying the fee, entities will not take these steps; instead of reducing emissions, they will simply pay the fee. Both “command-and-control” strategies and emissions trading involve complex legal and regulatory rules, which results in their use being specific to particular circumstances. For example, fee-based strategies are best suited to use in commercial airports.

D. Decreasing GAV and GSE Emmisions: Regulatory Policies

In a similar manner, limitations could be placed on ground transport utilised in airports. With regard to GSE fleets, electric machines are the most desirable alternative currently on the market. In terms of GAV, compressed natural gas (CNG) or electric are the most efficient fuels. In terms of strategies, a novel approach is to determine a target fleet level (TFL) of emissions on an entire fleet. This TFL would be calculated annually, and would decrease each year. Once the fleet meets this target, the emissions caused by individual vehichles would be irrelevant, once the indiviual emissions across the fleet are balanced so as to meet the TFL. The Urban Bus

Program utilises TFLs with regard to vehicles manufactured before 1994. The EPA sets the TFLs for this program.

3.2.3 The Policy of the Federal Aviation Authority (FAA)

Inherently Low-Emissions Vehicle (ILEAV) is a strategy to decrease the volume of emissions caused by airport vehicles currently being investigated by the FAA, the EPA and the DOE. A number of airports have agreed to take part in a pilot program to facilitate this investigation. Gas and diesel will be replaced with electricity and alternative fuels in so far as in possible. The aim of these organisations and other interested parties is to introduce a national program based on ILEAV. In particular, the FAA and EPA are attempting to introduce ILEAV in areas where air pollution levels exceed the national average, so-called “non-attainment” areas. (FAA, 2006)

In addition, airports themselves have introduced policies to decrease the volume of emissions from ground transportation within the airport, introducing hybrid technology for staff vehicles, CNA vehicles for airport security and shuttle buses, and alternative fuel vehicles and clean diesel vehicles for maintenance and construction departments. (FAA, 2006)

The Airport Improvement Program (AIP) and the Passenger Facility Charges (PFC) initiatives are strategies designed to lower airport emissions (FAA, 2006). The Voluntary Airport Low Emission (VALE) initiative is the current one, increases participation in AIP and PFC. These programs offer financial support to change ground transportation and infrastructure so as to decrease emissions, for example through the use of alternative fuels, retrofit and novel technologies, and other strategies aimed at improving air quality (FAA, 2006). With regard to ground transportation emissions, fast, free-flowing services are provided, as are parking services. Airports utilise a set of accepted processes in order to achieve safety requirements, to run on-time, to preserve fuel, and to ensure that they are in accordance with labour regulations. Such processes differ depending on conditions, aircraft, and issues with particular airports. (FAA, 2006)

FAA has developed the Emissions and Dispersion Modelling System (EDMS) to calculate emissions more accurately. EDMS is used to understand aviation's contribution to local air quality concerns as mentioned earlier in chapter 2. The System for evaluating Aviation's Global Emissions (SAGE) is being developed to evaluate the impact of aircraft engine emissions during the whole flight regime, specially climb out and cruise emissions. Since 2005, the FAA has funded 42 low-emission projects at 22 airports representing a total investment of $115 million ($88 million in federal grants and $27 million in local airport matching funds) in clean airport technology (ICAO, 2010).

3.2.4 EU (European Union) policy

Based on wide-ranging consultation of stakeholders and the public and analysing several types of market-based solutions, the Commission concluded that bringing aviation into the EU Emissions Trading System (EU-ETS) would be the most cost-efficient and environmentally effective option for controlling aviation emissions (EEA,2011). It is presently the world's largest emission trading system and the first emission trading scheme that crosses country borders. The directive proposed by European Commission's (EC) and agreed upon by the European Parliament and the

Council of the European Union (2008), was published in 2008. As per the directive, aircraft operators will have to submit allowances for essentially all commercial flights landing at and departing from any airport in the EU from 2012 onwards. As such, the EU-ETS will not only affect European airlines, but also airlines from developed countries like the US or developing countries (EEA, 2011). It contains the following provisions for the addition of aviation into the existing EU-ETS in 2012:

- Almost every airport operation in an EU airport after 2012 will be subject to the provisions of the EU ETS, irrespective of the nationality of the airline or whether the flight is international or domestic. There is provision to exempt a non-EU state from the EU ETS requirements if other policies with similar effect are in operation in that State.
- Emissions allowances for CO_2 can no longer be utilised by airlines. Instead, they must reserve the allowances and give them up.
- Any aircraft with a maximum take-off weight (MTOW) of over 5700 kilograms must have allowances. Certain flights are not compelled to comply with this requirement, such as rescue flights and aircraft operating under visual flight rules (VFR).
- There are a number of situations where compliance with the EU ETS requirements is not needed. First, flights operated under PSOs (Public Service Obligations) are excluded where the volume of passengers is less than 30,000 annually (EEA, 2011), and where the flight is to remote areas. Further, the de minims clause states that it will apply where, over a year, a route is utilised less than 243 times every four months by a particular airline. In addition, the de minims clause excludes flights where emissions are less than 10,000 tonnes

annually. This clause aims to facilitate infrequent flights run by domestic operators in developing states to Europe.

In addition, the directive sets down a number of regulations (EEA, 2011):

- Aviation allowances under EU ETS will be based on previous levels of emissions. In the first year, the allowance will be calculated on the basis of 97% of the average annual emissions of the participating airlines, between 2004 and 2006.
- There will be no charge for 85% of allowances issued during 2012. The distribution of allowances will be standardised throughout the EU states, unlike the current arrangement with regard to stationary installations (EEA, 2011).

  In order to calculate the free allowances to be issued to each airline, a three-stage approach is utilised:

  1) The proportion of allowances to be auctioned is taken away from the overall level of allowances.
  2) The confirmed tonne-kilometre data for every route covered by the EU ETS in 2010 is calculated based on information for the relevant airlines. The result of step one is divided by this figure.
  3) Tonne-kilometre values are determined by multiplying the quantity of the payload, including passengers and cargo, by the length of the flight (great-circle-distance plus added to a constant value of fixed 95 km). Each airline's tonne-kilometre value from 2010 is multiplied by the

result of step two to determine the allowance they are to receive (EEA, 2011).

- These allowances issued to airlines can only be used within the aviation industry during 2012. However, airlines will be allowed to increase their allowance by buying allowances from outside the aviation sector or from ‘‘Joint Implementation” or ‘‘Clean Development Mechanism,” two projects being run from Kyoto. These projects can supply up to 15% of the allowances airlines are compelled to give up in 2012. If allowances are not utilised in 2012, they can be reserved and are valid until 2020 (EEA, 2011).

It is assumed that these policies will be implemented not only in 2012, but also from 2013-2020, with a decreased level of permissible emissions and a greater level of auctioning allowances.

3.2.4 UK (United Kingdom) policies

Between 1997 and 2006, profit made in the airline industry has grown by 54% and the price of airline tickets has halved. Between 1990 and 2008, the volume of airline passengers in the UK has increased from 104 million to 238 million (130%) (AEF, 2011). In order to satisfy its goals with regard to environmental protection in the context of climate change, a strategy with regard to airline pollution was introduced in the UK. UK legislation compels an 80% drop in GHG emissions by 2050, from the volume recorded in 1990. The predict and provide approach to airport planning was endorsed by a white paper from December 2003, named “The Future of Air Transport”, which encourages UK airport growth. A similar strategy with regard to ground transportation was abandoned over 20 years ago, due to the fact that it was demonstrated that increased infrastructure led to an increase in congestion. Specific suggestions made by the "predict and provide" approach utilised in the White Paper include constructing additional runways in a number of large UK airports, such as Glasgow or Edinburgh, Stansted, Heathrow, and possibly Gatwick (AEF, 2011).

The Climate Change Act, which received Royal Assent in November 2008, was a turning point in UK climate change policy. It ensured that, for the first time, emissions reduction targets (for 2020 and 2050) were legally binding and it established five-yearly budgets to ensure progress towards the targets. The Act was considerably stronger than the draft Bill initially published: the headline 2050 target became an 80% cut on 1990 levels of all greenhouse gases, not a 60% cut, and although emissions from international aviation and shipping were not formally included in the carbon budgets, the Act required that the budgets were set 'with regard to' those emissions – and required the Government to include them formally by 2012 (AEF, 2011). The Act also established an independent advisory body, the Committee on Climate Change (CCC), whose advice made it clear that carbon budgets should be set lower if aviation emissions were not being reduced – in other words, they should be set as if aviation emissions were included. "Developing a sustainable framework for UK aviation" is a scoping paper introduced by the Department of Transport (DfT) on 30 March 2011. The aim of this paper is to advance new UK strategies with regard to airports and the environment. The paper is based on a six-month consultation, examining the values underlying UK strategy in the area. Criticisms and suggestions with regard to the paper will be taken into account in the creation of an outline of a strategy in March 2013. This strategy will be adopted in place of the "Future of Air Transport" from 2003. This shift in focus indicates a new watershed in the UK's approach to the area and represents an important chance to improve the structure of this regime (AEF, 2011).

Technology, operations and biofuels as approaches towards emissions reductions:

A. Improvements in fleet fuel efficiency in order to reduce emissions

Engine and airframe enhancements could increase the fuel efficiency of new aircraft by up to 40% in the 2020's relative to new aircraft in 2005. Main manufacturers presently plan to introduce these improvements in new narrow-body aircraft families in the 2020's, with no firm plans to introduce new families for other market segments beyond the 2010's. Once introduced, these families will make up a small but increasing proportion of new aircraft entering the fleet, where the latter reflects turnover of the existing stock (e.g. around 4% annually) and increased demand. More radical technological innovation (e.g. blended wing aircraft) could offer significant potential for emissions reduction, although this would require as yet unplanned high levels of investment (AEF, 2011).

B. Operational improvements

There is some possibility for improvements to Air Traffic Management (ATM), in particular from rationalising the use of European airspace – the so-called Single European Sky. This could achieve a theoretical maximum of a 10% reduction by 2020 (on 2006 levels), although less may be achievable in practice. Such a reduction would only apply to a maximum of one third of UK emissions (since two-thirds are from long haul). Looking worldwide, the global Air Traffic Management body, CANSO, estimates that air traffic management is already 92-94% efficient and has set a target for it to be 96% efficient by 2050. This means that further feasible efficiency gains are only 2-4%. Reducing taxiing emissions by towing aircraft using electric vehicles, instead of allowing them to taxi using main engines, or reducing cabin weight (currently the focus of an international airline PR initiative) could each offer one-off reductions of around 1% (AEF, 2011).

C. Potential for aircraft to utilise biofuels

The issue of whether biofuels are sustainable on a worldwide scale is vital when determining the extent of biofuel use in the UK. The Committee on Climate Change recommend that, by 2050, the authorities prepare for a 10% infiltration of biofuels in the aviation market. There are many matters that must be taken into consideration with respect to the use of biofuels in aircraft. First, there is a need for biofuels in other industries. Second, ensuring an adequate supply of food worldwide is vital. Further, there are certain concerns over the flight paths biofuels would be used for, particularly with regard to the impact of biofuels on farmland. Finally, the potential decreases in emissions must be considered (AEF, 2011).

D. Travel options other than air travel

A decrease in the frequency of air travel would improve local air quality and there are three potential substitutions for air travel. First, as already mentioned, travelling by high-speed train has the potential to reduce emissions. Second, with regard to business, interactions could be conducted via the Internet. Finally, taking vacations in locations that do not require significant travel would reduce the frequency of air travel (AEF, 2011).

E. Travelling by train

Trains result in a smaller volume of CO_2 emissions than aircraft and in the UK they create only 25% of the emissions caused by national air travel (Association of Train Operating Companies, 2010). In order to attract consumers accustomed to air travel, trains would have to be excellent value, both financially and in terms of time. A new system, HS2, is being developed in conjunction with UK authorities (AEF, 2011). This high-speed rail will cover routes from London to Birmingham and from Manchester to Leeds. This could decrease air travel, the use of cars, and congestion on existing rail services. Nevertheless, construction of such rail systems can have a negative impact on the neighbouring environment. Further, it utilises a significant volume of carbon, and may merely lead to a "hypermobility" phenomenon, with passengers travelling greater distances at greater speeds, leading to increased emissions.

F. Online business

There are limitations to the advantages that can be brought by high-speed trains. They involve significant construction and have no impact on long-haul flights. In contrast, the use on online interaction, for example via Skype, could entirely eliminate business-related flights. It has been suggested that video conferencing does not, in fact, achieve its aim of reducing emissions. Some suggest that because of its positive impact on businesses that utilise it, those businesses travel more than they would have otherwise. However, while this might be true, video conferencing remains a vital method of allowing businesses to interact from home (AEF, 2011).

G. Staycations

A 'staycation' involves UK citizens vacationing within the UK. On a staycation, no flights are involved. Recently, staycations have grown in popularity. At present, UK holidaymakers spend approximately £12 billion more outside the UK than non-nationals spend within the UK. In 2008, this figure was at its pinnacle, at £17 billion, rising to £20 billion in peak seasons (AEF, 2011).

At present, the aim is for the total volume of emissions in 2005 to be maintained until 2050. This positive beginning to the reduction in emissions is grounded on CCC predictions of realistic decreases in other industries. However, it must be noted that if the goal of an 80% overall decrease in emissions is to be met; the different approach in the aviation industry will compel other industries to achieve a 90% decrease in emissions (AEF, 2011). This may have a negative effect on the population at large, in terms of, for example, a rise in the cost of fuel. The CCC emphasises that the goals to be achieved must be unqualified.

3.2.5 Policies in Australian airports.

Australia is an extremely metropolitan country. It has a small number of sizable urban areas located at different corners of its vast territory. There are five sizable airports, a reasonable amount of average sized airports, and a large number of local airports within the country. Australian authorities focus on the influence of aviation on air quality (Gillen, 2008). A monitoring policy has recently been substituted for their initial reward based strategy. It was anticipated that the limitations on cost put in place by the government and managed by the Australian Competition and Consumer Commission (ACCC) would most likely remain in place (Gillen, 2008). Directly before the strategy was privatised, the level of the limitations on cost, which was grounded on charges already in place, was increased by approximately 12% for large airports. It emerged that these limitations were strict; significant financial losses occurred for numerous airports by 1999/2000, particularly for Brisbane. There were two motivations for ending the cost limitations. The closure of Ansett[2] created a crisis with regard to income. Further, the Productivity Commission, which makes financial recommendations to the Australian authorities, recommended such a move.

The elimination of government control over pricing has led to a sizable growth in income per passenger in the majority of airports. In Adelaide, there was a 76% increase from 2000-01 and from 2004-05; this was the greatest increase among the seven airports that were observed. In essence, the new policy concentrates on observation, analysis and potential penalties. The ACCC is committed to observe financial expenditure, earning and quality. There is no direct control of the cost of flights, with the exception of local flights in Sydney. The data collected through observation requires an analysis to be conducted during the first five years of the scheme. After the analysis, the reinstatement of government control over cost could advised. The purpose of this analysis is to promote the appropriate use of airports' influence over the market.

3.2.6 Policy at Changi Airport, Singapore

At Changi airport, there are numerous causes of emissions, such as congestion, ground transportation, catering, and climate control, all vital role in the effective running of airports (Changi Airport, 2012). Changi airport faces difficulties in terms of collaborating with colleagues, including airline operators, staff and national authorities, in order to control the volume of emissions.

The National Environmental Agency (NEA) regulates the condition of the air in Singapore, using the Telemetric Air Quality Monitoring and Measurement System

[2] An Australian Airline

(Changi Airport, 2012). This involves remote air observation devices, which record information on the condition of the air. The NEA analyses this information to guarantee that entities do not create excessive pollution or risk to citizens' well-being. A number of actions have been undertaken to enhance the condition of the air at Changi Airport, including the following;-

- Utilisation of natural gas tractors.
- The utilisation of hybrid tractors exclusively in the T3 baggage-handling zone.
- The introduction of the Changi Airport Sky Trains, which are electric and produce no emissions, to transfer individuals between the different areas of the airport.

The airport includes many high-speed taxiways, as well as connecting taxiways, to prevent traffic and overcrowding. As such, the duration of taxiing is decreased, which results in a corresponding decrease in emissions (Changi Airport, 2012).

3.3 Schemes to reduce emissions

Certain actions to reduce aviation-related emissions have been put in place in a number of airports globally:

3.3.1 Lambert-St. Louis International Airport

This is the major airport servicing the district of St. Louis, Missouri in the US; it is the most active airport in Missouri, servicing over 88 locations both in the US and globally, on a constant basis. The airport was utilised by 14.4 million individuals in 2008. Recent research indicates that 40% of greenhouse emissions in the city are caused by aviation. A number of initiatives to improve the environmental impact of the airport, including the utilisation of alternative fuels, have been put in place over the last seven years, according to St Louis authorities.

A. Plans to improve air quality at St Louis Airport

Alternative fuels have been used for many years at St Louis Airport, in the hope of reducing the use of oil and decreasing air pollution. The airport prioritises setting limits on emissions caused by the use of diesel engines, substances that create smog and fuel combustion, in order to ensure the welfare of the local citizens and of the airport itself. St Louis Airport is analysing a number of operating factors that contribute to emissions, such as waste disposal, buying electricity, ground transportation, and stationary combustion.

A number of strategies have been put in place in St Louis Airport to reduce pollution:

I. The designation of a car park where vehicles can remain until the individuals they are collecting disembark from the plane.

II. Use of alternative-fuelled vehicles for 100% of diesel units and 40% of gasoline units including:

- Biodiesel vehicles
- Compressed Natural Gas (CNG) maintenance vehicles
- CNG shuttle buses
- Hybrid vehicles
- Propane vehicles
- Electric vehicle.

3.3.2 Austin-Bergstrom International Airport

This is a commercial airport with various functions, comprising of 1,717 ha, two runways and three helipads. It is situated 8 kilometers to the southeast of the commercial region of Austin, Texas in the US (ABIA, 1998). In May 1999, the airport started operations. In 2008, 9,039,075 individuals utilised the airport (ABIA, 2010).

A. Airport Strategies

Austin constructed the airport in such a way as to produce as low a level of emissions as possible, in order to protect the condition of the local air (ABIA, 1998). There were a number of innovative approaches utilised in this construction:

- The design of the airfield is effective with regard to the amount of ground covered when taxiing. As such, less fuel is consumed and there is a consequential decrease in the level of emissions. The most important policy when attempting to decrease emissions is the decrease in the duration of engine activity. This is because alternative fuels are not an option. With regard to commercial aviation, a lower level of emissions is achieved when the requirement to utilise auxiliary power units (APUs) beside the terminal is removed. As an alternative, electricity is used while the aircraft is stationary on the ground (ABIA, 1998).
- The utilisation of CNS and electricity with regard to Ground Service Equipment (GSE) decreases levels of emissions, and as such reduces negative impacts on the condition of the local air (ABIA, 1998).

- Improving transportation links, with regard to both buses and light rail services.
- Utilisation of alternative fuel vehicles during take-off and landing.
- Decreasing the level of aircraft emissions by supplying stationary aircraft with energy from ground support equipment (ABIA, 1998).

CHAPTER 4

MATERIALS AND METHODS

This chapter describes the overall research methodology that includes the following components:

1. Collection of the background information on various aviation related activities,
2. Development of the aviation emissions inventory,
3. Air quality monitoring and measurements at the airport,
4. Air quality modelling,
5. Estimation of CO_2 emissions due to aviation activities and
6. Suggestions on the policy/ regulatory requirements for the improved control of air pollution resulting from the aviation activities.

4.1 Collection of the background information on various aviation related activities

Information on aviation related activities including operations of aircrafts, airside vehicles, power plants, fuel storage and landside vehicles etc., was collected. Meetings were conducted with the air traffic management at ADIA in order to obtain data on air traffic movement. Moreover, data on number of land side vehicles, which can help in preparing a base case emission inventory. Air pollutant data sets were received from airport authorities of ADIA.

4.2 Development of the aviation emission inventory

4.2.1 Emission sources at Abu Dhabi international airport.

For the calculation of the emission inventory, the model EDMS 4.4 has been used in combination with necessary specific pre-processed data. A detailed description of the model and inputs requirement for emission inventory is given in Appendix 1. The survey for the emission sources was conducted at ADIA for all airport-related activities and it was grouped into four main categories. Table 4.1 summarizes the four categories of airport emission associated activities.

Table 4.1Airport emission Sources

Group	Source	Description	Source of Data	Data Availability
Aircraft	Aircraft main Engine	Main engine of aircraft within the LTO	ADIA Authority	Data available
Aircraft Handling	GSE	Ground support equipment necessary to handle the aircraft during the turnaround at the stand, aircraft tugs, conveyer belts, passenger stairs, fork lift trucks, cargo loaders, etc.,	ADAS*	Data available
	APU	Auxiliary power units of aircraft providing electricity and preconditioned air during ground time	ADAS*	Data available
	Aircraft refilling	Fuel trucks or pipeline system	ADNOC**	Data available
	Airside Traffic	Service vehicle and machinery traffic (sweepers, trucks catering, sewage, cars), vans, buses within the airport fence	ADAS*	Data available
Airport	Power/Generating Plant	Facilities that produce energy for the airport's infrastructure: generators, cooling plants.	ADAS*	Data available
	Aircraft Maintenance	All activities for the maintenance of aircraft, i.e. washing cleaning, painting		No Data
	Fuel Farm	Storage, distribution and handling of fuel in the fuel farm	ADNOC**	Data available
	Fire Training	Activities for fire training	ADIA Authority	Data available
	Airport Maintenance	All activities for the maintenance of airport facilities	Engineering Department / ADIA Authority	Data available
Landside Traffic	Vehicle Traffic	Cars, vans, trucks, buses, and motor coaches associated with airport on access roads, vehicles from the road network around the airport		No Data
		Car park	ADIA Authority	Data available

*Abu Dhabi Airport Services Company is a part of Abu Dhabi Authority, *Direct communication.*

** Abu Dhabi National Oil Company, *Direct communication.*

4.2.2 Aircraft emission calculation methodology

A. Air traffic movement data

For the calculation of the aircraft engine emissions, the aircraft movements using the detailed flight schedule for the year 2006 were specified. Table 4.2 shows air traffic movement for the year 2006. It is evident from table 4.2 that the fleet mix contain large sum of old cargo aircraft as well as military aircrafts, helicopters, and other medium and long rang airliner.

Table 4.2 ADIA air traffic movement data for the year 2006

Aircraft Type	Total Movement /Year2006	Flight Fraction	Type
A109	6	0.01	Helicopter
A124	108	0.14	Large cargo
A306	1036	1.37	Airliner, long-range
A30B	582	0.77	Airliner, long-range
A310	2280	3.02	Airliner, long-range
A319	1364	1.80	Airliner, medium-range
A320	11364	15.03	Airliner, short-medium range
A332	10256	13.57	Airliner, long-range
A321	964	1.28	Airliner, short range
A333	604	0.80	Airliner, long range
A342	72	0.10	Airliner, ultra long range
A343	3486	4.61	Airliner, ultra long range
AN12	36	0.05	Military cargo, medium range
AN2	2	0.00	Small military craft
Ap139	2	0.00	Short range
AS32	4	0.01	Twin engine helicopter
AS55	12	0.02	Twin engine helicopter
AS65	84	0.11	Twin engine helicopter

ASTR	4	0.01	Medium range corporate jet
AT72	124	0.16	Regional airliner
B190	2	0.00	Regional airliner
B206	342	0.45	Single engine helicopter
B212	1466	1.94	Single engine helicopter
B350	112	0.15	Regional corporate aircraft
B407	8	0.01	Single engine helicopter
B412	11830	15.65	Twin engine helicopter
B430	10	0.01	Twin engine helicopter
B461	4	0.01	Medium range airliner
B703	24	0.03	Long range airliner/cargo
B721	4	0.01	3 engine airliner medium range
B722	334	0.44	Short-medium airliner
B732	852	1.13	Short range airliner
B733	720	0.95	Short range commercial airliner
B734	92	0.12	Short range airliner
B735	20	0.03	Short range airliner
B737	748	0.99	Short-medium airliner
B738	1356	1.79	Short-medium airliner
B741	4	0.01	Long ranger airliner
B742	1590	2.10	Long ranger, high capacity airliner
B743	44	0.06	Long ranger, high capacity airliner
B744	2874	3.80	Long range, high capacity airliner
B74S	366	0.48	Long range, high capacity airliner
B752	52	0.07	Medium range, airliner
B762	120	0.16	Medium-long range, airliner
B763	9690	12.82	Medium-long range, airliner
B772	1492	1.97	Long range high capacity airliner
BA11	16	0.02	Short range, airliner

BA46	12	0.02	Short range
BE20	44	0.06	Short range, corporate jet
BE4A	4	0.01	Short range
BE90	12	0.02	Short range corporate jet
C114B	8	0.01	Military
C12	4	0.01	Military
C130	932	1.23	Military, long range
C17A	4	0.01	Long range, cargo
C182	24	0.03	Light aircraft
C208	64	0.08	Light aircraft
C30J	92	0.12	Medium, military cargo
C340	4	0.01	Medium range, corporate jet
C550	44	0.06	Short range, corporate jet
C560	6	0.01	Short rang, corporate jet
CL60	76	0.10	Medium range, corporate jet
CN35	334	0.44	Medium range, airliner
DH8B	4184	5.54	Short range
E135	20	0.03	Short range airliner
EC35	20	0.03	Twin engine helicopter
F50	34	0.04	Short range airliner
F70	4	0.01	Short range airliner
F100	40	0.05	Short range airliner
FA20	4	0.01	\medium range
FA50	10	0.01	Long range airliner
GLEX	44	0.06	Ultra long range, high speed airliner
GLF2	32	0.04	Long range airliner
GLF3	36	0.05	Long range airliner
GLF4	330	0.44	Long range airliner
GLF5	40	0.05	Ultra long range airliner
H25B	36	0.05	Medium range
H25C	24	0.03	Medium range
HAWK	92	0.12	Military jet fighter, medium range
HS25	4	0.01	Military
IL76	584	0.77	Long range cargo

K35R	4	0.01	Military
L101	106	0.14	Long range airliner
LJ31	16	0.02	Light aircraft
LJ35	88	0.12	Light aircraft
LJ55	12	0.02	Mid-size jet
LJ60	8	0.01	Mid-sized jet
M339	4	0.01	Military
MBA	4	0.01	Light aircraft
MD11	4	0.01	Long range high capacity airliner
MD82	188	0.25	Medium range airliner
MD83	94	0.12	Medium range airliner
MD90	532	0.70	Medium range airliner
MIR	20	0.03	Military
MIR2	24	0.03	Military
P180	12	0.02	Medium range airliner
P28A	330	0.44	Light aircraft
P34A	28	0.04	Light aircraft
PA44	28	0.04	Light aircraft
PAT4	4	0.01	Light aircraft
PC7	156	0.21	Light aircraft
PUMA	12	0.02	Military helicopter
RJ85	12	0.02	Short ranger airliner
S360	46	0.06	Helicopter
S380	8	0.01	Helicopter
SC7	4	0.01	Medium range cargo
SW4	48	0.06	Medium range, airliner
T134	12	0.02	Short range aircraft
T154	2	0.00	Medium ranger aircraft
VC10	16	0.02	Long range military
Total	75590	100.00	

Source: ADIA Air Traffic department 2006.

B. Engine Assignment

EDMS has a data base for most of the aircraft using ICAO emission factors for aircraft engines, differentiating between each aircraft and engine type. Once an aircraft type is selected, the model will assign a default engine.

C. Time in Mode

The operational taxi time is 20 minutes according to the air traffic section at ADIA. The operational taxi time is defined as the time used for an aircraft to land and reaches the apron area, or the time used to take the taxi out. According to the EDMS model, this has been fixed at 26 minutes (ICAO). Table 4.3 presents the time in mode used in EDMS. ADIA air traffic movement is 15 flights/ hr during the peak hours which are from 11:00 to 14:00 Hrs and 21:00 to 01:00 Hrs.

Table 4.3: Aircraft time in mode and thrust setting according used in EDMS

Mode Time (min)	ICAO Reference EDMS	Thrust setting
Take-off	0.7	**100% F_{00}**
Climb out	2.2	**85% F_{00}**
Approach	4	**30% F_{00}**
Idle	26	**7% F_{00}**

D. Engine exhaust emission factors

The emission factors (in EDMS termed 'emission indices') for aircraft engines vary with engine type and for a given engine type depending on thrust setting. The chief source of emission factors and fuel flow rates used in the present work is the ICAO databank which is stored in the EDMS database.

4.2.3 Airside vehicles and ground support equipment

Airside vehicles are potentially a major emission category within airports. Such vehicles include: tugs, coaches, tankers, catering trucks and baggage trolleys. The operation of these vehicles is often characterized by relatively small distances travelled at a low speed and long periods of use. Ground support equipment (GSE) includes mobile generators and start compressors. Auxiliary power Units (APUs) are often necessary to provide a source of on board electrical, pneumatic and hydraulic power for the aircraft and a source of air for the aircraft's air conditioning systems. To calculate the emissions from (GSE) and (APUs), EDMS defaults assignment for each aircraft were used.

Table 4.4: Total population of GSE (Ground Support Equipment) at ADIA

	Equipment type	Equipment Name	Numbers	Type of Fuel
1	GPU	Ground Power Unit	20	Diesel
2	ASU	Air Starter Unite	7	Diesel
3	LDL	Lower Deck Loader	35	Diesel
4	CB	Conveyor Belt	36	Diesel
5	PS	Passenger Step	37	Diesel
6	ACU	Air Condition Unit	46	Diesel
7	PT	Pallet Transporter	21	Diesel
8	FL	Fork Lift	4	Diesel
		Electric Fork Lift	19	Electric
9	WSU	Water Service Unit	14	Diesel
10	TSD	Toilet Service Unit	11	Diesel
11	MDL	Main Deck Loader	11	Diesel
12	BT	Baggage Tractor	90	Electric
	ET	Electric Baggage Tractor	4	Diesel
13	ATT	Aircraft Towing Tractor	33	Diesel
14	APB	Apron Passenger Bus	37	Diesel
15	MHL	Medical High Loader	4	Diesel
16	URC	Unregistered Car	11	Diesel
17	RC	Registered Car	24	Diesel
18	MB	Mini Bus	17	Diesel
19	PU	Pick Up	21	Diesel
20	TB	Towbar	65	
21	TP	Tail Support Station	1	Diesel
22	RFT	Runway Friction Tester	1*	
23	RRR	Runway Rubber Remover	1*	
24	GC	Golf Cart	1	Electric
25	CT	Catering Truck	**	

*It is used 4 times in the year.
** Catering Truck 3 for wide-body aircrafts and 2 for narrow-body aircrafts

Source: Abu Dhabi Airport Service Company, Direct communication.

4.2.4 Landside vehicles

This category of emission sources includes all road vehicles movements outside the airport's operational area. Vehicles include cars, taxis and coaches. All the sub-categories of landside vehicles have emission profiles and the strength of the source is dependent upon factors such as, size of engine, speed and duration. Unfortunately, data were not available for the road network around the airport. Car park data with duration of stay were received from ADIA authorities. Currently there is no public mass transportation to the airport available, where passengers and employees can commute or travel to and from the airport.

4.2.5 Stationary power generation

Airports generally own and operate a number of power generation plants that are typically fuelled by gas or diesel. Abu Dhabi airport has 3 turbines that are used only for 6 hours per month, 2 engines used for 6 hours per month plus one emergency power or a backup power generator, all of which are located offsite.

4.2.6 Minor sources

There are a number of minor sources within the airport locality that emit a wide range of pollutants: these include fire training exercises, aircraft maintenance and fuel storage. Emissions from aircraft maintenance in the maintenance shop and from airport infrastructure maintenance (cleaning, repairs and painting) were not considered in this study, due to data unavailable.

4.2.7 Geometric configuration of the airport

The geometry of the airport consists of runways, queuing areas, ground support equipment (GSE) and auxiliary power unit (APU) locations, gates, taxiways, buildings, car parks and other miscellaneous items. The location and geometric dimensions were derived from Google earth. Within EDMS, the layout of runways and taxiways was used to locate emissions from aircraft LTO cycles. The layout of the gates was used to locate emissions from APUs and GSE.

Layout of the ADIA is shown in Figure 4.1 and runways are marked as 13 and 31. EDMS allows the entering of runway coordinates, taxiway coordinates as well as gates, peak-queue time in minutes, the queue time hourly profile and the queue length hourly profile.

Figure 4.1: ADIA layout *(Source: Google earth, date of access 30/8/2010*)

4.3 Measurements methodology

Continuous measurements data were received from ADIA authority. Measurement of ambient air quality at Abu Dhabi Airport was carried out by the SCADIA for baseline measurements of different pollutants. Monitoring was carried out for a period of four months from 14th November 2005 to 14th of March 2006 and hourly average pollutant concentrations were generated over the monitoring period. Monitoring equipment, meteorological sensors and associated supporting gases and equipment were all housed in a mobile laboratory. No site selection methodology were used like the ones mentioned in the DEFRA Technical Guidance LAQM.TG (09) (DEFRA, 2009), the selection of monitoring sites was constrained by security considerations of sites and availability of a stable power supply. The first site was placed in SCAIDA car park

Therefore, lots of the car emissions could reflect higher concentrations on the measurements records.

In addition, a calibration check was performed twice weekly and re-calibrations undertaken as necessary. All consumable items such as filters and reagents were checked regularly and replaced when necessary (SCADIA, 2005). Continuous monitoring was carried out at two sites. One of the monitoring sites was located to the west of the airport at SCADIA parking facility; the second monitoring station was located to the east of airport next to the airport police station car park. Monitoring was carried out from 15[th] March 2006 to 16[thl] July 2006. Figure 4.2 presents the location of the monitoring stations. A summary of measured pollutants and techniques, as used by SCAIDA for analysis, is given in Table 4.7, followed by a brief description for each measurement technique.

Figure 4.2: Air quality monitoring stations at Abu Dhabi international airport (*Source: Google earth date of access 29/8/2010)*

4.3.1 Meteorological data

Meteorological parameters (wind speed, wind direction and temperature) were also recorded at the AQMS. Wind rose plotting steps are presented in Appendix 2.

4.3.2 Data Capture

The first period (15th Nov.05 to 15th March 06) experienced a continuous electrical fault. Therefore, a considerable of hourly data, around 38% data, were missing. On the other hand, the second period (from 15th March 06 to 15th July 06) had better recording and had only 2% of missing data.

Table 4.5: Summaries of pollutants measured and measurement techniques used

Pollutants	Measurement Technique
Oxides of Nitrogen (NO_x)	**Chemiluminescence**
Sulphur Dioxide (SO_2)	**U.V. Fluorescence**
Ozone (O_3)	**U.V. Photometry**
Carbon Monoxide (CO)	**Infra-Red Gas Filter Correlation**
Particulate Matter less than 10 microns in diameter (PM_{10})	**Tapered Elemental Oscillating Microbalance (TEOM)**

4. 3.3 Sulphur Dioxide (SO_2)

SO_2 was measured using UV Fluorescence SO_2 Analyser (model 43S, Thermo Fisher Scientific Inc., USA). It is based on the principle of measuring the emitted fluorescence of SO_2 produced by the gas's absorption of UV radiation. Pulsating UV light is focused through a narrow band-pass filter mirror, allowing only light wavelengths of 1900 to 2300 angstrom units (A) to pass into the fluorescent chamber.

SO_2 absorbs light in this region without any quenching by air or most other molecules found in polluted air. The SO_2 molecules are excited by UV light and emit a characteristic decay radiation. A second filter allows only this decay radiation to contact a photomultiplier tube (PMT). Electronic signal processing transfers the light energy impinging on the PMT into a voltage which is directly analysed (SCADIA, 2005).

4.3.4 Ozone (O_3)

Ozone was measured by the following UV photometric method. The UV photometer determines ozone concentration by measuring the attenuation of light due to ozone in the absorption cell, at a wavelength of 254 nm. The concentration of ozone is directly related to the magnitude of the attenuation. Sample air is drawn continuously through an optical absorption cell where it is irradiated by light at a wavelength of 254 nm. The absorption of this radiation by the sample air is a measure of the ambient air ozone concentration. To avoid interference from other gases absorbing light at the same wavelength and from instability in the light source, an ozone catalytic converter, that converts the ozone to oxygen, is used to selectively remove ozone from the sample stream producing a reference gas. Two parallel sample cells are used to analyse the sample gas and reference gas (SCADIA, 2005).

4.3.5 CO analysis

Carbon monoxide was measured using GFC (Gas Filter Correlation) ambient CO analyser. GFC offers improved specificity and sensitivity over conventional non-dispersive infrared (NDIR) techniques. GFC spectroscopy is based upon comparison of the detailed structure of the infrared absorption spectrum of the measured gas to that of other gases also present in the sample being analysed. The technique is implemented by using a high concentration sample of the measured gas, i.e., CO, as a filter for the infrared radiation transmitted through the analyser, hence the term GFC. In this procedure radiation from an IR source is chopped and then passed through a gas filter alternating between CO and N_2 due to rotation of the filter wheel. The radiation then passes through a narrow band pass interference filter and enters a multiple optical pass cell where absorption by the sample gas occurs. The IR radiation then exits the sample cell and falls on an IR detector (SCADIA, user manual, 2005).

4.3.6 Particulate matter (PM_{10})

Particulate matter was measured using TEOM (Series 1400a), an ambient particulate matter (PM_{10}) monitor. The Tapered Elemental Oscillating Microbalance (TEOM) method offers a direct measure of the mass concentration of particles. The measurement is based on the frequency of mechanical oscillation of a tapered element. The element contains a filter upon which particles are deposited. When the instrument samples, the ambient sample stream first passes through a PM_{10} inlet. At its design flow rate of 16.7 1/min, the inlet allows particles smaller than 10 rim diameter to pass through. At the exit of the PM_{10} inlet, the 16.7 1/min flow is kinetically split into a three 1/min sample stream that is sent to the instrument's mass transducer and a 13.7 1/min exhaust stream. Inside the mass transducer the air stream passes through a filter made of Teflon-coated borosilicate fibre. This filter is weighed every two seconds. The difference between the filter's current weight and its initial weight (as automatically measured by the instrument after the installation of the filter) gives the total mass of the collected particulate matter (SCADIA, user manual, 2005). The advantage of TEOM is that it provides a direct measurement of mass. It has excellent sensitivity and is sensitive to all particles. On the other hand, it is sensitive to humidity and temperature which is considered to be a disadvantage, which requires a control of these two parameters. The filter also requires periodic changing, resulting in a 30 minutes to two hour downtime after each filter change. The TEOM needs to keep constant humidity to avoid any changes in PM concentration or volatile losses. The EC recommends having a correction factor which is 1.3.TEOM equipped with Sequential Equilibration System (SES) associated with a Nafion dryer who may be used to reduce humidity and lower the sample temperature at 4°C. In addition, the Filter Dynamics Measurement System (FDMS) were implemented to remove the aerosols from the stream of sample.

4.3.7 NO_x Measurement

Chemoluminescence Method

Nitrogen oxides were measured through chemiluminescence NO-NO_2-NO_X Analyser (Model 42 C, Thermo Fisher Scientific Inc., USA (SCADIA, 2005).

4.3.8 Measurement of NO_2 Using Passive Diffusion Tubes

In order know the spatial distribution of NO_2 at ADIA and its surrounding area, 2 diffusion tubes campaign have been conducted and the measurement results are presented herewith. Measurement of NO_2 was done using diffusion tubes (Figure 4.3).

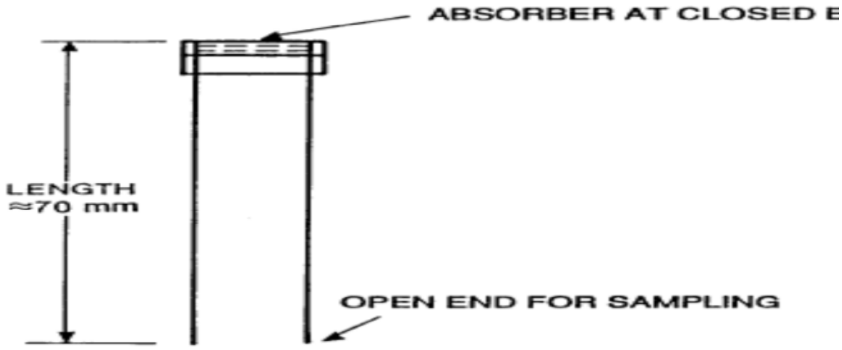


Figure 4.3: Diffusion tube sampler *(Source: UK diffusion tube instructions manual, 2003)*

Figure 4.4 Diffusion tubes placed at Khalifa City outside the airport, summer campaign. *Source: Author*

Figure 4.5 China Cargo aircraft on the runway and the diffusion tube placed next to the runway. *Source: Author*

The first area of investigation covered the areas close to the runway edges. The tube was placed at a maximum height of 2 m above the ground and 50 m away from the runway centreline. This mandatory distance is based on ATC, ICAO safety standards. Other tubes were placed close to certain airport polluting activities, such as the airside of the terminal, freight area, roads to the terminal, the main car park, etc. The rest of the investigation covered the area which is going to be developed as a major hub in the near future. The campaign also covered areas around the airport in the residential areas of Khalifa city A and, Khalifa city B. The passive diffusion tubes were placed on regularly spaced lines, perpendicular to the runways. For safety reasons, the tubes were fixed on wooden posts. Table 4.6 presents diffusion tubes used in the first pilot study and their coordinates.

Table 4.6 Diffusion tub number and their coordinates winter campaign.

Site NO.	Diffusion tube NO.	POINT_X	POINT_Y
1	IMX20	261019.74139700000	2704427.20414000000
2	IMX18	261513.33124699900	2704602.60699999000
3	IMX13	261783.07626300000	2704099.35136999000
4	IMX15	262225.94121700000	2703741.03335999000
5	IMX19	262576.20713400000	2702772.39999999000
6	IMX12	263236.96322400000	2702934.12344000000
7	IMX10	260866.81296499900	2703981.42322000000
8	IMX09	259054.95696099900	2705801.20552999000
9	IMX08	259159.07425599900	2705571.68041000000
10	IMX14	259987.62179899900	2705685.54729000000
11	IMX07	260928.10767500000	2705842.39870999000
12	IMX11	260671.01042100000	2704478.59142000000
13	IMX06	263868.25845600000	2703847.30114000000
14	IMX05	263964.69652900000	2702527.09717000000
15	IMX04	262531.42722800000	2702450.61180000000
16	IMX03	261886.28977000000	2702852.99134999000
17	IMX01	261307.66132900000	2703288.62539999000
18	IMX28	261118.11063200000	2703474.85064999000
19	IMX02	261167.30478000000	2701063.16218000000
20	IMX29	261006.29138600000	2709014.63901000000
21	IMX27	260213.71398599900	2707781.36125000000
22	IMX26	257859.89575800000	2705345.55225000000
23	IMX25	257149.30912399900	2704641.79817999000
24	IMX24	257398.69770200000	2703897.04872999000
25	IMX23	258283.51471300000	2703698.90438000000
26	IMX30	261985.92064500000	2707415.93807000000
27	IMX31	264412.57797799900	2704734.12289999000
28	IMX21	263391.94663500000	2706653.12246000000
29	IMX22	259161.49916100000	2703005.39915000000
30	IMX17	262411.18370400000	2703306.83375999000

Table 4.7: Diffusion tube number, location and NO_2 concentration for June/ July measurement

Site No.	Location	Tubes
1	Runway/centre taxiway/Papa –November	**IMB 6, 7, 8, 9 is blank**
2	Runway parallel to the south fire station	**IMB 13,14.15, 12 is blank**
3	Eco aircraft stand	**IMB 16,17,18,19 is blank**
4	End of the Runway/ Amiri Flights side	**IMB 1,2,3,4 is blank**
5	End of the Runway/ Abu Dhabi Aviation's side	**IMB 21,22,23,24 is blank**
6	Baseline/ the new developed area	**IMB 20,10,5,11 is blank**
7	Baseline/ the new developed area	**IMX37 ,36,35,33 is blank**
8	Next to the monitoring station	**IMB25,26,27,28,29is Blank,IMX38,39 is blank**
9	Baseline/ the new developed area/west	**IMB 30,31,32,33 is blank**
10	Baseline/ the new developed area /east	**IMB 35,36,37,34 is blank**
11	Khalifa City B *	**IMB 38,39, 40,41 is blank**
12	Baseline/ SCADIA Offices	**IMB 42,43,44,45 is blank**
13	Next to the ladies beach /outside the airport / under the flight path	**IMB 54,46,48,47 is blank**
14	Khalifa City A/ Etahad complex	**IMB 49,51,53,50 is blank**
15	Khalifa City A/HCT constriction site	**56, 57,58,52 is blank IMB**
16	Al Falah City / under the flight path	**IMB 55,56 , IMX34, IMX 40 is blank**
17	**Al Falah City**	**IMB 59,BL1,BL2, BL3 is blank**

In the summer diffusion tube measurement campaign at ADIA 70 samplers were installed at 17 different monitoring sites. At each site, 3 passive samplers and one blank tube were placed but the one next to the continuous monitoring site had 6 samplers and two blank (deployed on the 26 June for a period of 4 weeks, ending on next to ADIA police station until the 15th July 2006. Table 4.7 presents diffusion tubes sampler used in the campaign and their location the 24th July 2006). Continuous monitoring was carried out to the east of the airport.

An experiment was conducted in order to verify if covering of the diffusion tube samplers with aluminium foil minimizes the impact of direct sunlight on the samplers. A total of 3 trials were conducted in September 2006. In the first experiment, a total of 15 diffusion tubes were exposed for one week at three sites. At each site five diffusion tubes were kept out of which 2 tubes were wrapped with aluminium foil around the cap, while the other two tubes were left unwrapped and one blank. Table 4.8 presents diffusion tubes numbers and location. A second trial was conducted for another week starting from the 12 September until 19 September. Table 4.9 presents diffusion tubes numbers and location

Another two-week trial was also conducted in this series to see the impact of diffusion tube wrapping. In separate two-week trial 20 diffusion tubes were deployed at 4 sites, from the 5th September to 19th September 2006. Table 4.10 presents diffusion tubes numbers and location.

Table 4.8: Wrapped and unwrapped diffusion locations tubes exposed for one week.

Site No.	Location	Tubes
1.	Next to the weather radar Baseline/ the new developed area	**11,12,13,14,15**
2.	Baseline/ the new developed area ,next to the fence	**16,17,18,19,20**
3.	SCAIDA, baseline/ the new developed area/west	**31,32,33,34,35**

Table 4.9: One week diffusion tubes using foil wrapping on the top of two 2 tubes at each site.

Site No.	Location	Tubes
1	Next to the weather radar Baseline/ the new developed area	**41,42,43,44,45**
2	Baseline/ the new developed area ,next to the fence	**46,47,48,49,50**
3	SCAIDA, baseline/ the new developed area/west	**36,37,38,39,40**

Table 4.10: Diffusion tube sample location sites 2 weeks trial

Site No	**Location**	**Tubes**
1	Eco aircraft stand	**1,2,3,4,5,**
2	End of the Runway/ Amiri Flights side	**6,7,8,9,10**
3	End of the Runway/ Abu Dhabi Aviations side	**21,22,23,24,25**
4	Police station opposite to terminal car park	**26,27,28,29,30**

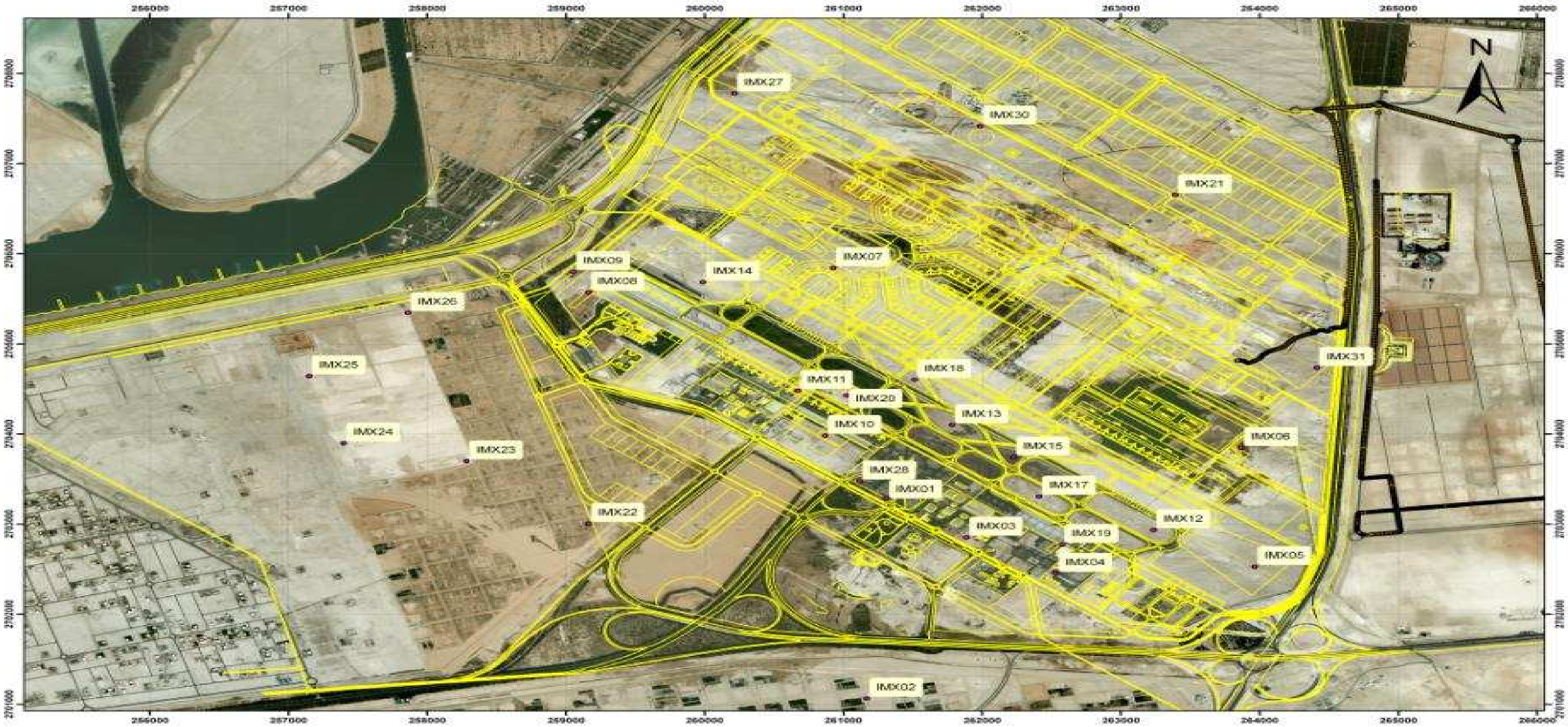


Figure 4.6: AIDA map with proposed development **and location of sampling sites (first campaign)**

Figure 4.7: AIDA map and location of sampling sites**, second campaign (summer)**

4.4 Air quality modelling using EDMS

The Emissions Dispersion Modelling System (EDMS) is used for civilian airport and military air basis to assess air quality by estimating emission from different airport sources including aircraft, GSE, APUs, stationary source and roads. EDMS has the capability to determine pollutant concentration in and around the airport. The Federal Aviation Administration (FAA), worked jointly with the United States Air Force (USAF), to develop EDMS since 1970s. Continues researches have been carried out by the FAA in order to enhance the model.

EDMS version 4.4 is used in this research, which has the EPA's version of AERMOD (02222) and its supporting weather and terrain processors, AERMET and AERMAP. EDMS also contain the version of the EPA MOBILE on-road vehicle emission factor tool to determine emission from roads network around airport.

The version of EDMS is version 4.4 which is said to allow for the methodology of gate simplification and offers features to the user on defining the region of gate activity by letting groups of gates also to be modelled as area sources (EDMS, 2004).

A. Features and Limitations of EDMS

EDMS incorporates both EPA-approved emissions inventory methodologies and dispersion models to ensure that analyses performed with the application conform to EPA guidelines. EDMS contain a comprehensive list of" aircraft engines, ground support equipment, ground equipment, auxiliary power units, vehicular and stationary source emission factor data "(EDMS, 2004). The pollutants currently included in the emissions inventory are CO, THC, NMHC, VOC, NOx, SOx, PM_{25}, PM_{10}, Aircraft PM emissions are only available for aircraft with ICAO certified engines. EDMS performs dispersion analysis by generating input to EPA's AERMOD dispersion model.

B. System Architecture

EDMS consists of several layers of interaction illustrated in order to perform both emissions inventory and dispersion modelling as in Figure 4.8 . This figure presents the interaction between different components within the framework of a single integrated environment.

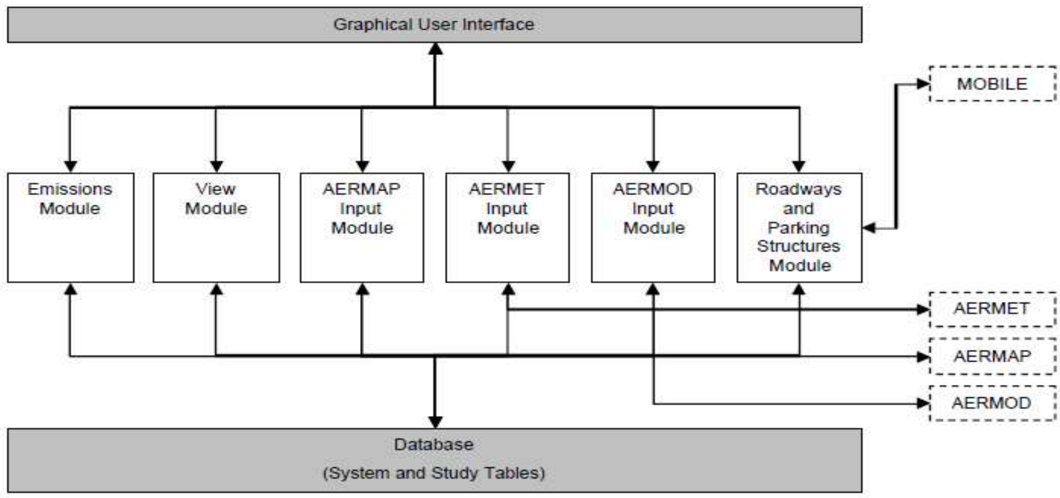


Figure 4.8 EDMS system architecture (Source: EDMS version 4.4, User's Manual)

The background for both the emissions inventory and dispersion modelling is the database including tables for system data and user-created sources. The front-end is the graphical user interface (GUI). The user interrelates with the model and the database through the GUI (EDMS, 2004). Appendix 1 presents a detailed description of the model: airport configuration, receptors location, and all data input for the model are included in Appendix 1.

4.5 CO_2 emission calculation methodology

4.5.1 Data collection

Fuel usage and aircraft movements data were needed to produce estimates of emissions from aviation for the current method.

4.5.2 Fuel consumption

Data have been received from Abu Dhabi National Oil Company (ADNOC-Distribution) Aviation sector; Table 4.11 presents the total yearly consumption for Jet A-1 in kilograms.

Table 4.11: ADIA Jet A-1 fuel consumption

Year	Consumption in tonne
2005	550,052
2006	626,767
2007	716,113

Source: Abu Dhabi National Oil Company 2006 Direct communication

4.5.3 Aircraft movement

The ADIA Authority has provided a sample of one day's air traffic data (01/12/2006), which include details of arrivals and departures of aircraft at ADIA, and international aircraft km flown. Table 4.6 presents departure flights from ADIA to different destinations with distance in kilometres, CO_2 emissions are only calculated for aircraft departures from ADIA.

4.5.4 ADIA CO_2 calculation methodology

A. Tier 3A methodology is listed in spread sheets available at the EMEP/EEA Guidebook website (EEA, 2009). By referring to the spread sheets, an estimate of fuel used during the LTO phase can be obtained based on the associated representative aircraft and the distance that is actually being flown. The total of fuel used for the flight is the sum of fuel used for LTO plus the fuel used in all operations above 3,000 ft (914 m) or cruise phase and then multiplied by the CO_2 emissions factor which is: 3.15 kg CO_2 /kg fuel. Tier 3 = fuel used during LTO + fuel used during CCD * CO_2 emission factor.

B. To validate the outcome of Tier 3 A, Tier 1 is used, and the fuel consumption illustrated in Table 4.14 was used for the year 2006 and multiplied by the CO_2 emissions factor of: 3.15 kg CO_2 /kg fuel.

Tier 1= fuel consumption x CO_2 emission factor

C. CO_2 emissions from freight were not calculated, due to insufficient data on aircraft type Table 4.12 presents aircraft type for all journeys except for cargo.

D. Future projections were conducted using Table 4.11, the fuel consumption per year, in addition to the total air traffic movement per year presented in Figure 5.11(Chapter 5) CO_2 emissions were calculated based on fuel consumption growth.

Table 4.12: Sample of aircraft movements for 01/12/2006 (departures flight only)

AIRCRAFT TYPE	ROUTING	DISTANCE KM
B757	AUH-GOI	2238
B757	AUH-ZRH	4774
CARGO	AUH-CDG	5248
B777	AUH_LHR	5512
B777	AUH-MCT	379.8
A310	AUH-CGP	3790
A330	AUH-VIE	4239
A330	AUH-TPE	6644
CARGO	AUH-LUX	5006
CARGO	AUH-DEL	2275
CARGO	AUH-BCN	5162
A330	AUH-AMM	1997
A330	AUH-AMM	1997
A330	AUH-CMB	3299
B767	AUH-BOM	1968
A340	AUH-BOM	1968
A340	AUH-BOM	1968
A330	AUH-KHI	1263
B767	AUH-ISB	2058
A330	AUH-PEW	1945
B767	AUH-LHR	5512
A330	AUH-LHR	5512
A340	AUH-LHR	5512
B777	AUH-LGW	5487
A330	AUH-MAN	5674
A330	AUH-MUC	5473
A330	AUH-FRA	4861
A330	AUH-CDG	5248
A330	AUH-GVA	4922
B777	AUH-BKK	4940
B777	AUH-BKK	4940
B777	AUH-CGK	6570
B777	AUH-MINL	6570
A330	AUH-BRU	5162
A330	AUH-CAI	2377
A330	AUH-CMN	6047
A330	AUH-BAH	452
A330	AUH-MCT	379.8
A330	AUH-RUH	804
A330	AUH-DMM	537
B777	AUH-DMM	537
B777	AUH-KWI	849
A330	AUH-JED	1612

CARGO	AUH-DEL	2275
CARGO	AUH-KRT	
CARGO	AUH-CCU	3440
CARGO	AUH-FRA	4861
CARGO	AUH-CCU	3440
A320	AUH-BAH	452
A320	AUH-MCT	379.8
A320	AUH-BAH	452
A320	AUH-BAH	452
A320	AUH-BAH	452
A320	AUH-MCT	379.8
A320	AUH-BAH	452
B737	AUH-CCJ	2689
B737	AUH-TRV	2982
A330	AUH-KWI	849
B737	AUH-CAI	2377
B757	AUH-GOI	2238
B757	AUH-HEL	4591
A330	AUH-BCN	5162
A330	AUH-RUH	804
A330	AUH-SHJ	231.5
B737	AUH-PEW	1945
A310	AUH-LHE	2880
A310	AUH-KHI	1263
B737	AUH-KHI	1263
A320	AUH-DOH	323
A320	AUH-DOH	323
A320	AUH-DOH	323
A320	AUH-DOH	323
A320	AUH-AMM	1997
A330	AUH-KRT	
B777	AUH-SIN	5880
B777	AUH-SIN	5880
MD90	AUH-RUH	804
MD90	AUH-RUH	804
B757	AUH-ASB	1546
B757	AUH-ASB	1546
B737	AUH-IST	3015
B737	AUH-IST	3015

(Source: ADIA Authority)

- Routing: is the distance between the airports of departure to the airport of arrival.
- AUH, Abu Dhabi International Airport, LHR is London Heathrow airport, DOH, Doha airport in Qatar. BKK, Bangkok airport in Thailand.

4.6 Suggestions on the policy/ regulatory requirements for the improved control of air pollution resulting from the aviation activities.

Methodologies explained in this chapter were used to collect the data and analyse it for suggesting policy and regulatory requirements for the improved control of air pollution resulting from the aviation activities. The following chapters address these areas in greater detail.

CHAPTER 5

DESCRIPTION OF THE STUDY AREA AND SOURCES OF AIR POLLUTION

In this chapter a brief description of Abu Dhabi and its climate is given in the first part together with the previous studies in the field of air quality in the Emirate of Abu Dhabi. In the second part an overall scenario of Abu Dhabi Airport is presented which includes several topics: Location and characteristics of ADIA, passenger and cargo load at present and the near future expansion of development programme at ADIA.

5.1 Introduction

United Arab Emirates is situated in the Arabian Peninsula between latitudes 22-26°N and longitudes 51-56°E (UAE, 2007). It is bordered by the Arabian Gulf on the north, the Sultanate of Oman and the Gulf of Oman to the east, Saudi Arabia and Qatar to the west, and Saudi Arabia to the south(UAE,2007) (Figure 5.1). The UAE's location between the Arabian Gulf and the Gulf of Oman provides it with a coastline of 650 km and its land mass (The Empty Quarter) totals 83,000 km^2 (UAE,2007) . The UAE covers the eastern corner of the Arabian Peninsula with most of the land being sandy desert, especially the interior areas. However, in the north and the east, there are mountainous areas and most of the cities are situated along the coastline (UAE, 2007). The UAE land consists of sand dunes which are greatly influenced by wind speed and direction. Some of the land is covered by "Sabkha," an Arabic term for low-lying saline flats which contain high salinity and crust. This type of land has a bad impact on plants (UAE, 2007). The UAE consists of seven Emirates, Abu Dhabi, Dubai, Sharjah, Ras Al Khaimah, Umm Al Qaiwain, Fujairah, and Ajman, listed by size, respectively (Figure 5.2). The word emirate means state or "Sheikhdom." Before independence, the emirates were called the Trucial Emirates (UAE, 2007). The Emirate of Abu Dhabi is the largest of the seven Emirates within area of (67,340) square kilometre amounting to 86.6% of the federation. Oil was discovered in the UAE in 1958, the oil revenue has been exploited to improve the standard of living. Before 1971, nearly 100% of the income was from oil. Now alternative sources of income have reduced that dependence on oil to about one-third the total UAE's GDP (UAE, 2007). The accelerated population and economic growth have increased the demand for the use of automobiles, refineries, power plants, airports and the other needs for a modern life style (UAE Ministry of Planning, 2004) resulting in increased air and water pollution. In this study the focus is on air pollution in the vicinity of Abu Dhabi airport which is expected to experience increased aviation activity in the coming years. Abu Dhabi Emirate (Figure 5.2) is divided into:

The group of islands which include Abu Dhabi city.

The western region which is divided into : Al -Dhafra and Bainuna which contain the onshore oil fields, and the industrial complex of Al- Ruwais- Jabal Dhana on the coast;

The eastern region represented mainly by one city, namely, Al Ain, the capital of the region.

Figure 5.1: Map showing location of the UAE *Source: The UAE Media / information Authority,2001*

Figure 5.2: The main cities in Abu Dhabi *Source: The UAE Media / information Authority2005*

Outside the ADIA, two residential areas, namely Khalifa City 'A' (40,000 people) and Khalifa City 'B' (26,000 people) have been constructed and continue to be developed to the extent that they will influence the southern and eastern boundaries of the current airport area. A palace guest house (Rawdat Al Reef Palace) and associated structures have been constructed to the east of the proposed development area (east of El1 highway). Several residential areas exist along the E33 highway (airport road) to Suweihan. The area across from the E10 highway, west of the airport, has been developed under the approach and take-off paths of both the existing and proposed runways (ADIA, 2004). To the south west of the greater airport area lies the Al Raha Beach area, currently comprising a hotel, shopping mall, theatre and other recreational areas. This is an approximately 8 km stretch along the Gulf and has been allocated for major redevelopment, to consist of new residential, commercial and recreational areas. The highways and projected future developments in the vicinity of the airport are shown in Figure 5.3.

5.2 Meteorological conditions

Abu Dhabi is located on the Tropic of Cancer at the southern end of the Arabian Gulf (UAE, 2007). This location, coupled with the sub-tropical anticyclone belt to the south, results in a tropical desert environment. The predominant climatic condition is dry, sunny weather with infrequent and irregular rainfall, which occurs mainly in the winter months (UAE, 2007).

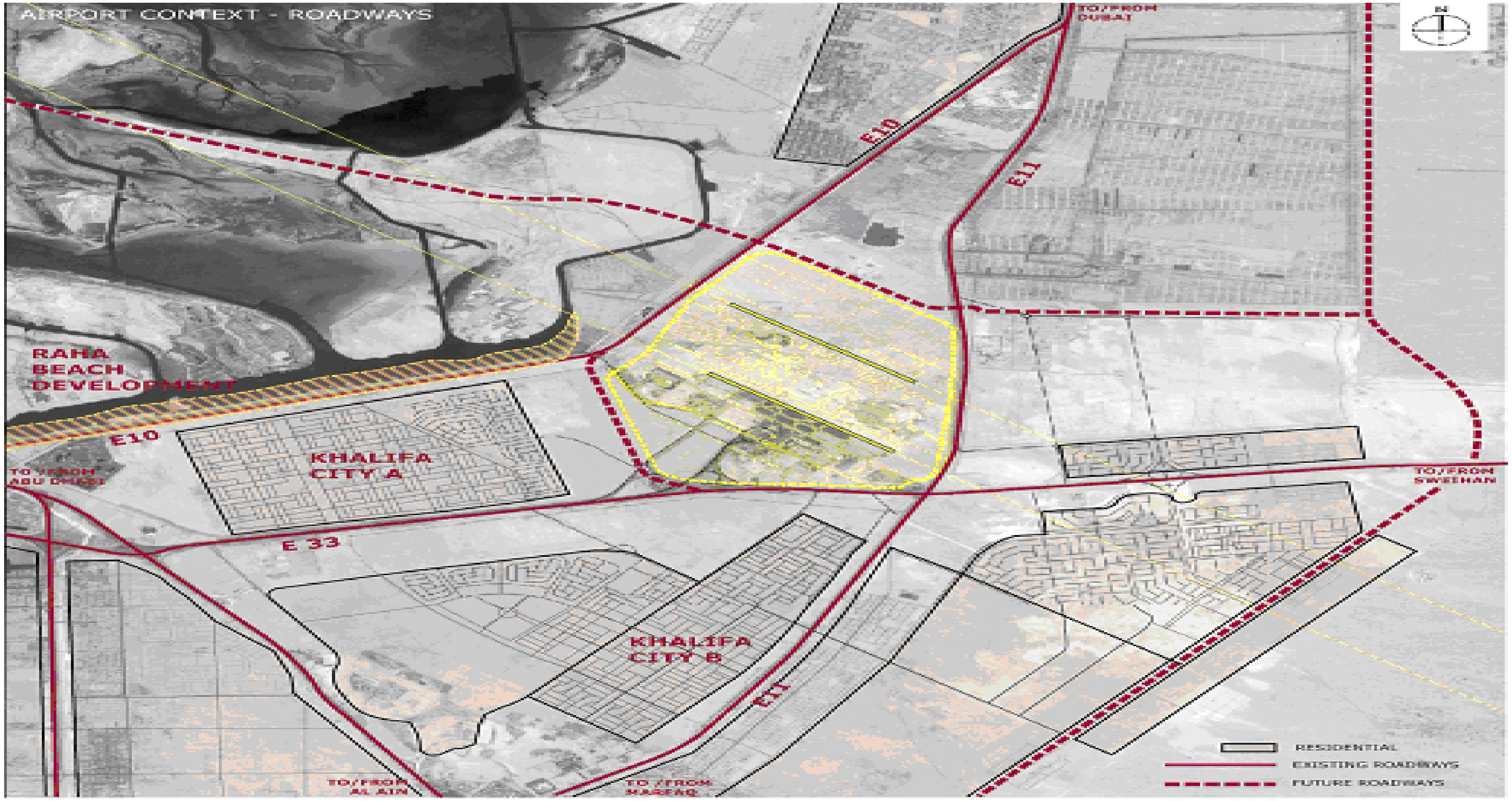


Figure 5.3: Highways and projected future developments in the vicinity of ADIA *(Source: SCADIA, 2005)*

5.2.1 Precipitation

The rainfall in Abu Dhabi, UAE, is very low and extremely variable from year to year. Overall, there is no long-term trend of increasing or decreasing rain; however, there is certain regularity in recurrence of wet years (UAE climate 1996). These wet years occur typically at 8 to 10 year intervals. The annual average rainfall presented in Table 5.1 in Abu Dhabi is 75.8 mm with most rain events occurring during the period from November to April; virtually no rain falls for the seven-month period from May to November (ADIA, 2005).

Table 5.1: Hours of sunlight and rainfall in Abu Dhabi

Month	Hours of Sunlight per day	Rainfall (mm)
January	9.3	**14.4**
February	8.8	**24.1**
March	9.0	**17.5**
April	9.3	**8.5**
May	11.8	**0.7**
June	11.6	**0.0**
July	10.2	**0.0**
August	10.9	**0.0**
September	10.3	**0.0**
October	10.1	**0.0**
November	9.6	**1.3**
December	8.2	**9.3**
	Mean: 9.9	**Total : 75.8**

(*Source: ADIA Meteorological Office, 2005)*

5.2.2 Relative humidity

Mean relative humidity varies from 55% to 69% in Abu Dhabi; humidity sometimes reaches 100% in coastal regions (ADIA, 2005).

5.2.3 Temperature

A hot summer (May to October) and a mild winter (November to April) are experienced in UAE. Interior summer temperatures reach 49°C (120°F), with coastal temperatures slightly lower but combined with high humidity (ADIA, 2004). Temperatures in the winter months range between 20° C and 35° C (Figure 5.4).

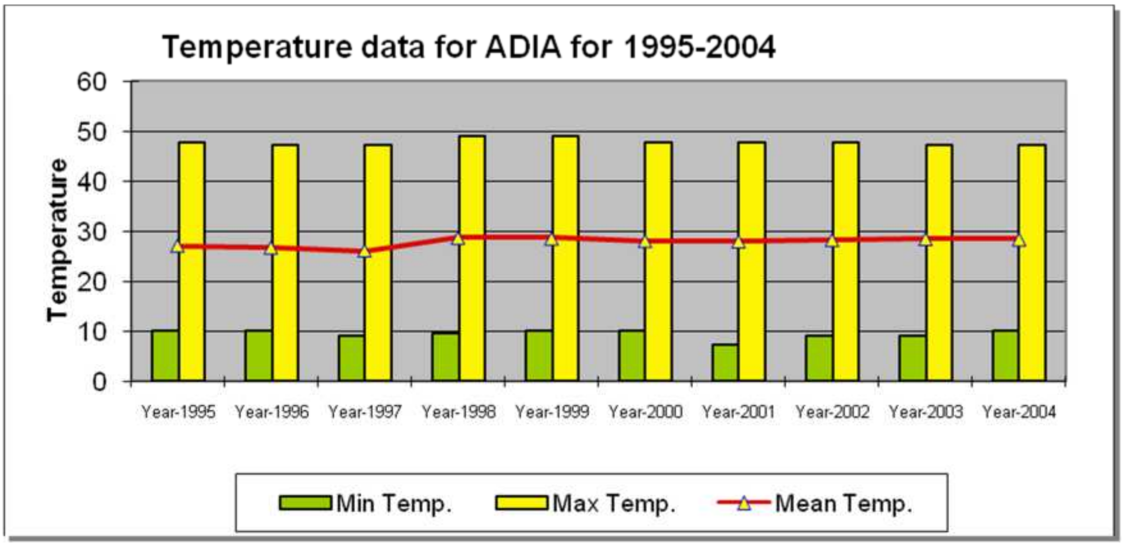


Figure 5.4: Temperature data for ADIA for the period 1995-2004 *(Source: ADIA Meteorological Office2005)*

5.2.4 Wind Pattern

The wind regime in the UAE is from north and northwest for most of the year and winds are generally of light to moderate speed (ADIA, 2005). Strong winds that blow from the northwest, the Shamals, occur mainly from November to March. Shamals also occur during summer months, usually during June and July. In contrast to the stormy conditions of winter Shamals, dry air and cloudless skies characterise those of the summer. Dust hazes regularly take place during the summer Shamals (ADIA, 2005). It is a well-known fact that attention must be paid to the wind direction in treating discrete source of air pollution FECC (1998). Therefore, the hourly records of wind speed and wind direction were utilized in defining the emission source of the measured atmospheric pollutants. Horizontal winds play a major role in the transport and dilution of pollutants. As the wind speed increases, the volume of air moving in a given period of time also increases FECC (1998). If the emission rate is relatively constant, a doubling of wind speed will halve the pollutant concentration, as the concentration is an inverse function of the wind speed. Pollutant dispersion is also considerably affected by variation in wind direction FECC (1998). If wind direction is constantly shifting, pollutants will be dispersed over a large area and concentrations of pollutants will be less in the area. Abu Dhabi is a coastal city, the difference in heating and cooling of land and water surfaces affects the air motion. In the early afternoon, the land surfaces heat more rapidly than water. The heated air over land rises and cold air flows in from the sea; this is known as cool sea breeze. At night the more rapid cooling of the land surfaces results in horizontal air flow toward water and the land breeze is formed, these circulation patterns form under light prevailing winds. The depth of the sea breeze varies from 1 km in January to 1-1.5km in April, July, and

October (Zhu and Atkinson, 2004). The circulation patterns in the UAE are dominated by a sea breeze indicated by northerly flow, while land breeze by southerly flow (Eager et al., 2004). The circulation of land-sea breezes may cause pollutants to re-circulate from time to time. FECC (1998) annual report, states that from noon to midnight the wind direction is dominated by sea breezes, and the land breezes prevail from 7:00 am to early afternoon. Figure 5.5 and 5.6 presents the wind pattern over the UAE and in ADIA respectively.

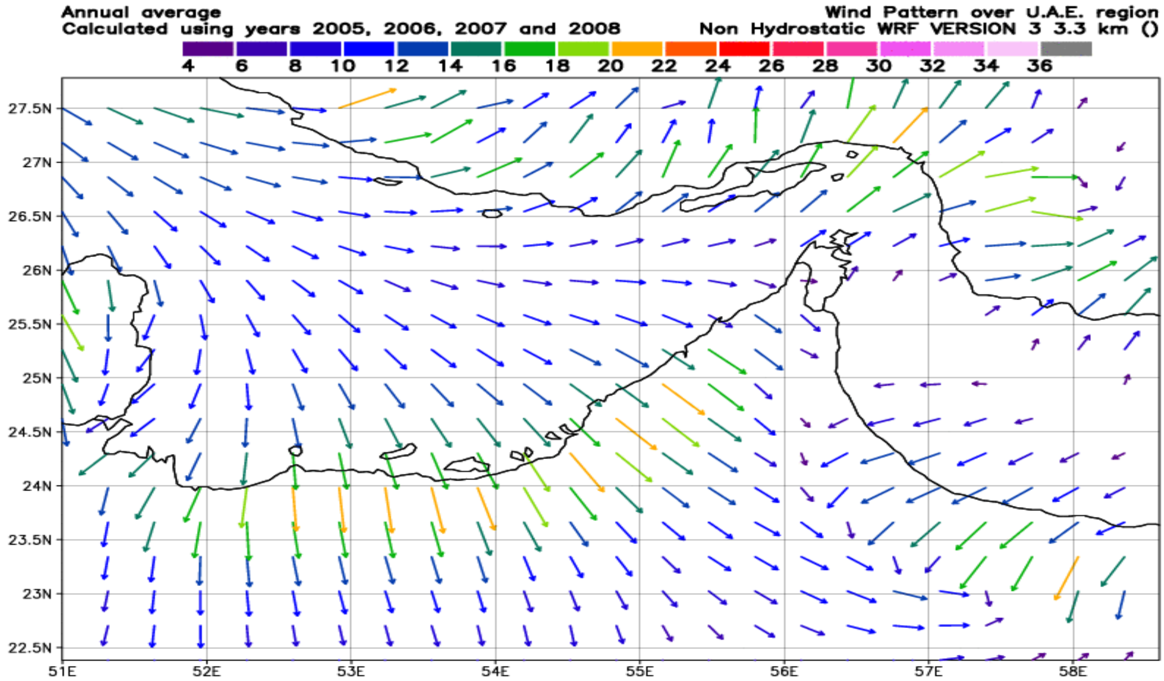
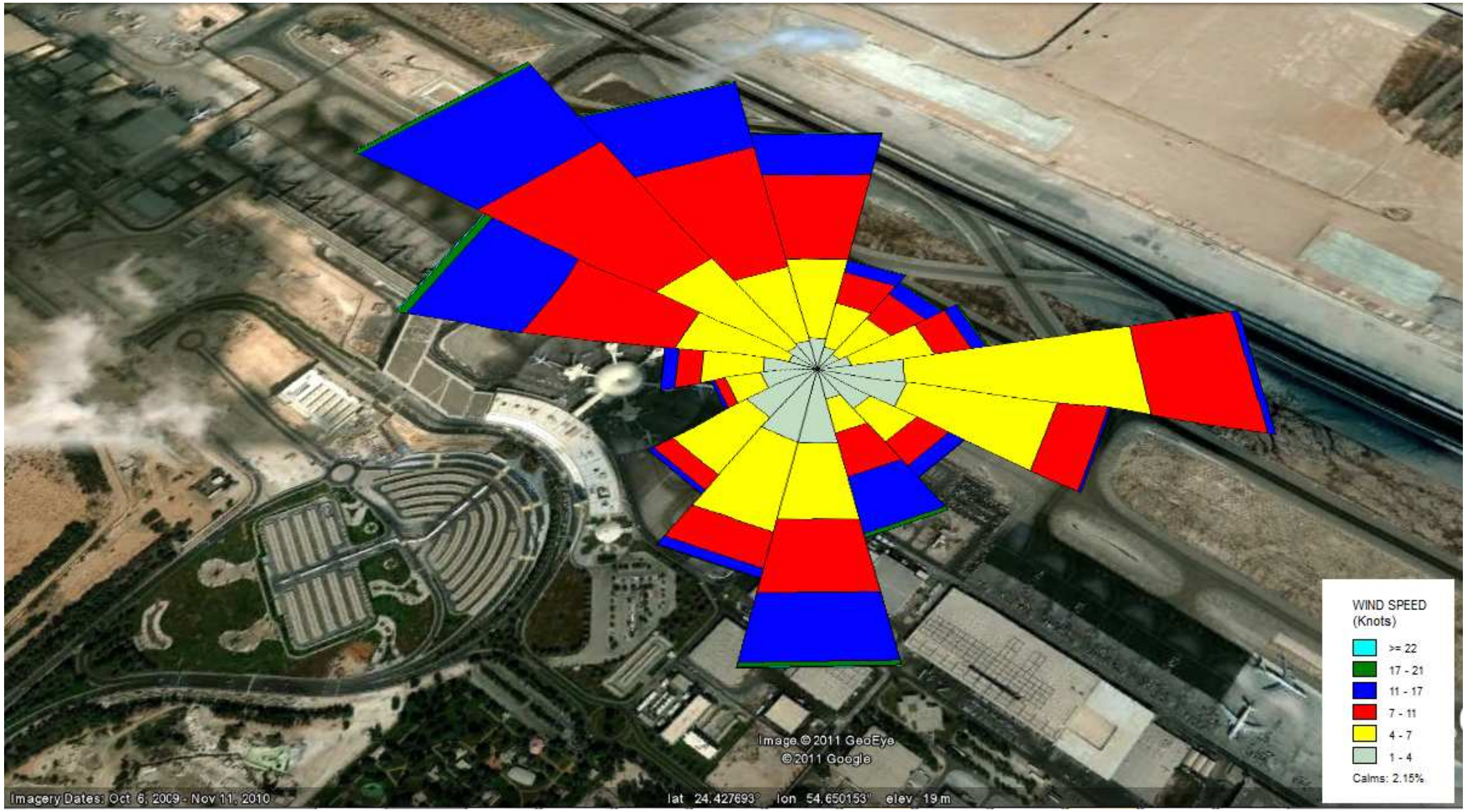


Figure 5.5: Wind pattern over the UAE *(Source: UAE, Air Force, 2007)*

Figure 5.6: Prevailing wind pattern in ADIA (1/1/1999 – 31/12/2009)



Source: plotted by the author using data obtained from ADIA metrological department Aermod software and Google map accessed date 23/11/11

5.3 Air Pollution Monitoring

The main source of air pollution is the oil and gas industry in Abu Dhabi Emirate, followed by the power and transportation sectors (ERODA, 2005). Also the UAE has a relatively high, naturally occurring levels of particulate matter from the desert dunes (Al Wasity, 1994), and the movement of dunes therefore increases the atmospheric contamination with SPM_{10} being highly affected by the wind blowing from the southern direction. The same study examined the acid gases, sulphur dioxide (SO_2) and nitrogen dioxide (NO_2) in the atmosphere, and found that there is a strong relationship between SO_2 and NO_2 and relative humidity levels in the atmosphere of Abu Dhabi due to the conversion of SO_2 to sulphuric acid (H_2SO_4) and NO_x to nitric acid (HNO_3). Moreover, nitrogen oxides in the atmosphere of Abu Dhabi City tend to be in the form of nitrogen dioxide (NO_2) and to a lesser degree in the form of nitric oxide (NO), and most of NO entering the atmosphere of Abu Dhabi from pollution sources consumes most of the O_3 to be oxidized to NO_2. Finally, O_3 was found in concentrations below the background levels, it originates in the form of secondary photoxidant through atmospheric photochemical reactions.

Currently, in the Emirate of Abu Dhabi, the Environmental Agency Abu Dhabi (EAD) is conducting an air quality monitoring and management project. So far, baseline data were collected, emissions were analyzed and dispersion patterns were examined, in order to determine the best possible number and locations of monitoring stations and the EAD is in the process of establishing the monitoring network (ERODA, 2005).

Evaluating the network in the Emirate *The Norwegian Institute for Air Research* (NILU) and *Messrs Dome Oilfield Equipment & Services* (Dome) consultants have carried out two studies to identify areas highly impacted by air pollution, i.e. the hot "spots". These are defined as those locations where air pollution levels exceed the air quality standards prescribed by the regulatory agencies, on account of different types of pollution sources (ERODA, 2005). Data were collected by continuous measurements employing a mobile unit.

The pollutants measured were NO_x, SO_2, H_2S, CO, O_3, PM_{10}, benzene, toluene and xylene (BTX) (ERODA, 2005). The measurements showed high concentrations of PM_{10} and that the average 10 days value exceeded the 24 hour average of the EAD air quality standards at seven of the eleven sites. Therefore, it is expected that the daily average value may exceed the limits stipulated in the guidelines at many more places. Similarly, O_3 was close to the one hour EAD guideline at five out of eleven sites, all of them outside the cities in areas with low traffic and low industrial development, indicating that ozone represents a regional problem. The NOx measurements show that the highest values were recorded inside the cities where maximum one hour average NO_2 concentrations may vary between 150-200 ug/m^3. The main sources of the NO_x concentrations were road traffic (ERODA, 2005). Peak values of sulphur dioxide were identified downwind of industrial sites at Ruwais and Habshan. Similarly higher values of H_2S were also reported from inside the Mussafah Industrial area and downwind of industrial sites, such as Ruwais and Habshan, which might suffer from odour problems in specific locations.

Moreover, a study was conducted by Al-Aidrouset (2001) in Abu Dhabi city to investigate SO_2, NO_2, PM_{10}, O_3 and CO concentrations during the period from August 1998 to December 2001 in three areas: 1) Al Salam area, representing a commercial area, 2) Al Bateen area, representing a residential area and 3) Al Mussaffah area, a main industrial area. Furthermore, an epidemiological study was also conducted on respiratory and non-respiratory patients admitted to Al Jazeerah and Al Mafraq hospitals. It concluded that the critical air pollutants in Abu Dhabi city were NO_2, PM_{10} and O_3. The study indicated a strong relationship between increasing O_3 and SO_2 levels and patients admitted for respiratory diseases such as asthma.

The air quality monitoring objective of the EAD is to obtain a better understanding of the urban, residential and industrial air quality, as a prerequisite to finding effective solutions to air quality issues for sustainable development of the Emirate.

The EAD ambient air quality monitoring network currently consists of ten fixed ambient air quality stations at various locations around the city of Abu Dhabi, Figure 5.7 presents the monitoring stations location.

In addition, two mobile air quality stations are deployed at selected areas of interest for short periods (ERODA, 2007).

Figure 5.7 Hamden street air quality monitoring site in Abu Dhabi city
Source: Environmental Agency-Abu Dhabi –April Report, 2007

Figure 5.8: Air Quality Monitoring Sites in Abu Dhabi Area
Source: Environmental Agency-Abu Dhabi –April Report, 2007

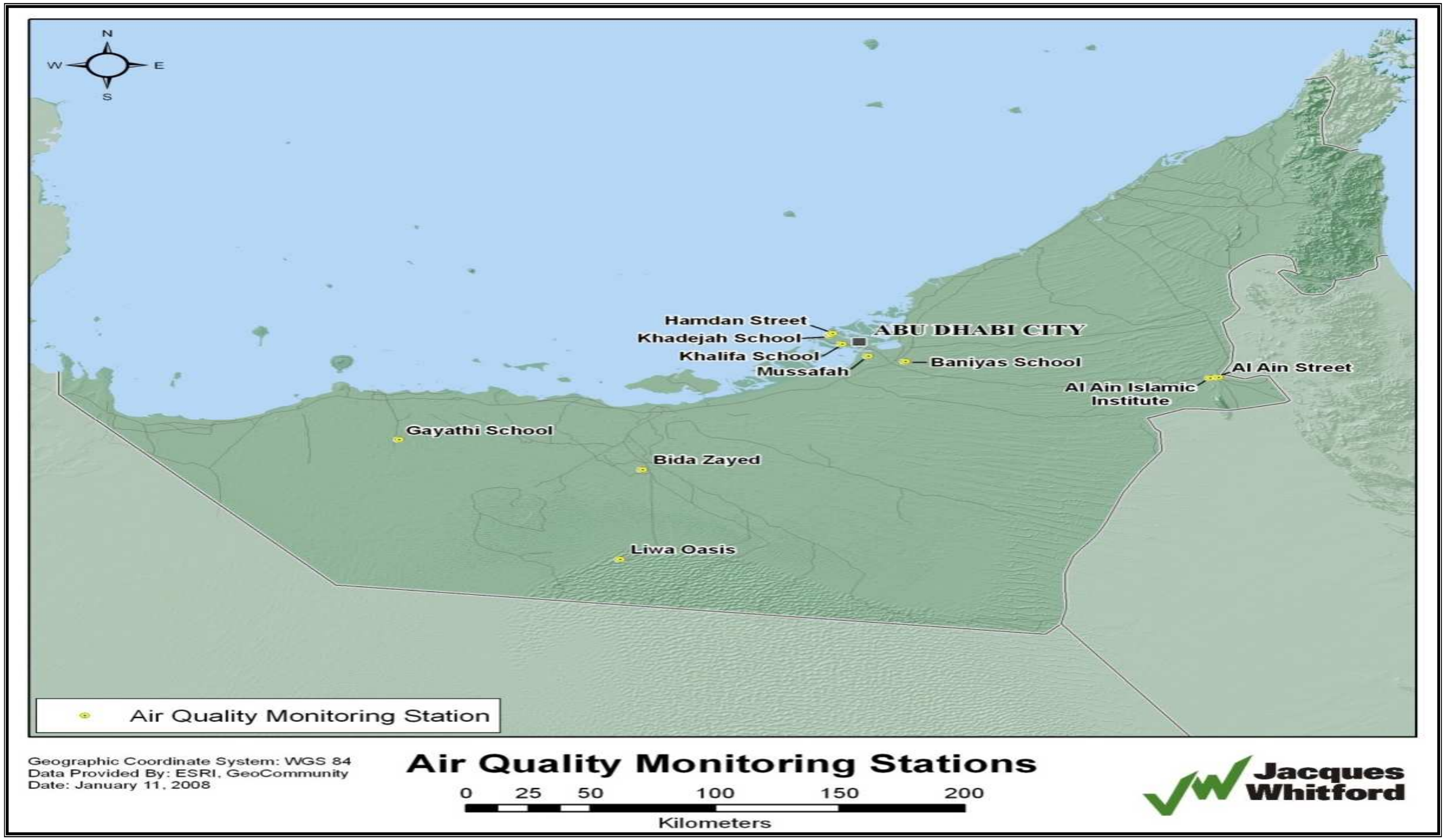


Table 5.2 Air Quality Monitoring Stations – Emirate of Abu Dhabi			
Air Quality Monitoring Station	**Parameters Measured**	**Type of Station**	**Coordinates**
Al Ain Islamic Institute	SO_2, NO_x, NO, H_2S, O_3, PM_{10}, CH_4, Noise	Urban/Residential	**N241309.8 E0554408.2**
Kadejah School	SO_2, NO_x, NO, H_2S, O_3, PM_{10}, CH_4, Noise	Down town	**N242902.6 E542150.6**
Khalifa School	SO_2, NO_x, NO, H_2S, O_3, PM_{10}, CH_4, Noise	Urban/Residential	**N242548.3 E542429.9**
Gayathi School	SO_2, NO_x, NO, H_2S, O_3, PM_{10}, CH_4, Noise	Down town	**N235008.0 E524838.2**
Bida Zayed	SO_2, NO_x, NO, H_2S, O_3, PM_{10}, CH_4, Noise	Urban/Residential	**N233904.2 E534114.0**
Baniyas School	SO_2, NO_x, NO, H_2S, O_3, PM_{10}, CH_4, Noise	Urban/Residential	**N241916.9 E543809.1**
Hamdan Street	SO_2, NO_x, NO, CO, PM_{10}, CH_4, BTEX, Noise	Road Side	**N242946.6 E542222.0**
Al Ain Street	SO_2, NO_x, NO, CO, PM_{10}, CH_4, BTEX, Noise	Road Side	**N241328.4 E554554.7**
Mussafah	SO_2, NO_x, NO, CO, PM_{10}, CH_4, BTEX, Noise	Industrial	**N242116.2 E543011.1**
Liwa Oasis	**SO_2, NO_x, NO, H_2S, O_3, PM_{10}, CH_4, Noise**	**Regional Background**	**N230544.3 E533622.8**

Source: Environmental Agency-Abu Dhabi –April Report, 2007

At these stations, some or all of the following parameters are measured: concentrations of SO_2, NOx, O_3, H_2S, PM_{10}, BTEX and NMHC, noise, wind speed, wind direction and ambient temperature, (EAD, 2007). Many of the stations are located within urban/residential areas. However, some stations are located to collect regional background and industrial data.

In the operation of the air quality monitoring stations, quality control and quality assurance protocols are followed to ensure the accuracy and precision of the data. This includes tasks such as data quality control, data security and storage, system checks and preventive maintenance on an ongoing basis. The procedures for the operation and maintenance of the ambient Air Quality Monitoring Stations (AQMS) are driven by protocols established by the United States Environmental Protection Agency. (EAD, 2007)

Data from the EAD ambient air quality network can be used to track and most importantly, to provide feedback on the need for appropriate emission control technologies where warranted. Statistics are provided on the maximum, minimum and average values for the measured air quality parameters recorded within the network. However, EAD has not covered all the mobile sources such as aviation air pollution or pollution from seaports. (EAD, 2007)

Table 5.3

Measurements constrictions of Air Quality Stations in the Emirate of Abu Dhabi.

PM10 Summary

	Al Ain Street	Hamdan Street	Khalifa	Kadejah	Gayathi	Liwa	Alain School	Musaffah
	ug/m^3	ug/m^3	ug/m^3	ug/m^3	ug/m^3	ug/m^3	ug/m^3	**ug/m^3**
Mean	242	165	147	86	180	194	130	**268**
Max	842	454	318	314	461	574	249	**726**
Min	60	51	45	27	40	56	42	**89**

Al Ain Street Data Summary

ALAIN STREET	PM_{10}	SO_2	NO	NO_x	CH_4	CO	WS	WD	TEMP -10	TEMP -2
	µg/m^3	PPB	PPB	PPB	PPM	PPM	m/s	Deg	°C	°C
Mean	242	-	27	46	2	1	1	157	31	**31**
Max	1032	-	134	156	2	2	14	355	42	**43**
Min	29	-	2	9	1	1	<1	5	17	**17**
Coverage (%)	99.58		99.58	99.58	38.19	38.19	99.58	99.58	98.89	**98.89**
Observations	717	0	717	717	275	275	717	717	712	**712**

ALAIN STREET	BENZ	TOL	E-BENZ	MP-XYL	O-XYL
	ug/m^3	ug/m^3	ug/m^3	ug/m^3	ug/m^3
Mean	1.25	7.74	1.32	4.45	**2.48**
Max	5.65	20.47	4.53	15.88	**7.83**
Min	0.00	1.69	0.03	0.03	**0.15**
Coverage (%)	82.08	100.00	90.00	98.89	**97.22**
Observations	591	720	648	712	**700**

Hamdan Street Data Summary

HAMDAN STREET	PM_{10}	SO_2	NO	NO_x	CH_4	CO	WS	WD	TEMP -10	TEMP -2
	µg/m^3	PPB	PPB	PPB	PPM	PPM	m/s	Deg	°C	°C
Mean	165	2	76	84	3	5	2	254	29	**29**
Max	801	16	125	131	4	11	4	346	40	**41**
Min	40	<1	15	25	2	1	<1	14	21	**21**
Coverage (%)	99.58	98.47	99.58	99.58	99.58	99.58	100.00	100.00	100.00	**100.00**
Observations	717	709	717	717	717	717	720	720	720	**720**

HAMDAN STREET	BENZ	TOL	E-BENZ	MP-XYL	O-XYL
	ug/m^3	ug/m^3	ug/m^3	ug/m^3	ug/m^3
Mean	4.93	12.78	3.75	8.15	**3.58**
Max	16.81	48.94	14.11	39.14	**16.30**
Min	1.53	0.07	0.08	0.07	**0.05**
Coverage (%)	100.00	100.00	100.00	100.00	**100.00**
Observations	720	720	720	720	**720**

Khalifa School Data Summary

KHALIFA SCHOOL	PM_{10}	SO_2	NO	NO_x	CH_4	H_2S	O_3	WS	WD	TEMP 10	TEMP 2
	ug/m^3	PPB	PPB	PPB	PPM	PPB	PPB	m/s	Deg	°C	°C
Mean	147	1	4	17	2	1	13	2	187	29	**29**
Max	443	6	52	66	3	6	53	7	351	41	**42**
Min	27	<1	<1	1	1	<1	<1	<1	1	16	**15**
Coverage (%)	97.78	74.31	77.64	77.64	97.78	91.53	97.78	91.53	91.53	98.47	**98.47**
Observations	704	535	559	559	704	659	704	659	659	709	**709**

Kadejah School Data Summary

KADEJAH SCHOOL	PM_{10}	SO_2	NO	NO_x	CH_4	H_2S	O_3	WS	WD	TEMP 10	TEMP 2
	ug/m^3	PPB	PPB	PPB	PPM	PPB	PPB	m/s	Deg	°C	°C
Mean	86	4	-	-	2	1	17	2	206	30	**30**
Max	435	20	-	-	2	5	51	5	359	41	**43**
Min	20	1	-	-	2	<1	<1	<1	8	21	**21**
Coverage (%)	98.19	99.58	0.00	0.00	99.58	95.56	99.58	99.58	99.58	99.44	**99.44**
Observations	707	717	0	0	717	688	717	717	717	716	**716**

Gayathi School Data Summary											
GAYATHI SCHOOL	**PM_{10}**	**SO_2**	**NO**	**NO_x**	**CH_4**	**H_2S**	**O_3**	**WS**	**WD**	**TEMP 10**	**TEMP 2**
	ug/m^3	**PPB**	**PPB**	**PPB**	**PPM**	**PPB**	**PPB**	**m/s**	**Deg**	**°C**	**°C**
Mean	177	2	2	6	2	1	37	3	155	30	**29**
Max	768	24	48	70	3	54	69	9	359	43	**43**
Min	23	<1	<1	<1	1	<1	3	<1	1	13	**13**
Coverage (%)	96.11	95.28	93.75	93.75	96.11	92.36	96.11	96.67	96.67	96.67	**96.67**
Observations	692	686	675	675	692	665	692	696	696	696	**696**

Liwa School Data Summary										
LIWA SCHOOL	**PM_{10}**	**SO_2**	**NO**	**NO_x**	**CH_4**	**O_3**	**WS**	**WD**	**TEMP 10**	**TEMP 2**
	ug/m^3	**PPB**	**PPB**	**PPB**	**PPM**	**PPB**	**m/s**	**Deg**	**°C**	**°C**
Mean	194	5	1	2	1	42	1	132	32	**31**
Max	1024	64	13	18	2	65	3	357	43	**42**
Min	29	<1	<1	<1	1	17	<1	1	16	**15**
Coverage(%)	99.44	99.44	83.33	83.33	99.44	99.44	100.00	100.00	100.00	**100.00**
Observations	716	716	600	600	716	716	720	720	720	**720**

Al Ain School Data Summary											
AL AIN SCHOOL	**PM_{10}**	**SO_2**	**NO**	**NO_x**	**CH_4**	**H_2S**	**O_3**	**WS**	**WD**	**TEMP 10**	**TEMP 2**
	ug/m^3	**PPB**	**PPB**	**PPB**	**PPM**	**PPB**	**PPB**	**m/s**	**Deg**	**°C**	**°C**
Mean	130	2	3	7	1	1	22	2	190	31	**32**
Max	439	12	30	41	2	5	61	8	356	40	**42**
Min	16	<1	<1	1	1	<1	1	<1	2	21	**22**
Coverage(%)	82.78	39.72	75.69	75.69	38.06	81.25	83.06	96.53	96.53	38.19	**38.19**
Observations	596	286	545	545	274	585	598	695	695	275	**275**

Musaffah Industrial Data Summary											
MUSAFFAH INDUSTRIAL	**PM_{10}**	**SO_2**	**NO**	**NO_x**	**H_2S**	**CH_4**	**THC**	**WS**	**WD**	**TEMP 10**	**TEMP 2**
	ug/m^3	**PPB**	**PPB**	**PPB**	**PPB**	**PPM**	**PPM**	**m/s**	**Deg**	**°C**	**°C**
Mean	268	2	18	42	1	2	2	1	198	29	**30**
Max	1024	23	115	135	25	2	3	3	359	42	**43**
Min	47	<1	<1	2	<1	1	1	<1	1	16	**15**
Coverage (%)	99.03	94.44	99.03	99.03	98.47	99.44	99.44	100.00	100.00	100.00	**100.00**
Observations	**713.00**	**680**	**713**	**713**	**709**	**716**	**716**	**720**	**720**	**720**	**720**

Abu Dhabi *Source: Environmental Agency-Abu Dhabi –April Report, 2007*

Source: Environmental Agency-Abu Dhabi –April Report, 2007

5.4 Sources of Air Emissions in UAE Abu Dhabi

The Environmental Research and Wildlife Development Agency (ERWDA) is implementing an "Abu Dhabi Air Quality Management Study" to determine the impact of current and future development activities on the quality of ambient air in Abu Dhabi Emirate.

NILU, through its counterpart in Abu Dhabi (DOME) and its subcontractor, Inter consult International AS (ICI) are undertaking the Abu Dhabi Air Quality Management Study on behalf of ERWDA.

The emission identification task involved review and analysis of various identified emission sources including point, area and line sources within Abu Dhabi Emirate.

Table 5.4: Emission source group for Abu Dhabi air quality management

Source Category	Source Group
Point sources	Oil industries (i.e. ADNOC and its group of companies)
	Power plants
	Small industries
	Medical waste incinerators
Line sources	Road traffic emissions.
Area sources	Open burning/landfill sites
	Petrol filling stations
	Fuel storage depots

Source: Environmental Agency-Abu Dhabi – NILU, ABU DHABI AIR QUALITY MANAGEMENT STUDY, 2004

The methodology used by the team mentioned above was first of all collecting the activity data regarding the sectors mentioned in Table 5.4. Consequently, the overall emission rates for various pollutants (e.g., NO_x, SO_x, CO, PM) were calculated using the US-EPA (Document "Compilation of Air Pollutant Emission Factors, AP-42, Fifth Edition, Volume I: Stationary Point and Area Sources", (EAD, 2007).

The Power Sector in Abu Dhabi

The Abu Dhabi Water and Electricity Authority (ADWEA) have nine main power and desalination plants in the Emirate of Abu Dhabi, located in the following areas(EAD, 2007):

Al Ain
Mina Zayed
Abu Dhabi City
Al Mirfa
Madinat Zayed
Al Taweelah.
Umm Al Nar

The Abu Dhabi Air Quality Management Study concluded that the major emission contribution in the Abu Dhabi Emirate from power sectors is from Al Taweelah and

Um Al Nar (UAN) areas. Table 5.5 presents the emission rate. The emission contribution of the power sectors in Abu Dhabi Emirate is given in table 5.

Table 5.5: The emission rate for the power sector in the Emirate of Abu Dhabi

Areas	Emission Rate, Tonnes/year							
	CO2	**CO**	**NOx**	**N2O**	**SOx**	**CH4**	**VOC**	**PM**
Al Taweelah	3852047.8	3130.605	16372.81	218.635	60.954	403.69	359.525	716.86
Al Ain	532.535	36.062	693.135	9.7455	2.7375	22.156	12.41	31.755
Abu Dhabi	1341.375	31.317	1750.175	24.455	6.8985	55.845	31.317	80.3
Al Mirfa	995080.92	698.245	1872.085	22.995	6.424	101.725	50.735	389.455
UAN	8600261.12	5911.605	13479.09	162.462	45.04	162.462	390.365	537.645

Source: Environmental Agency-Abu Dhabi – NILU, Abu Dhabi Air Quality Management Study 2004

Table 5.6: The emission from the power sector in the Emirate of Abu Dhabi

	Emission Rate, Tonnes/year							
	CO_2	**CO**	**NOx**	**N_2O**	**SOx**	**CH4**	**VOC**	**PM**
Total emission from power sector	13449263.8	9807.834	34167.28	438.2925	122.055	715.898	844.352	1756.015

Source: Environmental Agency-Abu Dhabi – NILU, Abu Dhabi Air Quality Management Study 2004

The oil and Gas Sector

The majority of air emission sources from ADNOC and its group of companies are generated from refining, gas processing, petrochemicals, exploration and production. Eleven companies were identified as contributing the most to air pollution (EAD, 2007). These companies are:

Abu Dhabi Company for Onshore Oil Operations (ADCO)
Abu Dhabi Gas Liquefaction Limited (ADGAS)
Abu Dhabi Oil Company (ADOC)
Abu Dhabi Marine Operating Company (ADMA-OPCO)
Abu Dhabi Polymers Company (BOUROUGE)
Bunduq Limited Company (BUNDUQ)
Ruwais Fertilizer Industries (FERTIL)
Abu Dhabi Gas Industries Limited (GASCO)
Abu Dhabi Oil Refining Company (TAKREER)
Total Abu Al Bukhoosh (TOTAL-ABK)
Zakum Development Company (ZADCO)

Exploration and production are the areas of activity that give rise to the highest levels of air emissions, resulting from the use of fuel (EAD, 2007), or from controlled flaring and venting, which are needed for safe operation. A major amount of the emissions are hydrocarbons, consisting mainly of methane. The residual emissions, principally NOx, Sox and CO, are produced during the fuel combustion. According to the study CO_2 was not included because its impact is much lower (EAD, 2007).

Figure 5.9 presents the emission totals for the eleven companies in relation to CO_2, CO, NO_x, SO_x, some VOCs (VOC and CH_4) and particulate matter.

The study indicated that many types of industries at work, in the Mussafah Industrial area involved in a wide variety of manufacturing activities, but no emission data were provided by the companies. Furthermore, no information was made available for Abu Dhabi Hospital Incinerators, air emissions or waste incinerators, open burning/landfill sites, fuel storage depots and petrol filling stations (EAD, 2007).

It also can be seen that the aviation sector was not included in the Abu Dhabi Air Quality Management Study; therefore, the importance of this thesis is to cover this important sector, in addition to help setting future strategies and policies for the aviation sector in Abu Dhabi Emirates.

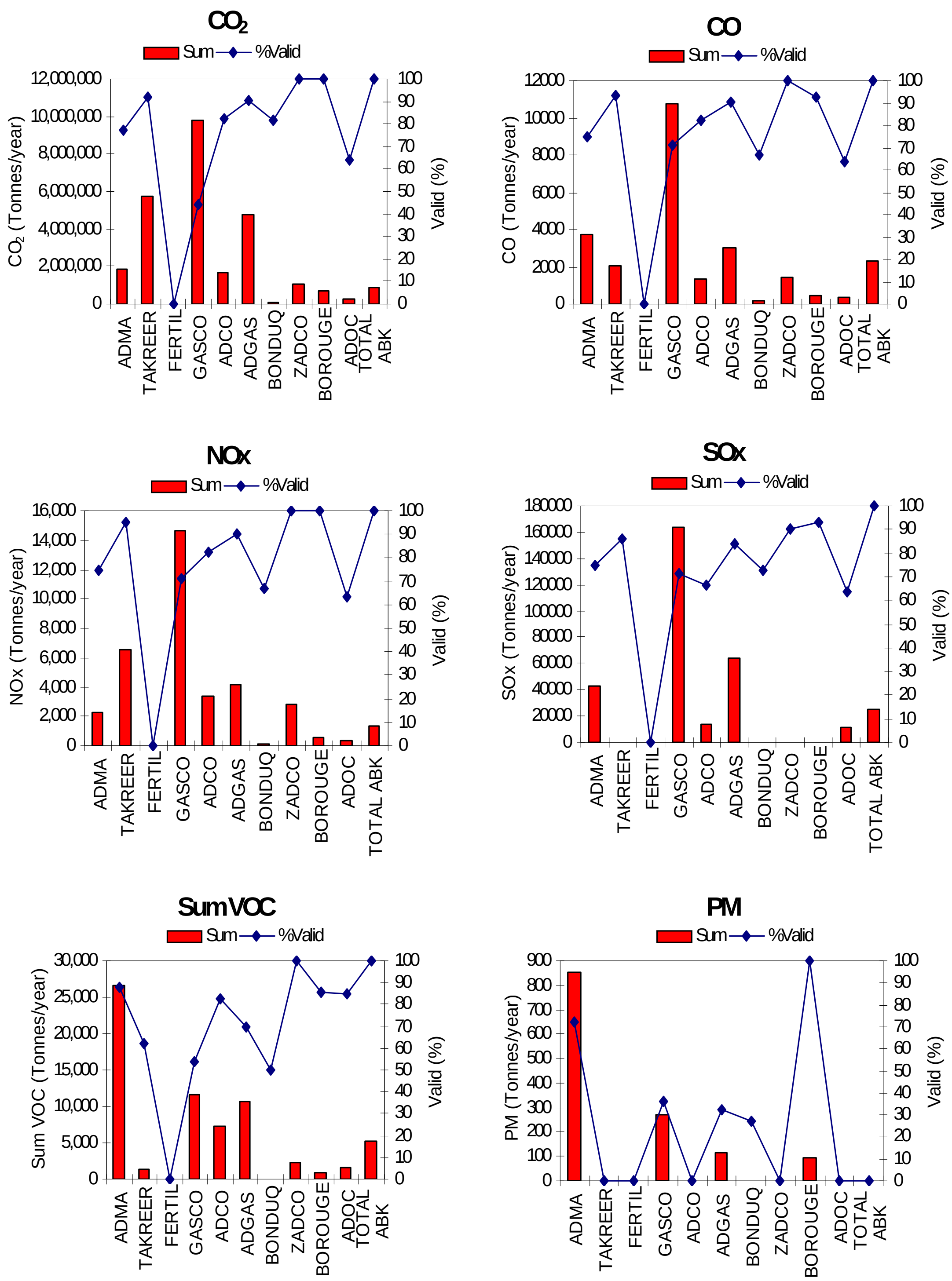


Figure 5.9: Total emissions and percentage of available sources with valid data for 11 ADNOC companies. "%Valid" is the percentage of valid emission data available as source wise information or as totals.

Source: Environmental Agency-Abu Dhabi – NILU, Abu Dhabi Air Quality Management Study 2004

5.5 The UAE greenhouse gas inventory

As climate change occurs it becomes increasingly important to monitor and record CO_2 emissions in the atmosphere. The first essential stage towards developing strategies to reduce GHGs emissions, carbon calculators, is used to present an estimate. Similarly, the UAE acceded to the United Nations Framework Convention on Climate Change in December 1995 and became an official party in March 1996 with a mandate, as a Non Annex 1 Party to the Convention, to submit National Communications. A team of UAE scientists and experts specialising in different disciplines in coordination with the Ministry of Energy were involved in preparing the National Communication (Ministry of Energy, 2006).

The UAE has compiled an initial set of strategies to demonstrate its shared aims with the international community in tackling the threat of climate change, as well as to inform future policy discussions. It is important to note that this corresponds to a voluntary and progressive approach to the climate change challenge since, as a non-Annex 1 country under the UNFCCC, the UAE is not obliged to follow explicit GHG reduction targets. The Environment Agency of Abu Dhabi has compiled the preparation of the national GHG inventory in cooperation with the Ministry of Energy and other concerned parties in the UAE. The revised IPCC Guidelines (1996) were used in which GHG emissions are calculated for different sectors but did not include the transportation sector. The report of the UAE GHG inventory mentioned the methodology used to compile the inventory without much detail. They used 1994 data, and a software tool developed by IPCC/OECD/IEA for compiling national inventories. The report highlights the use of the IPCC methodology and the software tool used to comply with the international goal of standardizing the system for emissions inventory and reporting, by meeting basic requirements, comparability and transparency. The report also highlights the need for developing reliable databases within each sector, to provide complete and standardized types of information. This is because, the data were designed for government planning purposes and it does not address all the information required for the IPCC methodology. Emission factors were based on IPCC default values and conversion coefficients, and the adjustments were made to reflect local conditions. In addition, locally derived default values were used in the land-use change and forestry, waste management, agriculture and industrial sectors, but not many details were given in the report to understand how these values were derived. The results of the UAE's national GHG inventory are summarized in Table 5.7.

Table 5.7: Total GHG emissions in the UAE, 1994 (Gg)

Sector	CO_2 equivalent	CO_2	CH_4	N_2O	NO_X	CO	NMVOCs	SO_2
Energy	70,870	60,246	396	5	162	836	95	18,310
Industrial process	3,455	3,443	1	0	1	138	6	5
Waste management	2,552	0	108	0	0	0	0	0
Agriculture	1,777	0	48	2	0	0	0	0
Land use	-4,227	-4,227	0	0	0	0	0	0
Total	74,436	59,462	533	7	163	974	101	18,315

(Source: Initial National Communication to the United Nation Framework Convention on Climate Change, Ministry of Energy, United Arab Emirates, April, 2006)

In January 2010, the Abu Dhabi Environmental Agency with the Ministry of Energy compiled the second report which is an update to its inventory of greenhouse gas emissions for the year 2000, (Table 5.8). In 2000, the total GHG emissions were 129,550 Gg CO_2-equivalent. On a net CO_2 equivalent basis, emissions in the UAE increased by nearly 61% over the period 1994 to 2000, or by about 8.3% per year(Ministry of Energy, 2010).

Table 5.8: Total GHG emissions in the UAE, 2000 (Gg)

GHG source & sink	CO_2 equivalent	CO_2	CH_4	N_2O	NO_X	CO	NMVOCs	SO_2
Energy	116,114	96,240	796	10	247	362	19	8,085
Industrial process	6,466	6,466	0	0	1	151	21	6
Solvent & other product use	0	0	0	0	0	0	0	0
Agriculture	4,348	0	80	9	0	0	0	0
Land use change & forestry	-9,665	-9,665	0	0	0	0	0	0
Waste	2,622	0	120	0	0	0	0	0
Total National Emissions	129,550	102,706	997	19	248	513	41	8,091
Net Natural Emissions	119,855	93,041	997	19	248	513	41	8,091

Source: Second National Communication to the United Nation Framework Convention on Climate Change, Ministry of Energy, United Arab Emirates, January 2010.

5.5.1 The UAE Climate Change Mitigation Initiatives

Greenhouse gas mitigation activities in the UAE have been increasing over the past few years. The most distinguished activity is the MASDAR initiative, a $15 billion programme linking climate change, economic opportunity and clean energy. It is located opposite ADIA at Khalifa A city, which includes new infrastructure, manufacturing, and renewable energy projects such solar power, hydrogen, wind power, and carbon reduction and management technologies. The objective is to raise more than $11 billion dedicated to research and development of renewable energy technologies, taking the UAE on its first major step in the development of clean sources of alternative energy.

Renewable energy will be used in MASDAR City to sustain a population of 50,000 and 1,500 companies. In addition to the MASDAR initiative, a governmental process has been in progress to recognize suitable strategies to decrease GHG emissions in the UAE. Given its important role in the GHG inventory, energy supply and demand has been the primary focus of policy-level discussions regarding potential GHG mitigation options. Investments in modern energy infrastructure, including the progressive deployment of energy efficient and renewable technologies are projected over the longer term to contribute to substantial reductions in GHG emissions. Moreover, enhanced oil recovery schemes using carbon captured from industrial flue gases and transported/injected into onshore oil fields, are being actively explored through a joint ADNOC (Abu Dhabi National Oil Company) and MASDAR collaboration. Main GHG mitigation strategies includes sustainable (green) building codes, ecological footprint assessment, and low-carbon electricity supply using renewable, peaceful nuclear energy, high efficiency natural gas plants, sustainable transport initiatives which introduce the concept of reliance on public transport. The analysis focuses on the component of Abu Dhabi Vision 2030 (Abu Dhabi Strategy, 2007) that calls for shifts from private modes of transport (i.e., cars and light duty trucks) to public modes of transport (i.e., metro, light rail, street cars and buses) and scales this initiative up to the UAE level. In the case of alternative transport fuels, the analysis focuses on the use of compressed natural gas (CNG) in bus fleets and a variety of climate change awareness raising campaigns targeted at the general public, media and businesses. Over the period of their implementation, the above measures are projected to yield reductions of about 1.1 billion tonnes of CO_2 equivalent cumulatively until 2030. The advantage of this plan is to highlight the initiative carried out by the Abu Dhabi Government and the UAE in general and to indicate that the aviation sector was not included; therefore the importance of this thesis is to fill the gap by covering the aviation sector in Abu Dhabi Emirate by calculating CO_2 emission from ADIA.

5.6 Abu Dhabi International Airport (ADIA)

Abu Dhabi is triangle shaped island situated in the western central cost of the Arabian Gulf. The city has an area of 67,340 km" (26,000 sq miles), and had a population of 860,000 in 2007. Abu Dhabi is a newly developed, well-planned metropolitan city in the UAE. Its fast development and urbanization, joined with the relatively high average income of its population, has brought about its transformation. Abu Dhabi is considered to be the main centre of political, cultural, commercial and industrial activities and it generates 15% of the GDP of the United Arab Emirates.

The present airport in Abu Dhabi was opened on the mainland in 1982, close to the main highways linking Abu Dhabi with Dubai, about 30 km from the city. The new Abu Dhabi International Airport was originally designed to accommodate a maximum of five million passengers a year. In the mid-1990s, however, further expansion became necessary and the terminal building was enlarged to accommodate increasing numbers of business and leisure travellers of which a large number are transit passenger between Europe and the Far East (ADIA, 2004). The airport appears relatively isolated as can be seen in a photograph from circa 1995 (Figures 5.7 and 5.8) (*Source: SCADIA, 2005*)

Figure 5.10: Abu Dhabi airport through an aerial view (*Source: SCADIA, 2005*)

Figure 5.11: Aerial photograph of ADIA, 1995 (*Source: SCADIA, 2005*)

The airport is now undertaking a major expansion; the total amount allocated for projects is US$ 6.8 billion. The Abu Dhabi Department of Civil Aviation along with the Supervision Committee for the Expansion of Abu Dhabi International Airport (SCADIA) began work in 2004 on the expansion plan to change Abu Dhabi International Airport into a major transport hub for the Middle East for both cargo and passengers. The urban location nearby ADIA and its current and projected expansion is illustrated in Figure 5.10.

Figure 5.12 Projected future development in the vicinity of ADIA (*Source: SCADIA, 2005*)

The plan for the project includes the new terminal, which is set for the first phase completion in 2012. There is to be a 4,100 m runway, two km parallel to the existing airstrip, a new air traffic control centre, enhanced cargo facilities, business park and property developments. The midfield terminal is designed to handle up to 20 million passengers per year with options for it to double in capacity to 40 million. A capacity of 50 million is also under consideration in the design.

5.6.1 ADIA core statistics

ADIA is the second busiest airports in UAE after Dubai airport. The majority of mobility at the airport includes passenger and cargo. As illustrated in Figure 5.10, total aircraft movement at ADIA was 74,000 during 2004. The highest movement of aircraft at ADIA was passenger aircraft (46,000 movements) followed by air cargo 6000 movements, General Aviation 6000 (GA), military, 2000 government 1000 and helicopter is 13000 movements. Details about total fuel consumption are given in chapter 4 the methodology.

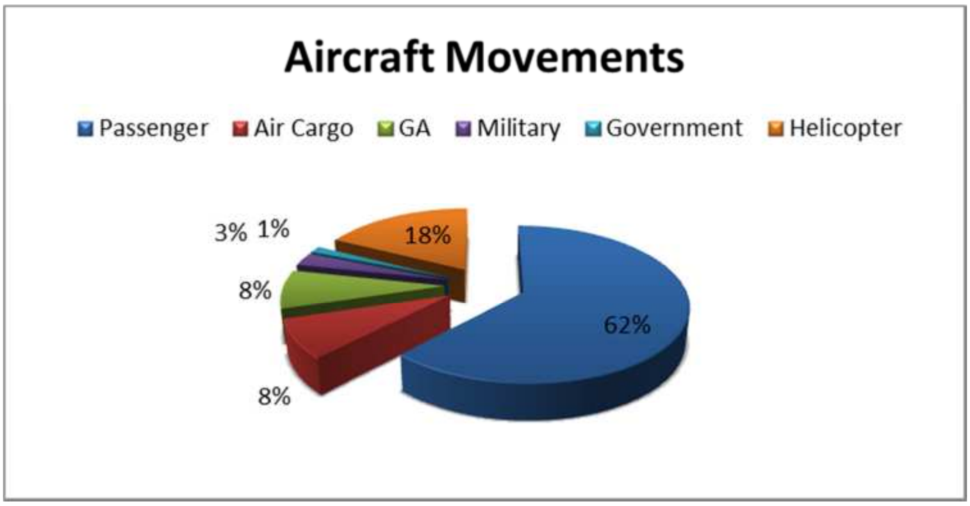


Figure 5.13 Aircraft movement statistics on 2004 (*Source: SCADIA, 2005*)

During the last decade a considerable growth in the number of aircraft has been seen at ADIA. As illustrated in Figure 5.11, total aircraft movement increased from 45,927 (1998) to 93,163 (2008), showing approximately 50.0 % increment during last 10 years. The aircraft fleet mix was given in chapter 4 table (4.2)

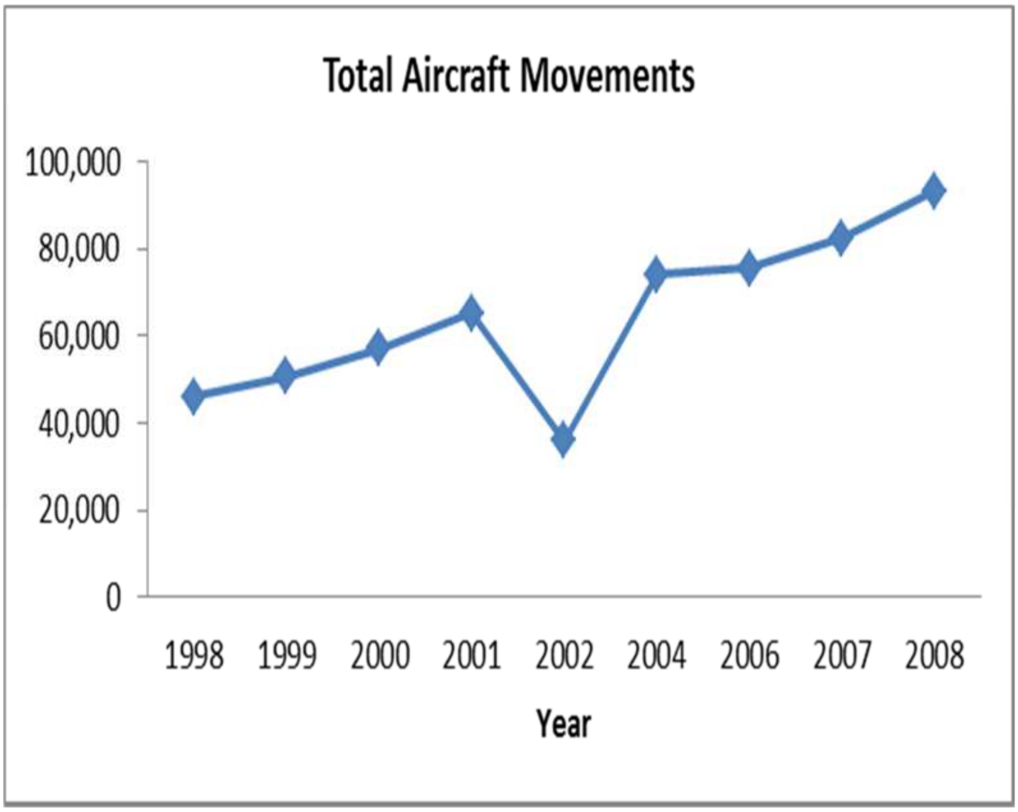


Figure 5.14 Total aircraft movement at ADIA during recent years *(Source http://www.abudhabiairport.ae/news/news20090118.asp)*

The passenger load also increased at ADIA during the last few years (Figure 5.14). During 2004, the total number of passengers travelling was 5,213,405, including 2,475,853 as transfer, 512,185 as transit (Figure 5.17). It clearly indicates that passenger transfer was the maximum (47 %), followed by transit and A/D (arrivals and departure).

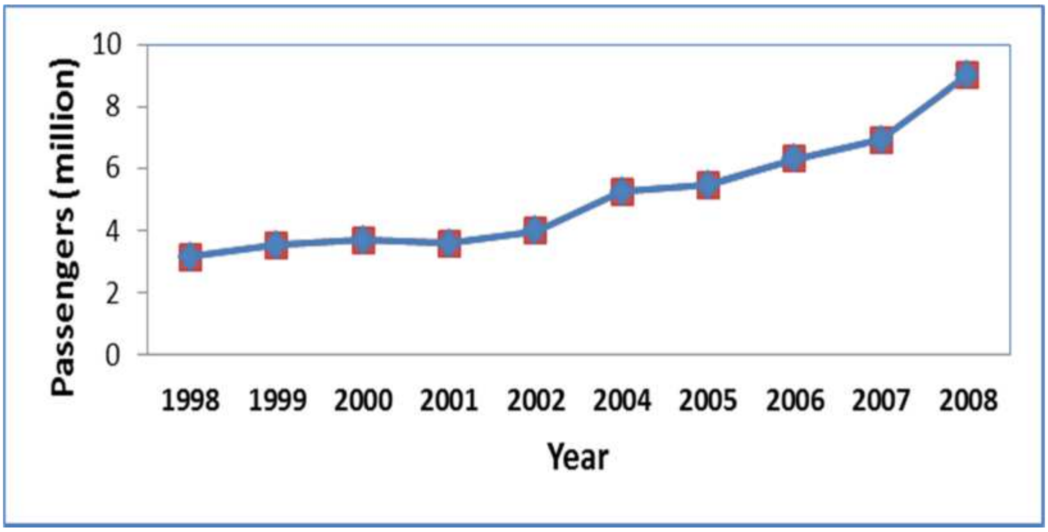


Figure 5.15: Growth patterns of total passengers at ADIA during the last decade

Cargo transportation through air is an important task at ADIA. During 2003 total cargo (metric tons) was 398,652 including 60,141 as enplaned, 78,376 as deplaned and 259,232 as transit (Figure 5.16). Total passenger, transfer, transit, arrival and departure are shown in Figure 5.17.

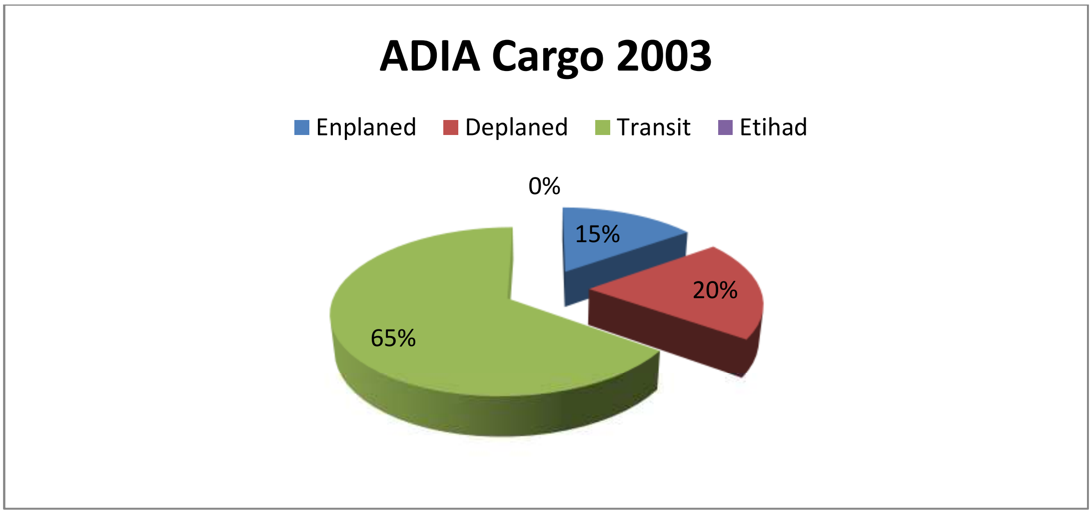


Figure 5.16: ADIA cargo distributions. (*Source: SCADIA 2005)*

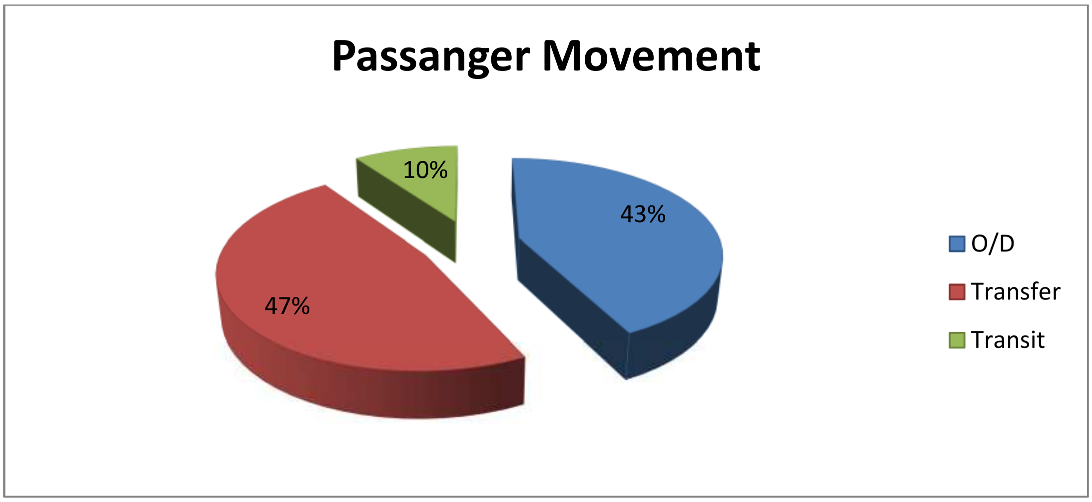


Figure 5.17: Total passenger, transfer, transit, and O/D (Origin & Departure) **(***Source: SCADIA, 2005).*

5.6.2. Future trends at ADIA: forecasting of passenger and cargo load

Regarding the future expansion of ADIA, a passenger projection is calculated in order to estimate the future aviation transportation. In the master plan two sets of passenger forecasts were estimated (SCADIA, 2005). The first was based on the Booz Allen Hamilton (BAH) forecasting work, moderating their "extreme" high forecast, based primarily on a variety of projections for GDP over the forecast period. The second forecast was based on Etihad Airways fleet acquisition plan and growth targets.

Base Case High. The Base Case High incorporates generally optimistic assumptions into the Origin & Departure (OD) and Transfer and Transit (TT) projected growth rates. (SCADIA, 2005)

The Base Case High projection incorporates optimistic assumptions, supporting OD and TT passenger growth, adjusting earlier forecasts developed by BAH. Total passengers are projected to grow from 5.2 million in 2004 to 17.3 million in 2030, representing an average annual growth rate of 4.7%. OD passengers are projected to grow from 2.2 million in 2004 to 6.6 million in 2030, representing an average annual growth rate of 4.3%. TT passengers are projected to grow from 3.0 million in 2004 to 10.7 million in 2030, representing an average annual growth rate of 5.0%.

Etihad High. This scenario was developed using input provided by Etihad Airways on its service development and expected response by other airlines. This Etihad Trend line relies mainly on data provided by Etihad to make the passenger and aircraft operations trend line for Etihad (SCADIA, 2005). Total passengers are planned to rise from 5.2 million in 2004 to 26.7 million in 2030, representing an average annual growth rate of 6.5%. OD (Origin and Destination) passengers are planned to rise from 2.2 million in 2004 to 13.8 million in 2030, representing an average annual growth rate of 7.3%. Transfer and Transit (TT) passengers are projected grow from 3.0 million in 2004 to 12.9 million in 2030, representing an average annual growth rate of 5.8%. In Figure 5.15 a comparative scenario of projected passengers is illustrated.

The master plan team created their own forecast of cargo activity at ADIA to complement the passenger and aircraft operations forecasting. However, the globalization of world markets and non-economic issues, such as terrorism and increased security regulations, affect the worldwide air cargo industry. There are market drivers that are uniquely specific to Abu Dhabi that will impact future air cargo activity at ADIA (SCADIA, 2005). The master plan was divided into the following sectors: (1) regional and national economic growth, (2) balance of cargo capacity on all-cargo and passenger aircraft at ADIA, (3) the competitive airport landscape and ADIA's ability to attract cargo activity from Dubai and Jebel Ali, and (4) the ability of ADIA to properly respond to market opportunities with appropriately designed and managed cargo facilities and requisite infrastructure. There is a strong historical relationship between growth in the regional and national economy and air cargo growth. Figure 5.16 demonstrate the future cargo at ADIA.

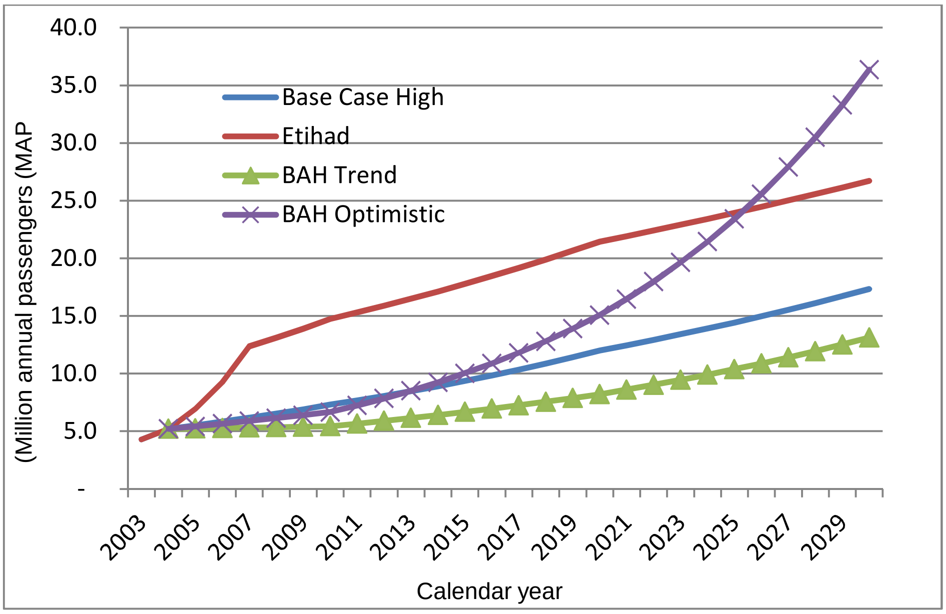


Figure 5.18 : Comparative scenarios (*Source: SCADIA, 2005*)

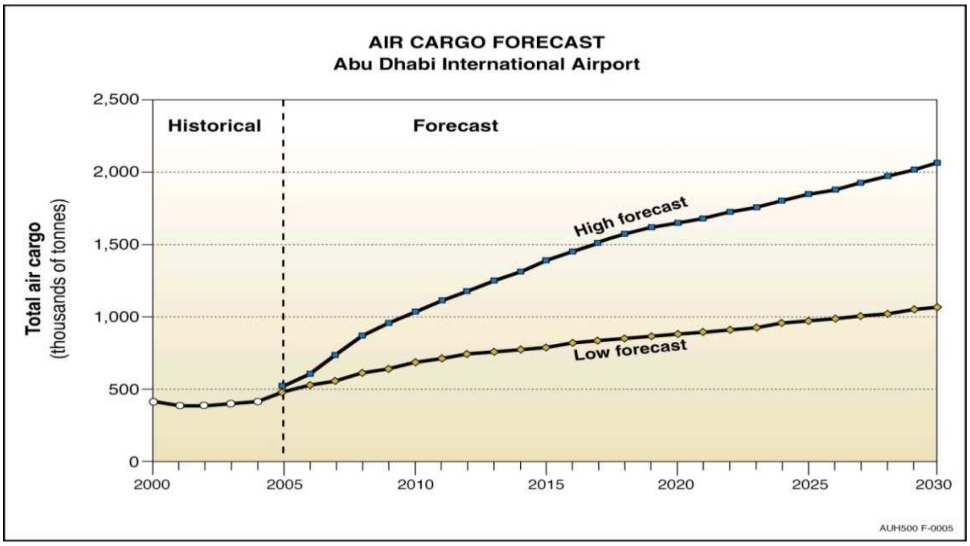


Figure 5.19: Air cargo forecast (*Source: SCADIA, 2005*)

CHAPTER 6
AIR EMISSION INVENTORY FOR ADIA

6.1 Emission inventory

The results of EDMS model are presented in Table 6.1. The total emissions from different airport related sources, considered for EDMS are expressed in tons/year. The major pollutants considered for the emission inventory were: CO, NO_x, SO_x, and PM_{10} which are emitted from different sources at airport, such as the aircraft operations, APU, GSE, stationary sources (including fire training) etc.

Table 6.1: The total emission estimation from different sources in tonnes/ year for the year 2006

Category	CO	NO_x	SO_x	PM_{10}
Aircraft	1,142.52	1,290.45	95.764	13.9
GSE/APU	2,508.47	153.798	19.845	8.762
Parking facilities	13.48	1.1	0	0.02
Stationary Sources	159.996	4.02	0.215	0.263
Fire	2.341	0.018	0.002	0.627
Total	3,826.80	1,449.38	115.826	23.572

The emission inventory illustrates that aircraft movements produce approximately 1,290 tonnes which equivalent to 89% of NO_x of the total airport-related emission, while GSE accounts for 153 tonnes which is only 11% of the total emission. The aircraft operation makes a major contribution to the pollutant emissions at the airport, except for carbon monoxide, which is mainly produced by GSE operations due to the incomplete combustion process.

It is clear that the CO emission by the aircraft accounts for only 30% of the total emissions. Stationary sources account for 4% of the total emissions followed by GSE/APU (66%) and emissions from fires are negligible. In contrast, aircraft act as major contributor to SO_x emission, accounting for about 83% of the total emissions. It is followed by GSE/APU (17%), stationary sources and parking. Fires accounted for negligible SO_x emission. Similarly, for particulate matter, aircraft operation contributes the highest emission (59 %) at ADIA. Stationary sources accounts for 1%, fires at 3% and GSE/APU at 37%. As mentioned earlier, the EDMS uses the ICAO data bank for the emission factors. The ICAO databank does not contain emission factors for PM_{10} directly, but does include 'smoke number' (SN), an indirect measure of particulate emissions calculated from the reflectance of a filter paper measured before and after the passage of a known quantity of smoke-bearing gas. Some of the aircraft fleet mixes are considered as old technology and PM data for some aircraft is unavailable. Figures 6.1, 6.2, 6.3 and 6.4 present the total emission estimation from the different airport sources for the major pollutants.

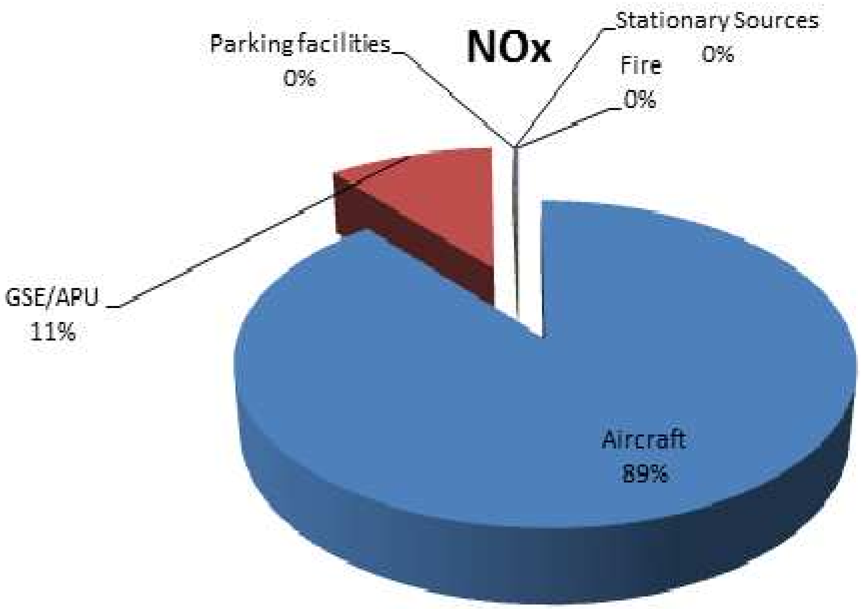


Figure 6.1: ADIA ground-level airport-related NOx emissions by source category

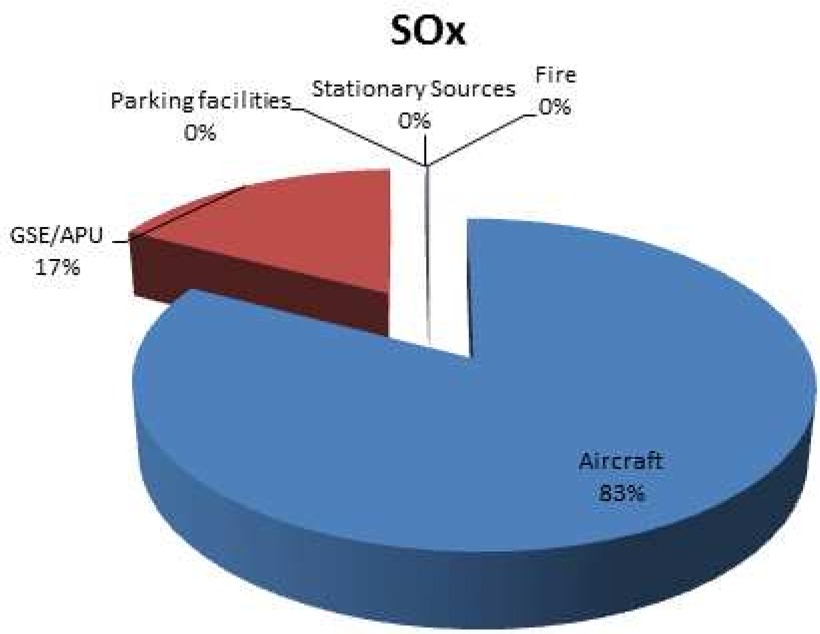


Figure 6.2: ADIA ground-level airport-related SOx emissions by source category

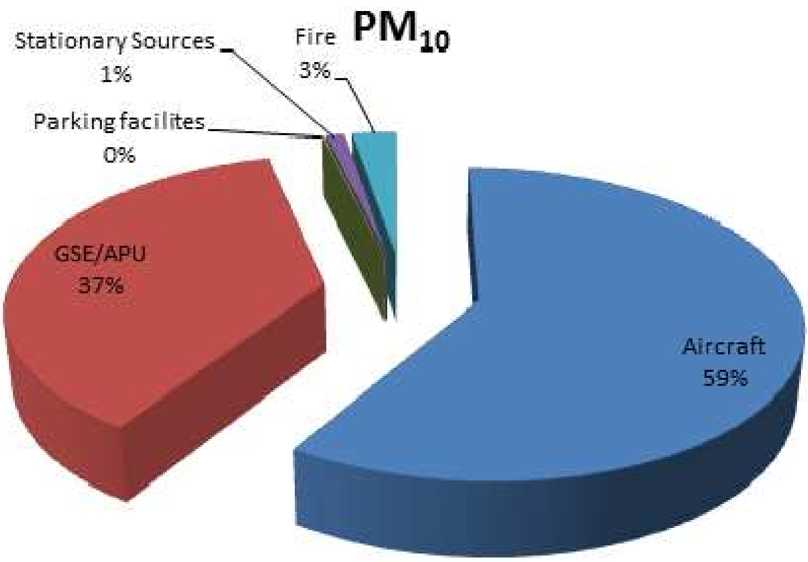


Figure 6.3: ADIA ground-level airport-related PM_{10} emissions by source category

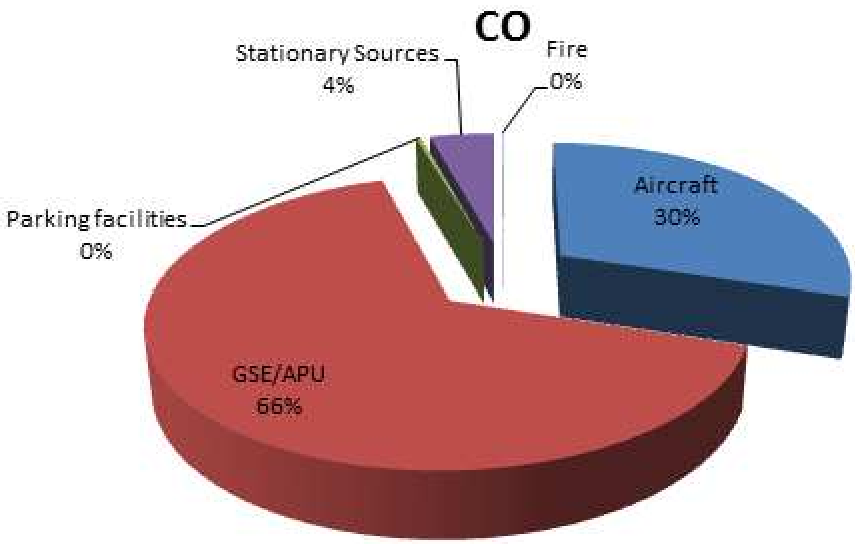


Figure 6.4: ADIA ground-level airport-related CO emissions by source category

6.2 Aircraft emission within LTO cycle

The main scope of this inventory is NO_x emission from the different airport related sources and by examining the aircraft engine emission during the LTO cycle, climb out phase that produced the maximum NO_x emission (Figure 6.5) with 41% of the total LTO emission attributed to this source.

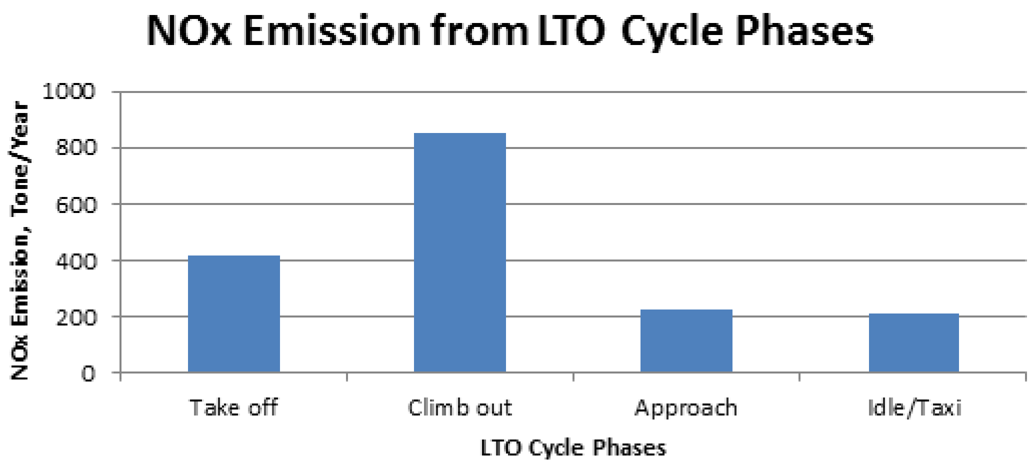


Figure 6.5: NOx emission LTO cycle phases

The four thrust settings in the ICAO databank are designed to be representative of the principal phases of the LTO and the default methodology for aircraft emissions assigns each LTO mode to one of the settings, indicating that the climb out phase is 85% of the thrust setting and the duration time is 2.2 minutes.

6.3 Comparison of NO_x emission results of ADIA with UK airports

Table 6.2 gives a breakdown by source category of the estimated annual airport NO_x emissions. Clearly, aircraft emissions are the dominant contributor to total airport-related NO_x emissions.

Table 6.2: Estimated annual NOx emissions from ADIA airport for 2006

Group	Source	NO_X Emissions (tonnes/year)
Aircraft	Aircraft main Engine	1290.45
	Approach	193.567
	Climb out	853.57
	Take off	309.708
	Idle	167.758
Aircraft handling	APU/ GSE	162.571
Stationary source	Power/Generating Plant	4 .02
	Fire Training	0.018
Land side Vehicles	Parking Facilities	1.1

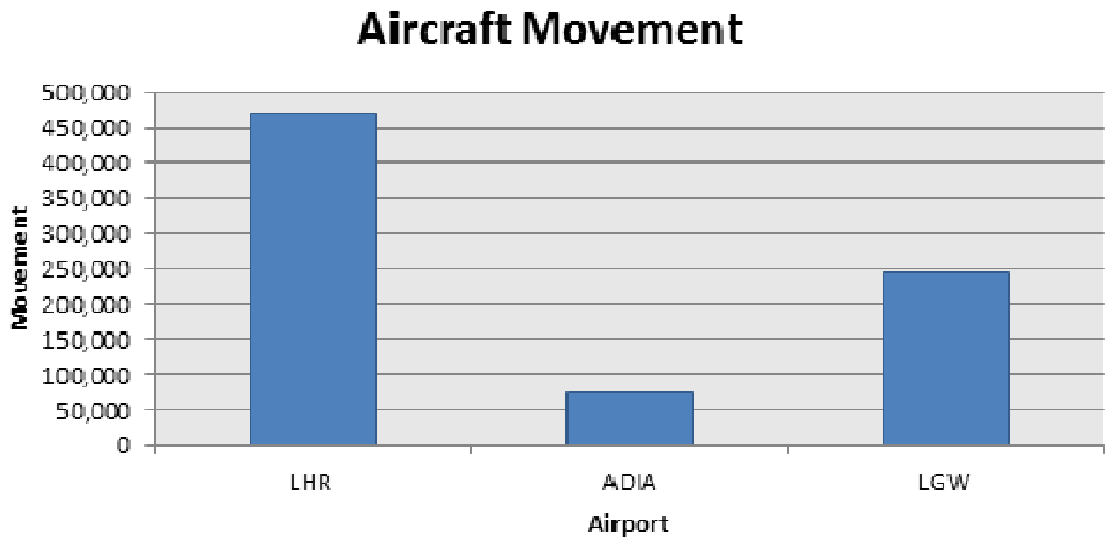


Figure 6.6: Aircraft movement/year for ADIA2006, Heathrow (LHR) 2002 and Gatwick (LGW) 2002

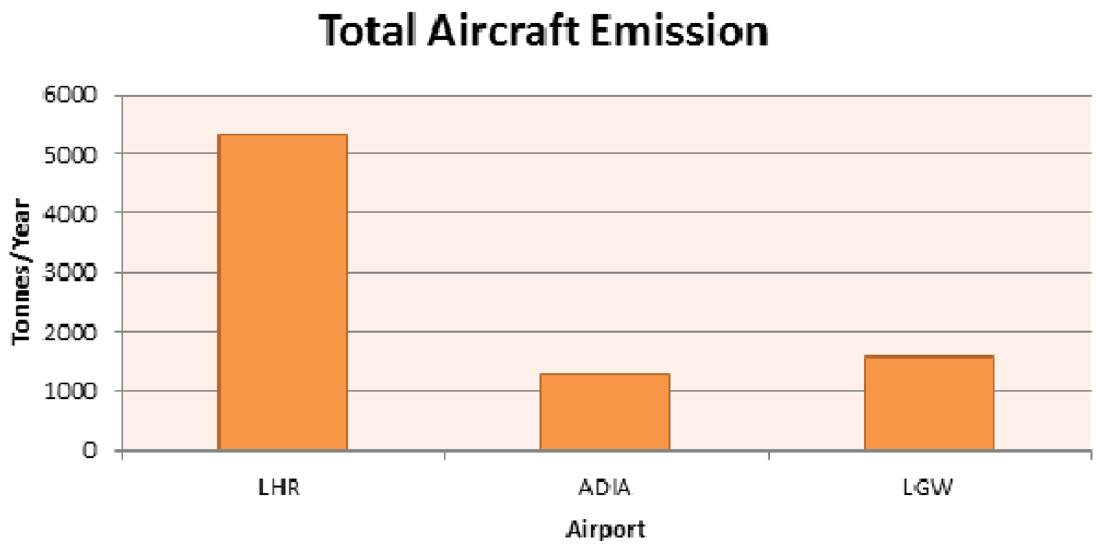


Figure 6.7: Comparison between Aircraft Emission from LHR, ADIA and LGW

When compared, the total aircraft movement between Heathrow Airport, ADIA and Gatwick Airport, it is found that the highest aircraft movement was in LHR with 469, 763 movements in the year 2002, followed by LGW 244, 989 movements in the same year (Figure 6.6). The lowest is ADIA, with 75000 movements in the year 2006. As expected (Figure 6.7), the total aircraft NO_x emission is the highest at LHR (5318 tonnes/year) followed by LGW (1589.79 tonnes/year) and the lowest at ADAI (1290.44

tonne/year). However, ADIA aircraft emission is close to LGW, this may be due to the different methodologies used or the type of aircraft (according to size) or (according to age). LGW is well known for the use of narrow and medium-sized aircraft body for short haul flights for Europe or medium haul, whereas ADIA uses more of the large-sized jets because most of the flights are connecting flights between the Far East and Europe. A small exercise was conducted to check the methodology, time in mode and the fuel rate and the emission factors for the above- mentioned three airports and the findings are discussed below.

First, the EDMS has an option to choose how to calculate emission inventory whether it is based on ICAO/EPA methodology or on performance based methodology. By choosing the performance based methodology, the NO_x emission from aircraft was reduced to 1171 tonne/year at ADIA. Table 6.3 presents NO_x emissions using EDMS performance methodology for ADIA. The performance methodology depends on the real operational time in mode used, rather than the ICAO specified time in mode. Therefore, NO_x emission from aircraft decreased by changing the (time in mode) factor.

Table 6.3: Estimated NOx Emission from ADIA using EDMS

Category	NOx
Aircraft	1171
GSE/APU	153
Total	1325

Moreover, other two important factors that influence the total aircraft NO_x are the fuel flow rate and the NO_x emission factors. Therefore, this study investigated three different aircrafts types (A320, A340-300 and B747-400) in terms of NO_x emission factor and fuel flow rate and comparisons were carried out. Data from ADIA were used and time in mode was fixed as per ICAO recommendations. Table 6.4 presents the total number of aircraft movements per year along with the number of engines to be used along with data obtained from the three different aircrafts. The following equation had been used in order to quantify the aircraft NO_x emission in the year 2006 movement for each aircraft type.

$E_{PJ} = (T)_{jk} \times (EF)p_{jk} \times (NE)_j$

E_{pj} : total emission of pollutant P, produced by aircraft type j for one LTO cycle

T_{jk} : time in mode for mode k, for aircraft j

EF_{pjk} : fuel flow for mode k , for each engine used on aircraft type j

NE_j : number of engines used on aircraft type j

Table 6.4: Three different aircraft and number of yearly movement at ADIA

Aircraft Type	No. of Engines	No. of Movements/year
A320	2	11364
A340-400	4	3486
B747-400	4	2874

Table 6.5 presents the fuel flow and NOx emission factors used in three airports (LHR, LGW and ADIA). Table 6.6 present the results of this exercise in terms of the total aircraft NOx emission using different airport methodologies. For different LTO modes, the aircraft type, A320 showed a similar pattern of emission at LHR and ADIA, while those at LGW were recorded as higher. For the A340-300, ADIA showed higher levels of NOx emissions as compared to LHR and LGW. Moreover, for the B747-400, LHR showed the highest NOx emission followed by ADIA and

LGW. It is evident that the calculation of aircraft NOx is affected by three important factors: the emission factor, the fuel flow rate and the time in mode.

Britter et al., (2005) conducted a similar study for LHR (Heathrow). Estimation of emissions from aircraft and aircraft operations were based on the EDMS internal database. For all other sources, they used emission rates and emission factors or emissions generally that were supplied through the HEI (2004). Based on this approach, it was found that the aircraft emissions calculated by EDMS were larger than those by HEI (2004). They concluded that such difference could be attributed to the use of 100% thrust on the aircraft take-off roll at ADIA EDMS, whereas this was typically smaller at Heathrow. A "workaround" that they adopted was to change some of the engine selections in order to bring the EDMS aircraft emissions in line of those in the HEI (2004)

Table 6.5: Comparison between three different aircraft in terms of fuel flow and NOx emission factors used in three airports LHR, LGW and ADIA

A320	**ADIA (Abu Dhabi) using EDMS**		**LHR (Heathrow)**		**LGW (Gatwick)**	
Mode	Fuel Flow Kg/S	NOx Emission Factor g/kg	Fuel Flow Kg/S	NOx Emission Factor g/kg	Fuel Flow Kg/S	NOx Emission Factor g/kg
Take off	1.053	26.500	1.0758	25.25	1.1049	28.67
Climb out	0.880	22.300	0.892	20.72	0.916	23.73
Approach	0.319	8.900	8.524	0.3126	0.3192	10.03
Idle	0.128	4.77	4.45	0.117	0.1163	4.75
A340-300	**ADIA**		**Heathrow**		**Gatwick**	
Mode	Fuel Flow Kg/S	NOx Emission Factor g/kg	Fuel Flow Kg/S	NOx Emission Factor g/kg	Fuel Flow Kg/S	NOx Emission Factor g/kg
Take off	1.395	34.100	1.3732	34.82	1.3488	34
Climb out	1.143	26.700	1.1287	27.22	1.1088	26.7
Approach	0.370	9.900	0.3692	10.31	0.3641	10.18
Idle	0.115	4.100	0.1204	4.23	0.1193	4.21
B747-400	**ADIA**		**Heathrow**		**Gatwick**	

Mode	Fuel Flow Kg/S	NOx Emission Factor g/kg	Fuel Flow Kg/S	NOx Emission Factor g/kg	Fuel Flow Kg/S	NOx Emission Factor g/kg
Take off	2.342	28.100	2.6301	40.54	2.429	25.71
Climb out	1.930	22.900	2.1025	29.63	1.9872	20.2
Approach	0.658	11.600	0.7079	10.71	0.6515	12.42
Idle	0.208	4.800	0.241	4.42	0.2003	4.73

Table 6.6: Comparison between three different aircraft in terms of total NOx emission in tone/year using LHR, LGW, ADIA methodologies

Aircraft Type	**Mode**	**ADIA(Abu Dhabi)**	**LHR(Heathrow)**	**LGW (Gatwick)**
A320	**Take off**	26.637	26.4	**30.24**
	Climb out	58.874	58.87	**65.21**
	Approach	15.486	15.49	**17.46**
	Idle	21.330	21.33	**19.59**
A340-300	**Take off**	32.121	28.003	**26.86**
	Climb out	63.896	56.55	**54.49**
	Approach	21.059	12.74	**12.4**
	Idle	17.905	11.8	**10.93**
B747-400	**Take off**	31.775	51.48	**30.15**
	Climb out	67.68	94.53	**60.91**
	Approach	21.059	20.92	**20.81**
	Idle	17.905	19.1	**16.99**

Table 6.7: Emission inventory of criteria pollutants (tonnes per year) at different airports using EDMS

Emission Sources	ADIA[1](2006)*				FLIA[2](2010)**				SDIA[3](2010)***				DIA[4](2009)****			
	CO	NO_x	SO_x	PM_{10}	CO	NO_x	SO_x	PM_{10}	CO	NO_x	SO_x	PM_{10}	CO	NO_x	SO_x	PM_{10}
Aircraft	1142.5	1290.4	95.764	13.9	1632.1	1203.5	93.2	48.8	760	813	86.9	12.1	3401.9	2784.9	260.1	207.5
GSE/APUs	2508.5	153.8	19.8	8.762	4639.1	256.7	26.1	6.7	117	44.4	0.0	1.1	12113.3	459.7	50.63	26.0
Parking Facilities	13.5	1.1	0	0.02	501.1	37.9	0.3	0.8	20.6	2.1	0.0	0.4	-	-	-	-
Stationary Sources	159.9	4.02	0.215	0.263	4.4	20.2	1.3	1.4	3.8	12.4	4.0	0.6	54.2	52.9	1.3	8.8
Total	3824.5	1449.4	115.82	22.95	6776.7	1518.4	121.0	57.7	901.4	871.9	90.9	14.2	15569.4	3297.5	312	242.3

[1]Abu Dhabi International Airport (*Present study; Total aircraft movement in 2004 = 74,000 and total passenger = 5,213,405)
[2] Fort Lauderdale-Hollywood International Airport (**www.co.broward.fl.us/Airport/Community/.../5b%20air%20quality.pdf; Total aircraft operation in 2010 = 272,293 and total passenger = 22,412,627; *Source*: ACI, Airport Council International).
[3]San Diego International Airport (***http://www.san.org/documents/AQMP/Appendix%20A/Criteria%20Pollutant%20&%20Greenhouse%20Gases%20Baseline%20Emissions%20Inventory.pdf; Total traffic movements in 2009 = 199,209 and total passenger= 16,974,172; *Source*: ACI, Airport Council International)
[4]Denver International Airport (****www.colorado.gov/.../diaDenver_SIPemissionsinventory_finaldraft.pdf; Total aircraft operation in 2008 = 625,884 and total passenger = 51,245,334; *Source*: ACI, Airport Council International)

6.4 Emission inventory of criteria pollutants (tons per year) at different US airport using EDMS.

A comparison (in Table 6.7) has been made between different airports based on the emission inventory of criteria pollutants using EDMS. such as the Fort Lauderdale – Hollywood International Airport (FLIA), with total aircraft movement of and total passenger of 22,412,627 in 2010, and the second airport was San Diego International Airport (SDIA) with total aircraft movement 199,209 and total passengers of 16,974,172 for the year2009 and the third one was the Denver International Airport (DIA) with total aircraft movement 625,884, and total passenger of 51,242,334 passengers. It is evident that aircraft operations contributed the maximum NO_x emission at ADIA, FLIA and SDIA, while at DIA, CO emission exceeds the NO_x emission from aircraft. In aircraft operations, NO_x emission is followed by CO, SO_x and PM_{10} at almost all airports. Further, except at SDIA, the main source of CO at all airports is found to be the GSE/APUs activities. As far as parking facilities and stationary sources are concerned, the emission did not seem to follow any trend at the airports and may vary with the number of units present. In addition, it can be seen that in spite of more aircraft operations and a greater number of passengers in other airports, ADIA shows relatively more total airport emissions in 2006. This could be due to lack of proper air quality management strategies in the airport. Thus, special effort should be made to control the point source emissions and thus improve the air quality of the airport.

6.5 Future projection

The aviation industry has been increasing at a rapid rate in UAE. Abu Dhabi is the second busiest airports in the country and showed a tremendous growth with respect to passengers, as well as total annual statistics. The total number of passengers is projected to grow from 5.2 million in 2004 to 26.7 million in 2030, representing an average annual growth rate of 6.5%. OD (Origin and Destination) passengers are projected to grow from 2.2 million in 2004 to 13.8 million in 2030, representing an average annual growth rate of 7.3%.

During the last decade a considerable growth in number of aircraft has been seen at ADIA. As illustrated in Figure 5.11 (Chapter 5), total aircraft movements increased from 45,927 1998 to 93, 163 (2008), showing approximately 50.0 % increment during last 10 years. However, the growth in aircraft movement in the last 3 years (2006-2009) was 20% per annum.

Table 6.8: Aircraft movement growth and NOx emission future projection

Year	Aircraft movement	NOx Emission Mt
2006	75,437	1,290
2009	93.386	1,597
2010	102,300	1,750
2020	138,600	2,371
2030	181,000	3,096

Table 6.8 presents the growth in the aircraft movement and the NOx emission until the year 2030 in terms of NOx aircraft only. No technology enhancements were taken into

consideration in this projection. The future emission reduction scenarios are given in the discussion chapter of this thesis. The future projection of NOx emission at ADIA is shown in Figure 6.8

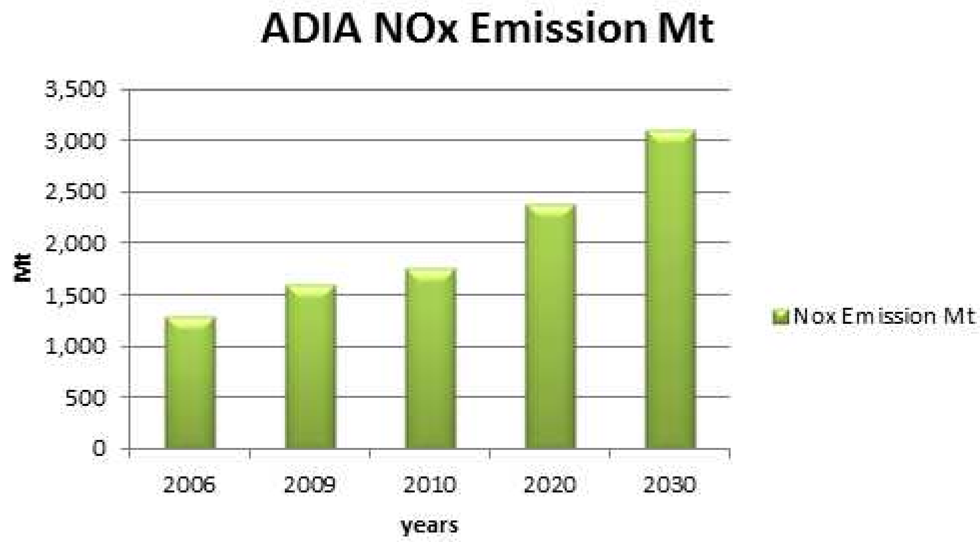


Figure 6.8: Future Projection of NOx emission at ADIA

CHAPTER 7
ADIA AIR QUALITY MEASUREMENT RESULTS

7.1 Chapter overview

The purpose of this study was to determine the area influenced by air traffic and to determine the level of impact of the current airport operations on the air quality around the ADIA. Furthermore, it aimed to generate baseline values for characterising the existing 'pre-development' stage, to serve as bench marks against which future deterioration in air quality can be assessed. This chapter describe the results of the pilot measurement campaign to determine nitrogen dioxide in the ambient environment using diffusion tubes. The measurements were carried out at ADIA during the winter of 2005 as well as the summer of 2006 in the immediate vicinity of the airport. In addition, continuous monitoring of NO_2 was carried out by the Supervision Committee for the Expansion of the Abu Dhabi International Airport (SCADIA) at two sites.

One of the monitoring sites was to the west of the airport (at SCADIA's parking facility) and the second site was located to the east of the airport. Five criteria pollutants, namely (CO), (NO_x), (SO_2), (PM_{10}) and (O_3) were considered for the study and average hourly values were recorded. Meteorological parameters including wind speed and direction, air temperature and relative humidity were also measured. The air quality data were used to determine the diurnal and monthly fluctuations in the level of pollutants. Measurements made using diffusion tubes were compared with NO_2 values obtained from continuous monitoring carried out during the measurement campaign. In addition, seasonal NO_2 pollution roses were plotted to ascertain sources of specific pollutants.

7.2 Continuous monitoring data analysis & results

7.2.1 Air quality standards

The measurements of pollutants were compared with ambient air quality standards proposed by the Federal Environmental Agency, (FEA), UK National Standards, and WHO guidelines. Table 7.1 describes the baseline measurements and standards and is expressed in $\mu g/m^3$ and ppb.

The maximum 1-hour mean concentration of O_3 during the monitoring period was 70 ppb and it did not exceed the FEA O_3 standard of 100 ppb/hour. However, for 8 hours average, O_3 value (63 ppb) the standard specified by FEA, U.K. and WHO guidelines. Moreover, particulate matter is a major air pollution problem in the area under investigation caused by busy traffic and some natural sources, like sandstorms. In addition, in May 2005, the new runway construction began involving considerable soil excavation and land filling activity for site development, transportation of sand and other construction materials to and from the construction site. This could have made a significant contribution to the loading of PM_{10} particles significantly, the level of which was high.

Table 7.1: Comparison between concentrations of air pollutions in the ambient air with FEA air quality standard, UK National Air Quality Strategy and WHO Guidelines (Measurement period 15/NOV /05 to 15/July/06)

Parameter	Standards & Guidelines	Measurement concentration (ppb)	Averaging Period	Standard (ppb)	Measurement concentration(μg/m³)	Averaging Period	Standard (μg/m³)
NO_2	UK	52	1 hour	209	99	1 hour	400
	UAE	30	24 hour	78	58	24 hour	150
	WHO/UK	18	Mean1 year	21	35	Mean1 year	40
	WHO	52	1 hour	105	99	1 hour	200
SO_2	UAE-FEA	11	1 hour	131	30	1 hour	350
	UAE-FAE	5	24 hour	56	12	24 hour	150
	UAE-FAE	1	Mean1 year	23	3	Mean1 year	60
	WHO	5	24 hour	8	12	24 hour	20
O_3	UAE-FAE	78	1 hour	100	156	1 hour	200
	UAE-FAE	63	8 hour	60	126	8 hour	120
	WHO	63	8 hour	50	126	8 hour	100
CO	WHO/ UAE-FEA	1.8**	1 hour	25.76**	2.1 mg/m³	1 hour	30 mg/m³
	WHO/UAE - FEA	1.2**	8 hour	8.5**	1.4 mg/m³	8 hour	10 mg/m³
PM_{10}	UAE-FAE	134	24 hour	70	134	24 hour	70
	UK	80	Mean	40	80	Mean	40
	WHO	134	24 hour	50	134	24 hour	50
	WHO	80	Mean1 year	20	80	Mean1 year	20

** CO in ppm

*** UAE/FEA = UAE/Federal Environmental Agency.

7.2.2 Role of meteorological parameters

It is a well-known fact that attention must be paid to the wind direction in treating discrete sources of air pollution. Therefore, the hourly records of wind speed and wind direction were utilized in defining the emission source of the measured atmospheric pollutants. Horizontal winds play a major role in the transport and dilution of pollutants. As the wind speed increases, the volume of air moving in a given period of time also increases. If the emission rate is relatively constant, a doubling of wind speed will halve the pollutant concentration, as the concentration is an inverse function of the wind speed. Pollutant dispersion is also considerably affected by variation in wind direction. If wind direction is constantly shifting, pollutants will be dispersed over a large area and concentrations of pollutants will be less in the area. Abu Dhabi is a coastal city, the difference in heating and cooling of land and water surfaces affects the air motion. In the early afternoon, the land surfaces heat more rapidly than water. The heated air over the land rises and cold air flows in from the sea; this is known as cool sea breeze. At night, the more rapid cooling of the land surfaces results in horizontal air flow towards water and the land breeze is formed, these circulation patterns form under light prevailing winds. The depth of the sea breeze varies from 1 km in January to 1-1.5km in April, July, and October (Zhu and Atkinson, 2004). The circulation patterns in the UAE are dominated by a sea breeze indicated by northerly flow, while land breeze by southerly flow (Eager et al., 2004). The circulation of land-sea breezes may cause pollutants to re-circulate from time to time. FECC (1998) annual report, states that from noon to midnight the wind direction is dominated by sea breezes, and the land breezes prevail from 7:00 am to early afternoon. The transition period lies in between.

The daily means of hourly speeds and frequencies are graphically represented by wind roses in Figures 7.1 and 7.2. From the presented meteorological data, it seems reasonable to say that:

1) The significant frequency of wind direction at the first monitoring station, (the winter season) with the north and north westerly has a total average frequency of 40%, with speed of 20 knots, followed by east and east southerly direction with a total average frequency of 33.5% and a maximum speed 20 knots. During the winter, the western depression and Siberian High that can be observed in January will affect the UAE and the February wind roses indicate the maximum wind speed. In March, the prevailing wind direction is north and northwest. This is considered to be the end of the winter season activities and the trend continues through April.
2) Figure 7.2 describes the wind rose for the summer period where the most significant wind direction was dominated by north and north westerly with a total average frequency 45% and a speed reaching 20 knots, followed by a south and south westerly. Southerly winds start to blow from the Empty Quarter, by the end of April and beginning of May. This is the transition to the summer season that brings with it brings large quantities of sand particles and high temperatures. Following this, during June and at the beginning of July, the wind continues blowing mostly from the north and south, dominated by Shamal (Arabic name for northerly wind) named as "Forty Days Shamal" reaching speeds of 30 knots and more. At the end of July besides northerly and southerly winds, the country is influenced by the westerly winds which blow as result of the Indian Monsoon flow that leads to heavy showers.

Cumulonimbus (CB) clouds and easterly winds are associated with the monsoon trough along the eastern part (high ground) of the country. It can be seen that the predominant wind direction for most of the time of the study period is northwest and north, suggesting that the pollutants are transported towards a northwest and north direction from the airport, which is the main focus of pollution emissions in the area.

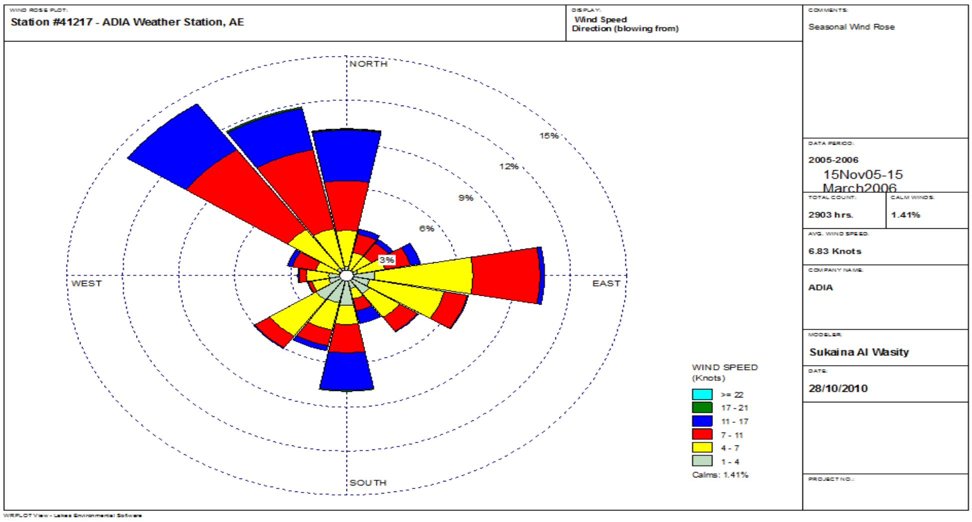


Figure 7.1: Wind rose for winter season (15 Nov 05 -15 March 06) in knots

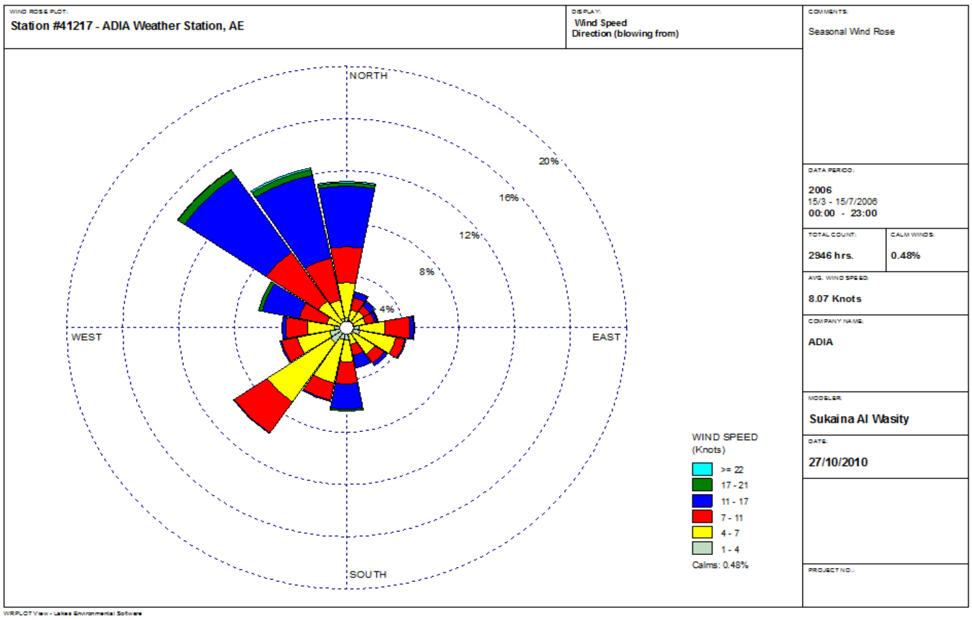


Figure 7.2: Wind rose for the summer season (16th March 06 – 15th July 06) in knots

7.2.3 Diurnal variation

Concentration of pollutants at any site shows a diurnal variation which closely corresponds to meteorological conditions which play a very important role in knowing how the variation of pollutant concentration fluctuates with the time of the day. The observed diurnal variation of NO, NO_2, NO_x, O_3 are shown in Appendix 2.

7.2.4 Seasonal variation

Winter and summer variations are presented in Figures 7.3 and 7.4. A summary of O_3 and nitrogen diurnal pattern during the seasons is discussed below.

A. Ozone diurnal pattern

The diurnal patterns of O_3 (Figures 7.3 and 7.4) show a general tendency for average concentrations to be higher during some hours of the day and lower during others. This tendency is clear in the diurnal pattern of O_3 concentrations in the winter season (Figure 7.3) which shows an increase in the O_3 level beginning at 7 a.m. with an average concentration of 32 ppb, reaching a maximum of average concentration of 52.33 ppb at 2 p.m., then decreasing to 45.12 ppb at 3 p.m. and 38.34 p.m. at 5 p.m. begins to gradually decrease till the end of the 24-hr period at midnight. This is due to the presence of sunlight which catalyzes the reaction between O_2 and NO_2 (as result of the anthropogenic activities) that causes O_3 production during the day.

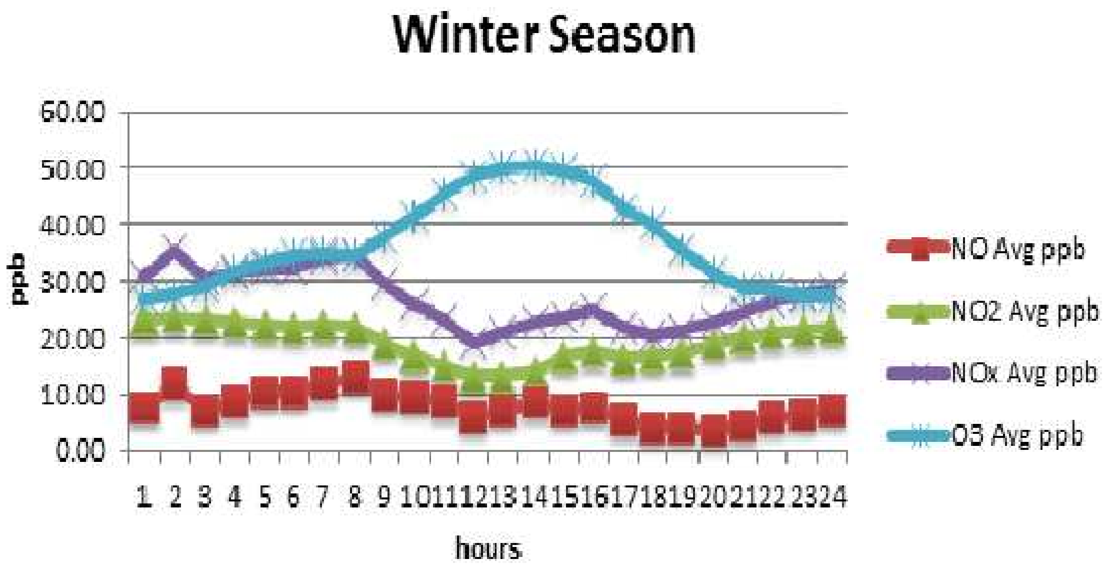


Figure 7.3: O_3, NO_2, NO, NO_x diurnal variation in winter season in 2005

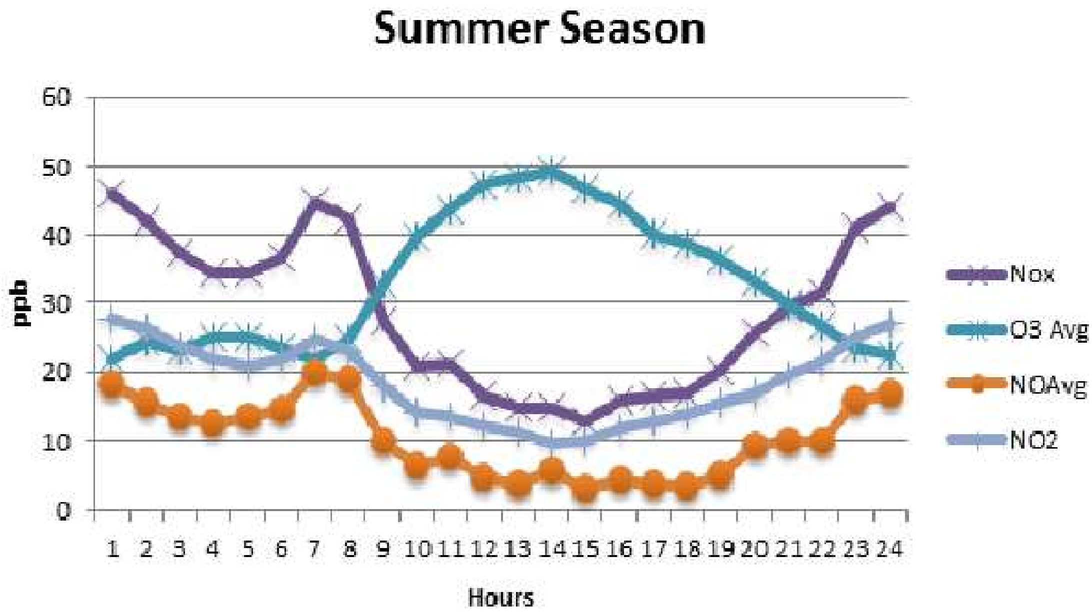


Figure 7.4: O_3, NO_2, NO, NO_x,O_X diurnal variation in summer season in 2006

Ozone concentrations that occur over urban and nonurban areas reflect interplay emissions of NO_x and HCs, transport meteorology and atmospheric chemistry. If the passage of a small mass of relatively clean air is followed over an urban area downwind, some of the dynamics involved in O_3 formation and its subsequent history can be detected (Godfish, 1991).

As an air mass moves toward an urban centre, it picks up NO_x and HCs. Within an hour, OH begins to degrade HCs, producing RO_2 (peroxy radicals). As O_3 decreases due to the chemical reactions between O_3 and NO, O_2 and NO_2 are produced and this action will break O_3 atoms to normal O_2 molecules, as result of NO produces over the urban area. As the air mass moves over the urban centre, O_3 precursors peak and then declines with increasing downwind distance. O_3 concentrations increase and are sustained over a period of 1-5 hr as the more reactive olefinic and aromatic HCs are depleted by photochemical reactions.

After 5-10 hr travel time downwind, moderately reactive HCs increasingly play a more important role in net O_3 production. O_3 levels in the air mass subsequently decrease as a consequence of dilution, conversion of NO_2 to HNO_3 and surface removal. Under night time conditions, O_3 production ceases.

Ground based heat inversions rise to a height of tens to hundreds of meters, limiting the mixing of ground-level emissions, which would serve as O_3 scavengers. Protected by the inversion layer, O_3 may persist aloft with a half-life of as much as 80 hours. At sunrise, the inversion breaks up, bringing O_3 and other products isolated aloft during the night time hours to the ground, where they mix with pollutants confined below (and those newly produced) to begin the next day's photochemistry. The persistence of O_3 aloft at night can result in its long range transport. It is apparently the cause of night time concentrations exceeding those reported for midday at remote sites. This contradicts the view, once widely held, that maximum O_3 concentrations always occur near solar noon (Godfish, 1991).

B. Nitrogen Oxides diurnal pattern

Diurnal patterns of NO, NO_2 and NO_x in winter (Figure 7.3) indicates that there is an increase in their concentrations beginning at around 2 a.m. with an average concentrations of 12 ppb and 38 ppb for NO and NO_2 respectively. This is followed by a gradual decrease beginning at around 8 a.m. with an average concentrations 15, 30 and 45 ppb for NO, NO_2 and NO_x until they reach the maximum decrease at noon, with concentrations of 5 ppb, 10 ppb, and 15 ppb for NO, NO_2 and NO_x respectively.

Finally, a relatively gradual increase begins at 4 p.m. with average concentrations of 2.7 ppb, 6.6 ppb and 9.3 ppb for NO, NO_2 and NO_x respectively .

Diurnal pattern of NO, NO_2, NO_x in summer is shown in Figure 7.4 and it shows a similar trend for the decrease and increase of the concentrations of the three parameters. Usually, atmospheric levels of NO are related to the fuel combustion processes associated with the various human and industrial activities taking place in the area of concern. On the other hand, a principal sink process for NO occurs through its conversion by both direct oxidation and photochemical processes to NO_2.

Through examining the data of nitrogen dioxide levels in the two monitoring stations and in two seasons in ADIA, it has been noticed that there is a strong inverse relationship between NO_2 and O_3 concentrations. Therefore, the daily cycles of NO_2 and O_3 concentrations are presented in Figures 7.3 and 7.4 that clearly show the inverse relationship between NO_2 and O_3. A progressive depletion of NO_2 occurs with increasing values of O_3 during daytime.

7.2.5 Interrelationships between different air quality parameters

As illustrated in Figure 7.5 and 7.6, NO_x and NO_2 show a significant positive relationship in different seasons (r^2 = 0.69 in winter and r^2 = 0.87 in summer). It may be due to more solar radiation and day length in summer than in winter in this region. However, other meteorological conditions are also different in both seasons and could be responsible for the observed difference.

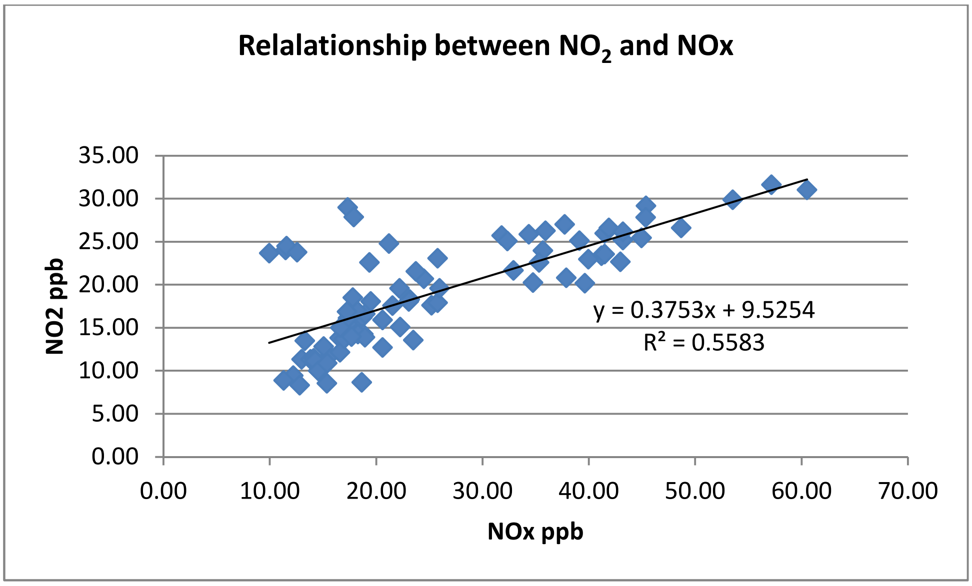


Figure 7.5: Interrelationships between NO_2 and NOx in winter

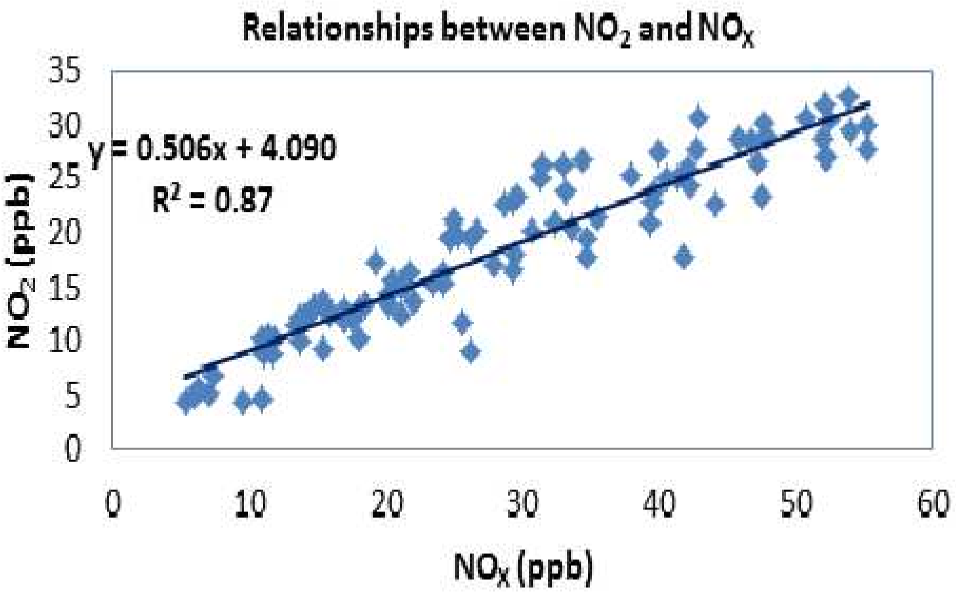


Figure 7.6: Interrelationships between NO_2 and NOx in summer

7.3 Results of diffusion tubes samplers of NO_2

In order know the spatial distribution of NO_2 at ADIA and its surrounding area, 2 diffusion tube campaigns were conducted and the measurement results are presented herewith.

7.3.1 Winter campaign: a pilot study

In order to identify any future deterioration of air quality in the area under investigation, a total of thirty-eight diffusion tube samplers were deployed around the airport and the surrounding residential areas. After sampling, the samples were analysed for NO_2 concentration at different sampling sites. The results revealed that the highest (22 ppb) NO_2 concentration (observed using passive diffusion sampler) was at ECO BASE APRON location (aircraft stand) and the lowest (l ppb) was at IMX 29 location. However, this was unexpected and indicated some fault or inaccuracy in the tube. The monitoring sites IMX 22, 23, 24, 25 and 26 at residential area Khalifa city A showed NO_2 concentration of 13, 16, 11, 17 and 6 ppb, respectively. In addition, existing airport activities monitoring sites IMX 10, 11, 20, 13, 8, 28, 1, 18, 15, 17, 3, 19, 4, 12 and 5 showed NO_2 levels as: 22, 11, 14, 12, 19, 13, 12, 13, 15, 19, 12,14, 14 and 16 ppb, respectively.

Baseline measurements at IMX 27, 30, 29, 31, 6 and 7 in pre-development stage showed the lowest values of NO_2: 4, 8, 1, 15, 11 and 10 ppb, respectively. NO_2 concentration at the airport main car parking (site: IMX 28 and 1) were 13 and 12 ppb, respectively during the winter campaign (Figure 7.7).

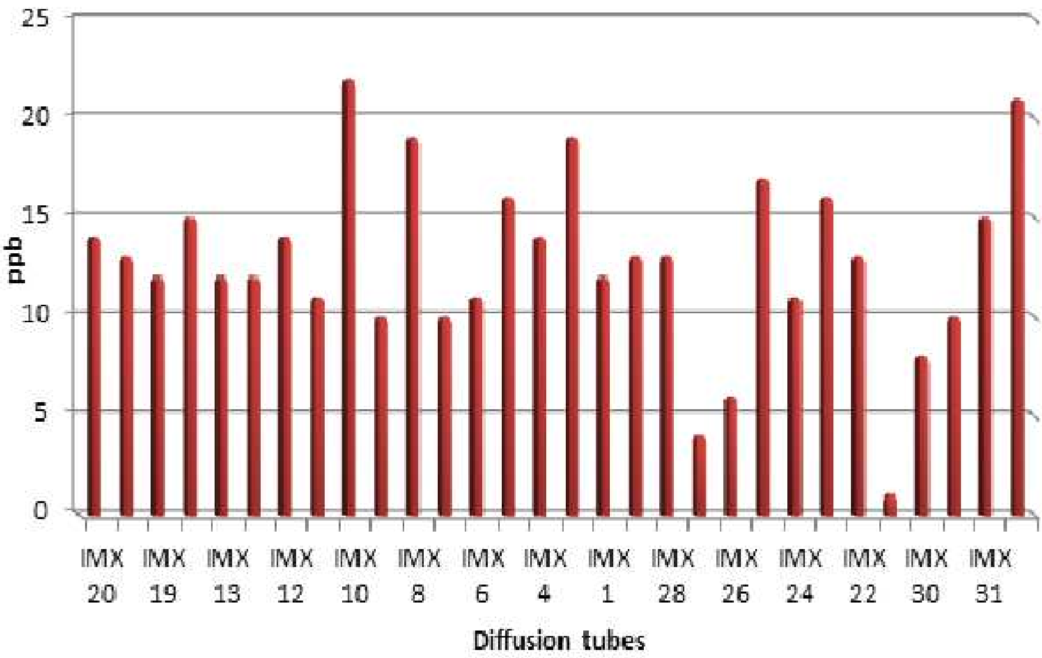


Figure 7.7: NO_2 concentrations during 21st Jan 2006 to 21 Feb 2006.

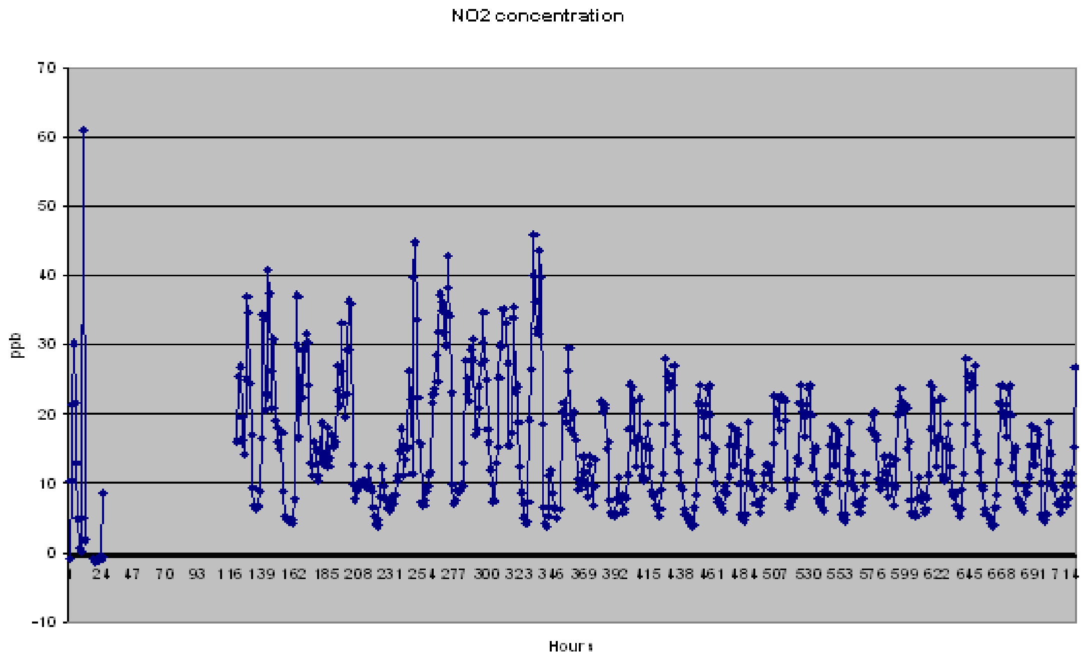


Figure 7.8: Hourly average NO_2 concentration measured using chemiluminescence method at SCADIA car parking facilities situated towards the West of ADIA (for the period between 21.1.2006 to 21.2.2006).

Khalifa city B had 8 monitoring sites, however, most of the passive tubes were lost during the exposure period and only IMX2 represented the second residential area where NO_2 concentration reached up to 13 ppb. This study has shown that at the diffusion tube reading at SCADIA car park, where the chemiluminescent monitor was stationed, the NO_2 concentration was 10 ppb (IMX 9), and the monthly average value was 14.7 ppb (Figure 7.8). The average NO_2 concentration determined by the diffusion tube was 35% more than those measured by the chemiluminescent analyser. Prior studies indicated that diffusion tubes samplers may overestimate NO_2 concentrations by up to 30%, whereas others have shown underestimation within the estimated overall uncertainty of the chemiluminescent results. According to a study conducted by Bush et.al, (2000), the overall average NO_2 concentration calculated from diffusion tube measurements was found to vary up to 10% of the values obtained from measurements made by chemiluminescent method.

7.3.2 NO_2 pollution rose

Figure 7.9 and 7.10 shows the NO_2 pollution rose in winter and summer respectively. Methodology of how to generate the pollution rose is presented in Appendix 2.

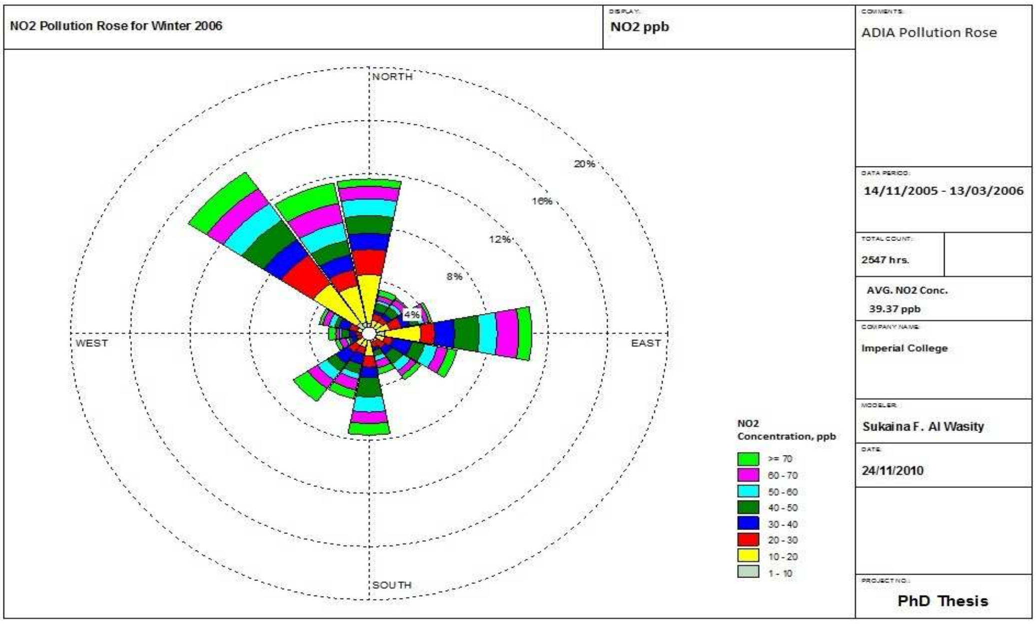


Figure 7.9: NO_2 pollution rose in winter

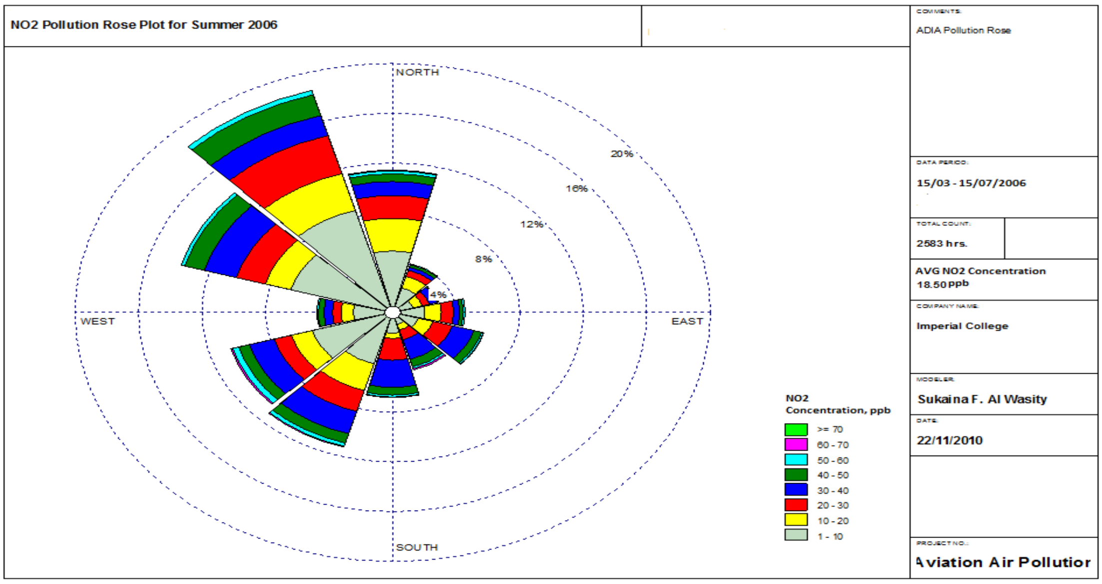


Figure 7.10: NO_2 pollution rose in summer

The pollution rose shows the highest concentrations in the winter, occurring from the north-west to north-east. Furthermore, the airport concentration reflects the amount of NO_2 that drifted and was transported out of the airport in the direction of the Umm

Al Nar refinery and Abu Dhabi marine oil fields as located in the north-west, while the high way and the main roads are located in the north-east. Therefore, winter season in the UAE is dominated by a high pressure synoptic system.

In summer time a southern wind is experienced due to low pressure that is centered on the Arabian Peninsula desert, but more NO_2 concentration distribution is seen in the southern part of the airport, caused by the road traffic around the airport from E33 highway (airport road) to Suweihan. In addition, much of NO_2 concentration is pushed from the north-east due to E10 road traffic (Figure 7.11).

Also, the diurnal local wind systems play a significant role in pollution concentration in the airport particularly because ADIA is located near the coast which is affected by sea and land breeze daily changes. When the winter and summer pollution roses are compared, NO_2 concentration in winter is found to be much higher than in summer. This is due to less vertical dispersion and less sunshine to dissociate the $NO_{2.}$ Moreover, NO_2 comes from other sources rather than the airport activities. A map showing the sampling locations in ADIA during first and second campaign are shown in Figure 7.11 and 7.12. The pollution rose location at ADIA is given in Figure 7.13. Concentrations of NO_2 during first and second campaigns are shown in Figure 7.14 and 7.15.

Figure 7.11: ADIA map with location of pollution rose

Figure 7.12: ADIA map with location of sampling sites and the NO_2 concentration during winter campaign

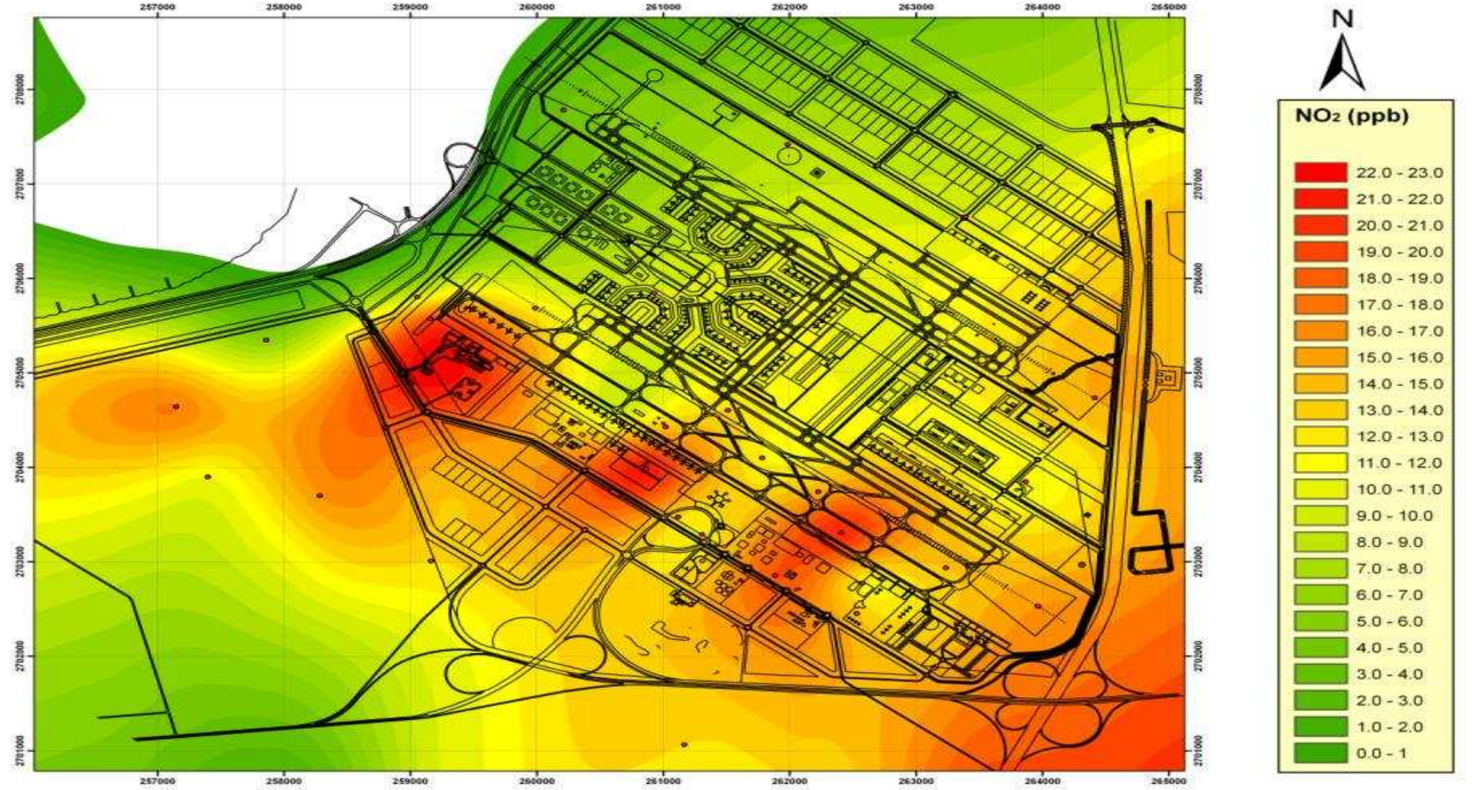


Figure 7.13: Map showing monthly average NO_2 concentration at various monitoring locations at ADIA and its vicinity

Source: - by the Author

7.3.3 Summer NO_2 measurement campaign using diffusion tube samplers

This study has observed very low values. As can be seen in Figure 7.14, the concentrations of NO_2 vary between l ppb (at site 7) to 5ppb (at site 17), and the average value for all sites was 3 ppb.

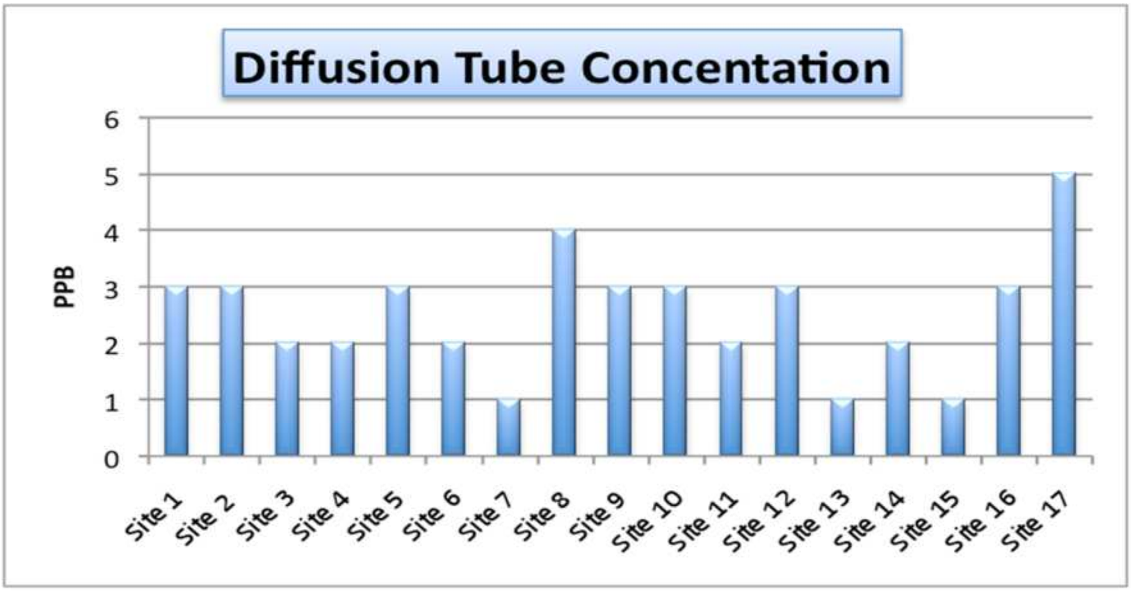


Figure 7.14: Summer NO_2 measurement campaign using diffusion tube samples

Moreover, the chemiluminescent monitoring was located next to the ADIA police station to the east of the airport. The NO_2 monthly average concentration measured by the chemiluminescent method was 30 ppb. It is observed that the difference in the average NO_2 concentration determined by the diffusion tube is much lower than those measured by chemiluminescent analyser measurements. Duplicate tubes showed low concentrations varying between 2 ppb to 4 ppb.

The Eco aircraft stand recorded the highest, at 2ppb, during the last measurement campaign. The most important question is why the value of NO_2 obtained using diffusion tube samples shows low concentration or under-estimates NO_2 versus the values obtained using the chemiluminescent monitor. A possible explanation appears to be that the under-estimation is probably due to prevailing very hot and dry conditions. In 1987, Palmes & Johnson (1989) confirmed that the TEA absorbent must be hydrated during exposure to react with NO_2. Therefore, due to high temperature which reached up to 49°C, the diffusion tubes might get dehydrated. It is also possible that the absorbed TEA-nitrite complex is broken down from exposure to intense sunlight, and the opaque end caps do not provide adequate protection from the intense sunlight

The hourly data of NO_2 measurement, using a continuous monitoring method, showed great fluctuations throughout the duration of the study (Figure 7.15) possibly due to variations in the traffic activities at ADIA, as well as aviation activities; being the main contributor to the NO_2 levels in the vicinity of the ADIA and its adjoined areas.

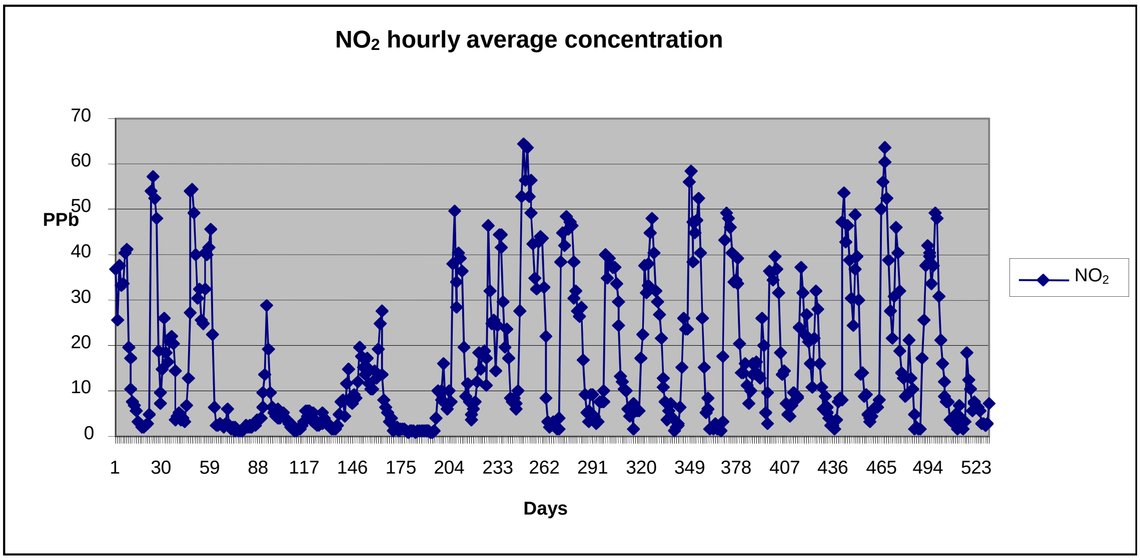


Figure 7.15: Hourly variations in NO_2 level using a continuous monitoring device

7.3.4 Comparison between wrapped and unwrapped diffusion tube samplers

An experiment was conducted in order to verify if covering the diffusion tube samplers with aluminium foil minimizes the impact of direct sunlight on the samplers. Three trials were conducted in September 2006 and in the first experiment, a total of 15 diffusion tubes were exposed for one week at three sites. At each site five diffusion tubes were kept, out of which 2 tubes were wrapped with aluminium foil around the cap, while the other two and one blank tube were left unwrapped. A comparison of wrapped and unwrapped diffusion tube samplers is given in Figure 7.16 and 7.18.

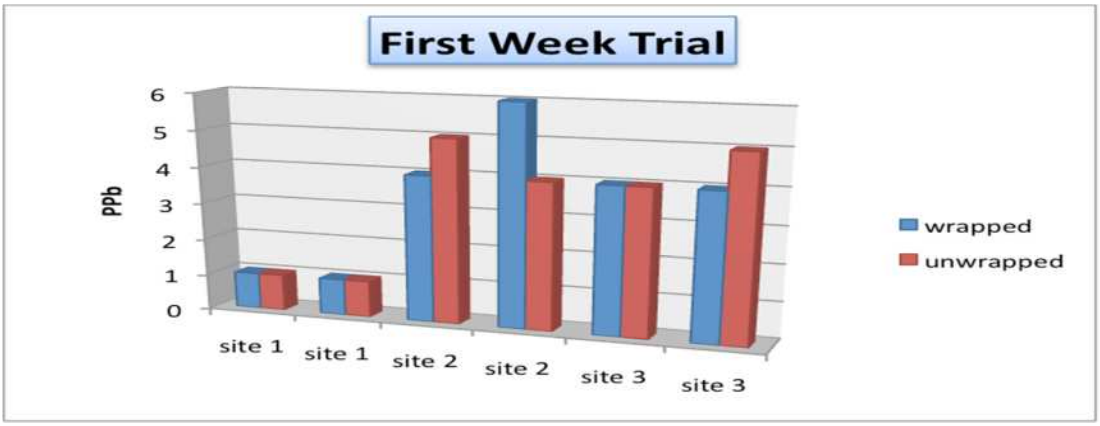


Figure 7.16: Level of NO_2 (ppb) in wrapped and unwrapped diffusion tube samplers

Figure 7.17: Level of NO_2 (ppb) in wrapped and unwrapped diffusion tube samplers (2nd trial)

The results of the first trial are presented in Figure 7.16, and it is found that each NO_2 concentration was under-estimated. Additionally, there was no difference between NO_2 values obtained from foil wrapped tubes and unwrapped ones and in all samples the concentration was 4 ppb, whereas in the blank sampler the level of NO_2 was 3 ppb. Results of the second trial were slightly different than first trial. The wrapped tubes showed 4.6 ppb NO_2, while the unwrapped tubes exhibited 5.4 ppb. Likewise at site 3, the wrapped tubes showed 4.4 ppb NO_2 and for the unwrapped tubes it was 5.4 ppb. Thus, it is clear from above observation that wrapping with aluminium foil did not have a considerable impact on working performances of tube samplers at Abu Dhabi. It is therefore concluded that aluminium foil although might stop direct impact of sunlight on diffusion tube sampler, but indirect impacts of hot climates, i.e. heat, wind velocity, air temperature etc. could not be minimized. Further technical designs needs to be revised for diffusion tube samplers to be used in such a hot and dry climate.

A second trial was conducted for another week starting from 12th September until 19th September. As illustrated in Figure 7.17. Results indicated that at the first site the level of NO_2 in wrapped tubes was 11 ppb, while the value for the unwrapped tube was 18 and 19 ppb. However, the second site showed 14 ppb for the wrapped tubes, while the unwrapped showed 15 and 14 ppb of NO_2. It clearly indicates that the unwrapped tubes overestimated the level of NO_2 as compared to wrapped tubes. Different behaviour was also observed at the third site; here the value for unwrapped tubes was 13 and 14 ppb, while values for the wrapped tubes were slightly high ranging between 12 to 16 ppb.

Another two-week trial was also conducted in this series to see the impact of diffusion tube wrapping (Figure 7.18). In a separate two-week trial, 20 diffusion tubes were deployed at 4 sites, from the 5th September to 19th September 2006. Figure 7.20, describes the diffusion tubes numbers, identifying the foil wrapped and unwrapped tubes. Results clearly indicated that the wrapped diffusion tubes had the same level of NO_2 as unwrapped ones, highlighting the failure of the wrapping technique of tube sampler. Overall, it is now concluded that the temperature regimes at Abu Dhabi drastically affected the working performances of diffusion samplers. There was a trend of underestimation of NO_2 level through diffusion tube methods. In a similar experiment, Kirby et al. (2001) concluded that diffusion tubes over-estimate NO_2 concentration more in summer than winter. The important point here is that the maximum temperature in UK during summer is 33°C which is identical with the winter weather conditions in UAE. Therefore, it is suggested that diffusion tube samplers may only show accurate results during winter months in U.A.E., although the functioning of diffusion tubes at lower temperature regimes still need to be evaluated.

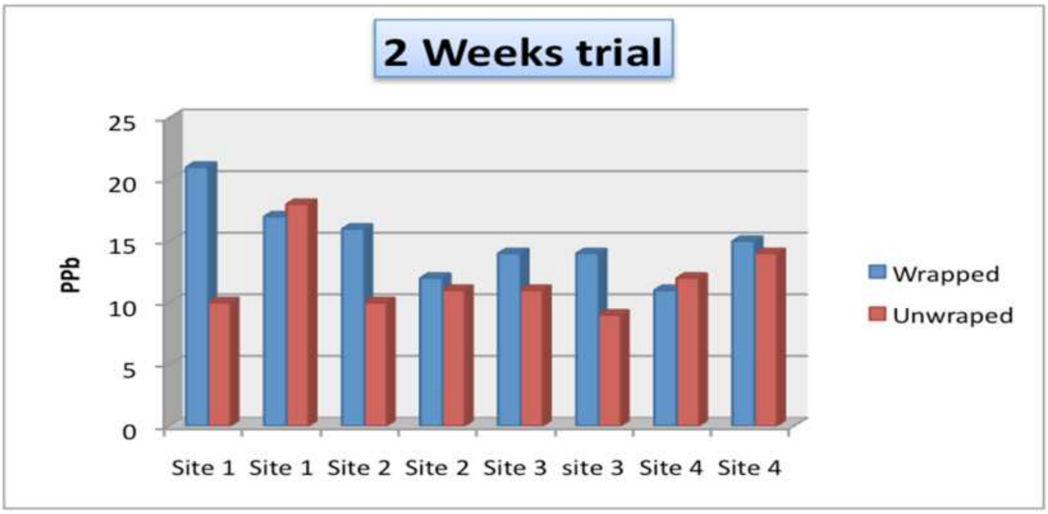


Figure 7.18: Level of NO_2 (ppb) in wrapped and unwrapped diffusion tube samplers. (2 week trial)

CHAPTER 8

AIR QUALITY MODELLING RESULTS

This chapter presents the results generated from the EDMS modelling.

8.1 Comparison of monthly averaged concentrations estimates using EDMS with measured values

EDMS provides hourly concentrations for a specified period. The specified period has been taken as 1 month in the present study. These estimated concentrations can be compared with monitored data for assessing the model's performance. For the purpose of comparison Figure 8.1 shows specified receptor locations around ADIA.

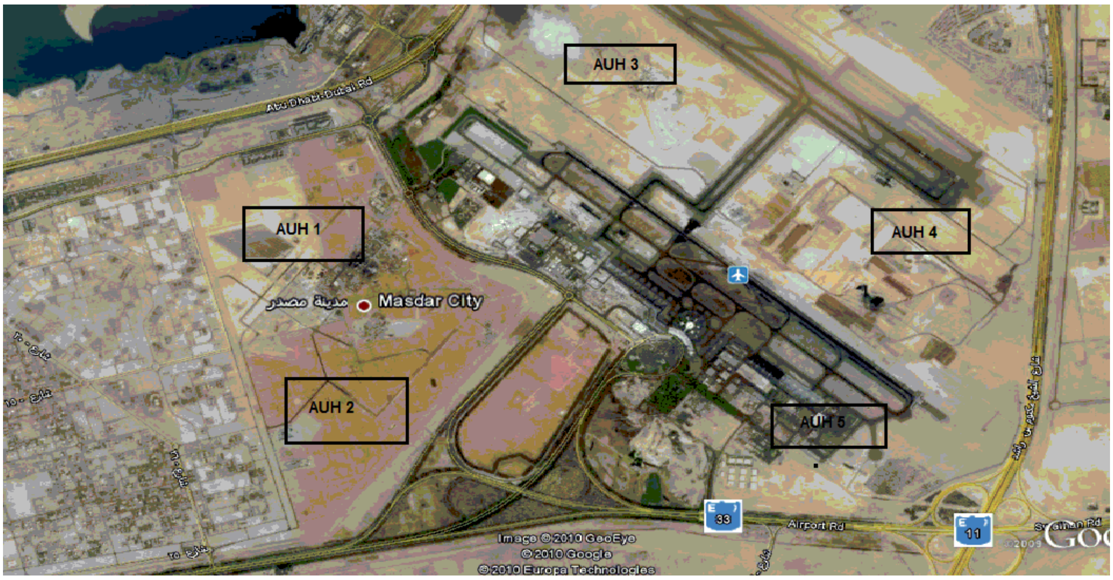


Figure 8.1 Receptors location around ADIA

The monitoring data was available only for 9 months and the quality of data was not good for the initial period (as discussed in chapter 7). Furthermore, the monitoring data representative of the traffic on the roads network around ADIA was not available. Consequently, the modelling run only included airport emissions (mainly aircrafts). NO background concentrations were available from Abu Dhabi Environmental Agency. Comparison between monitored monthly average NO_x concentrations and those predicted by EDMS are presented in (Table 8.1). The monthly average predicted concentrations showed low concentrations, as compared with measured concentration. This is primarily due to the fact that the emissions from other sources such as roads were not included.

It was noted that during the months of May and July, the modelled concentrations were higher than the other periods. This is due to higher air traffic during the summer season in which a large number of UAE people tend to travel abroad. Also from May onwards the ambient temperature increases and that would expedite the photochemical reaction, which results in the decrease in the total NO_x concentration.

It can be seen that the NOx concentrations during February for receptors AUH 1 and AUH 2 were 3.69 ppb and 4.88 ppb respectively (Table 8.1), whereas, the measured concentrations for the same month was 37.02 ppb. The receptors AUH 1 and AUH 2 are located in the Khalifa city and a large portion of the NOx is due to road traffic.
Similarly, the receptors AUH3 and AUH4 which are located in the new development area are showing a lower predicted NOx concentration as compared with measured values for all the months. In January the concentrations for AUH 3 and AUH 4 were

7.98 ppb and 8.48 ppb respectively, as compared with the measured value of 22.47 ppb for the same month.

Table 8.1 Monthly averaged NOx concentrations from EDMS Vs measurements

Month	Concentration at the Receptor Location					Measured Value
	AUH 1	AUH2	AUH 3	AUH 4	AUH 5	
Jan	8.37	8.56	7.98	8.48	18.30	22.47
Feb	3.69	4.88	4.33	5.21	19.12	37.02
Mar	1.19	2.14	3.78	3.11	19.43	21.44
Apr	3.03	4.04	4.98	2.12	18.38	32.85
May	7.04	4.97	9.01	5.75	31.37	29.90
Jun	3.62	9.12	11.27	7.90	24.57	35.15
Jul	3.08	5.06	5.70	2.61	32.32	29.55
Aug	3.64	3.40	7.75	2.00	19.40	
Sep	1.69	2.23	5.22	2.98	19.56	
Oct	0.68	0.98	1.15	3.43	19.31	
Nov	0.77	2.35	3.22	3.94	19.59	17.39
Dec	5.59	8.24	6.87	3.35	19.12	11.85

Note: All the values are in ppb

8.2 Comparison between diffusion tubes results and modelled concentration

A comparison of predicted NOx concentrations with winter measurements using diffusion tubes has been presented in Table 8.2. Most of the predicted concentrations were lower than the diffusion tube NO_2 concentration and that was expected because EDMS model only NO_x and the comparison with diffusion tubes it should be NO_2 predicted concentration .Morover, the modelling was conducted for aircraft only and, as mentioned before, no background concentrations or emissions from roads around the airport were available. Measured and modelled NOx concentration is shown in Figure 8.2.

Table 8.2: Comparison between diffusion tubes results and modelled concentration during the month of February

Receptors location	Diffusion tubes	NO_2 diffusion tubes concentration, ppb	NO_x modelled concentration, ppb
AUH 1	IMX26	6	3.69
AUH 2	IMX 22	13	4.88
AUH 3	IMX 07	10	4.33
AUH 4	IMX 06	11	5.21
AUH 5	IMX 04	14	19.12

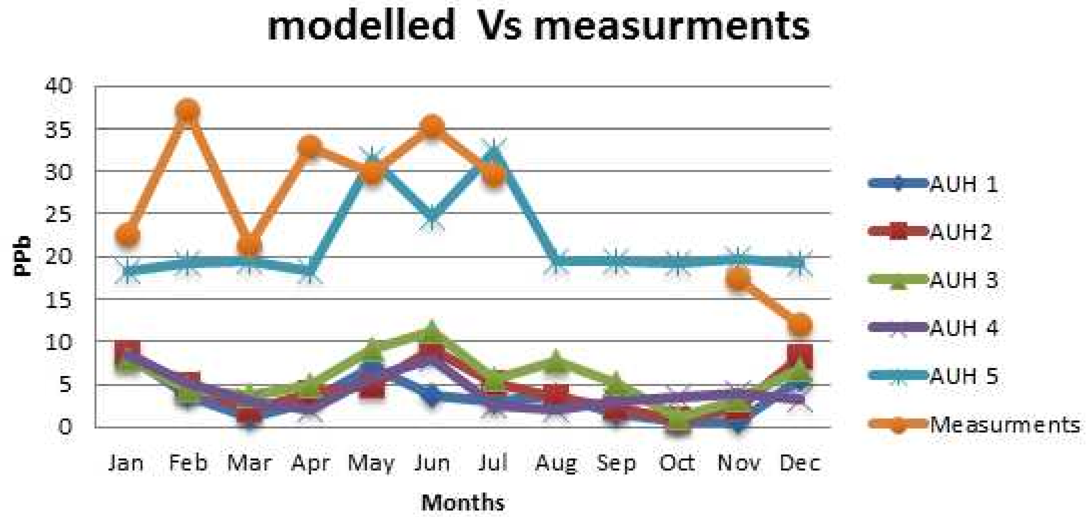


Figure 8.2 Monthly averaged predicted NOx concentration Vs 9 months measured values

8.3 Area of improvement

It is evident that there is a need for a complete emission inventory for the surrounding areas and roads around ADIA, in order to conduct further modelling and further spatial monitoring to validate modelling results. Moreover, EDMS model only NO_x, therefore an extension to NO_2 modelling is required. Therefore, NO_2 concentrations can be calculated from the modelled NO_X concentrations using a simple correlation method, such as the study which was was conducted in collaboration with UK DfT as part of an air quality status investigation near Heathrow Airport. Britter, et al., (2005), which recommended that NO_2 concentration near roads, is made of two parts: 1) NO_2 from road traffic and 2) NO_2 from background concentration. The road traffic contribution to NO_2 can be defined as a constant proportion (approximately 16%) of road traffic NO_X. Though, the actual NO_2 proportion depends upon the total amount of NO_X.

Britter, et al., (2005) indicated that the annual average results are satisfactory between the modelled and monitored concentrations with the differences between them lying in range of 5 - 12 % and 24 % for estimated and monitored NO_x and NO_2, respectively. Unfortunately, such results similarity couldn't be generated in this study due insufficient measurement data spatially and no complete emission inventory for the road network around the airport as mentioned before. Furthermore, future projection is also needed.

CHAPTER 9

CO_2 ESTIMATION INVENTORY FOR ADIA

This chapter describes the results from the estimations of CO_2 emissions for aviation activities. The methodology was described in chapter 4.

Tier 3 was used to calculate the total fuel consumption for ADIA. Table 9.1 presents the calculation for each flight and the result for one day is equivalent to 15,747,773 kg, which means the annual average fuel consumption will be around 574,792,218 kg of jet fuel. The total CO_2 emission for one day sample air traffic data is 4,973,133.8 kg, which is equivalent to 1,815,194 metric tonne of CO_2 per year. This calculation is used in this study for all international of passengers or carriers.

9.1 Tier 1 results

To validate the results Tier one was utilized which essentially depends on fuel consumption per year or fuel sold by the airport. Table 4.11 presents aviation fuel consumption for the year 2006, which is equivalent to 626,767 tonne per year and by multiplying this number by the CO_2 emission factor, the CO_2 emission for the year 2006 is calculated as 1,974,314 tonne.

9.2 Comparison between the two methodologies

Figure 9.1 shows that the difference between the two methodologies is 8%, this is due to the cargo aircraft which listed in Table 4.12 were not included due in sufficient data on cargo aircraft type.

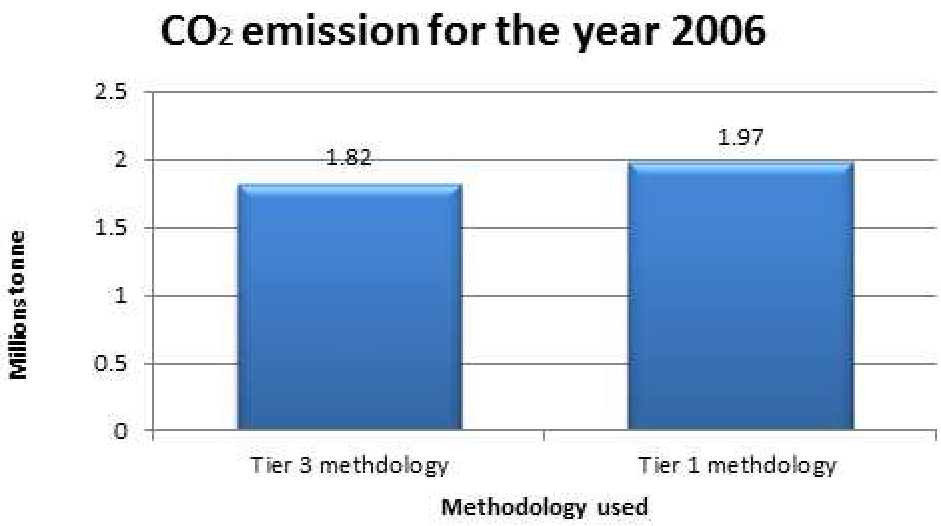


Figure 9.1: CO_2 emission results comparison between the two methodologies

Table 9.1: Fuel consumption for all departure flights (01/12/2006)

AIRCRAFT TYPE	ROUTING	DISTANCE KM	Fuel Consumption /LTO/kg	Fuel Consumption /CCD/kg	Fuel Consumption /TOTAL FLIGHT/kg
B757	AUH-GOI	2238	1253	10592.7	11845.7
B757	AUH-ZRH	4774	1253	17772.9	19025.9
B777	AUH_LHR	5512	2562.8	40580.4	43143.2
B777	AUH-MCT	379.8	2562.8	4472.3	7035.1
A310	AUH-CGP	3790	1540	17441.1	18981.1
A330	AUH-VIE	4239	2231.5	29483	31714.5
A330	AUH-TPE	6644	2231.5	42080.4	44311.9
A330	AUH-AMM	1997	2231.5	11890	14121.5
A330	AUH-AMM	1997	2231.5	11890	14121.5
A330	AUH-CMB	3299	2231.5	23402.7	25634.2
B767	AUH-BOM	1968	1617	9228	10845
A340	AUH-BOM	1968	2019.9	12181	14200.9
A340	AUH-BOM	1968	2019.9	12181	14200.9
A330	AUH-KHI	1263	2231.5	9128.4	11359.9
B767	AUH-ISB	2058	1617.1	13791.5	15408.6
A330	AUH-PEW	1945	2231.5	11890	14121.5
B767	AUH-LHR	5512	1617.1	28292	29909.1
A330	AUH-LHR	5512	2231.5	35812	38043.5
A340	AUH-LHR	5512	2019.9	37094.9	39114.8
B777	AUH-LGW	5487	2562.8	79504.6	82067.4
A330	AUH-MAN	5674	2231.5	35812	38043.5

A330	AUH-MUC	5473	2231.5	35812	38043.5
A330	AUH-FRA	4861	2231.5	29483.3	31714.8
A330	AUH-CDG	5248	2231.5	35812	38043.5
A330	AUH-GVA	4922	2231.5	29483.3	31714.8
B777	AUH-BKK	4940	2562.8	71092.3	73655.1
B777	AUH-BKK	4940	2562.8	71092.3	73655.1
B777	AUH-CGK	6570	2562.8	88130.4	90693.2
B777	AUH-MINL	6570	2562.8	88130.4	90693.2
A330	AUH-BRU	5162	2231.5	35812	38043.5
A330	AUH-CAI	2377	2231.5	17558.9	19790.4
A330	AUH-CMN	6047	2231.5	42080.4	44311.9
A330	AUH-BAH	452	2231.5	3630.9	5862.4
A330	AUH-MCT	379.8	2231.5	3630.9	5862.4
A330	AUH-RUH	804	2231.5	6383.9	8615.4
A330	AUH-DMM	537	2231.5	3630.9	5862.4
B777	AUH-DMM	537	2562.8	4472.3	7035.1
B777	AUH-KWI	849	2562.8	7567.5	10130.3
A330	AUH-JED	1612	2231.5	11890	14121.5
A320	AUH-BAH	452	802.3	1695	2497.3
A320	AUH-MCT	379.8	802.3	1695	2497.3
A320	AUH-BAH	452	802.3	1695	2497.3
A320	AUH-BAH	452	802.3	1695	2497.3
A320	AUH-BAH	452	802.3	1695	2497.3
A320	AUH-MCT	379.8	802.3	1695	2497.3
A320	AUH-BAH	452	802.3	1695	2497.3
B737	AUH-CCJ	2689	919.7	7802.1	8721.8
B737	AUH-TRV	2982	919.7	7802.1	8721.8
A330	AUH-KWI	849	2231.5	6383.9	8615.4
B737	AUH-CAI	2377	919.7	7802.1	8721.8
B757	AUH-GOI	2238	1253	10592.7	11845.7
B757	AUH-HEL	4591	1253.9	17772.9	19026.8
A330	AUH-BCN	5162	2231.5	35812	38043.5
A330	AUH-RUH	804	2231.5	6383.9	8615.4
A330	AUH-SHJ	231.5	2231.5	1862.1	4093.6
B737	AUH-PEW	1945	919.7	5271	6190.7
A310	AUH-LHE	2880	1540.5	12992	14532.5
A310	AUH-KHI	1263	1540.5	6540.7	8081.2
B737	AUH-KHI	1263	919.7	4030	4949.7
A320	AUH-DOH	323	802.3	1695	2497.3
A320	AUH-DOH	323	802.3	1695	2497.3
A320	AUH-DOH	323	802.3	1695	2497.3
A320	AUH-DOH	323	802.3	1695	2497.3
A320	AUH-AMM	1997	802.3	5224.9	6027.2
A330	AUH-KRT		2231.5		2231.5
B777	AUH-SIN	5880	2562.8	79504.6	82067.4

B777	AUH-SIN	5880	2562.8	79504.6	82067.4
MD90	AUH-RUH	804	1003.1	3560.9	4564
MD90	AUH-RUH	804	1003.1	3560.9	4564
B757	AUH-ASB	1546	1253	7137.7	8390.7
B757	AUH-ASB	1546	1253	7137.7	8390.7
B737	AUH-IST	3015	919.7	10518.3	11438
B737	AUH-IST	3015	919.7	10518.3	11438
A320	AUH-MBA	3457	802.3	10063.6	10865.9

Source: - calculated by the Author using table 4.12 sample of aircraft movements for 1/12/2006 and fuel consumption for LTO and CCD was obtained from EMPEP/ EEA Guidebook website (EEA, 2009) and calculated for total flight journey

9.3 Future projection

Aviation industry has been increasing at a rapid rate at ADIA. The total number of passengers is projected to grow from 5.2 million in 2004 to 26.7 million in 2030, representing an average annual growth rate of 6.5%. OD (Origin and Destination) passengers are projected to grow from 2.2 million in 2004 to 13.8 million in 2030, representing an average annual growth rate of 7.3% (refer Chapter 5 for details about ADIA expansion programme).

During the last decade a considerable growth in number of aircraft has been seen at ADIA. As illustrated in Figure 5.11, total aircraft movements increased from 45,927 1998 to 93,163 (2008), showing approximately 50.0 % increment during last 10 years. However, the growth in aircraft movement in the last 3 years (2006-2009) was 20% increase every year. Therefore, depending on this growth rate, future fuel consumption and CO_2 emission were calculated and are presented in Table 9.2. Future growth in air traffic movement, fuel consumption and CO_2 emissions is shown in Figure 9.

Table 9.2: Future growth projection in aircraft movement, fuel consumption and CO_2 emission

Year	Aircraft movement	Fuel in metric tonne	CO_2 in metric tonne
2006	75,437	574,792	1,815,194
2009	93,386	711,557	2,241,404
2010	102,300	779,474	2,455,343
2020	138,600	1,056,061	3,326,592
2030	181,000	1,379,127	4,344,250

Source: calculated by the Author

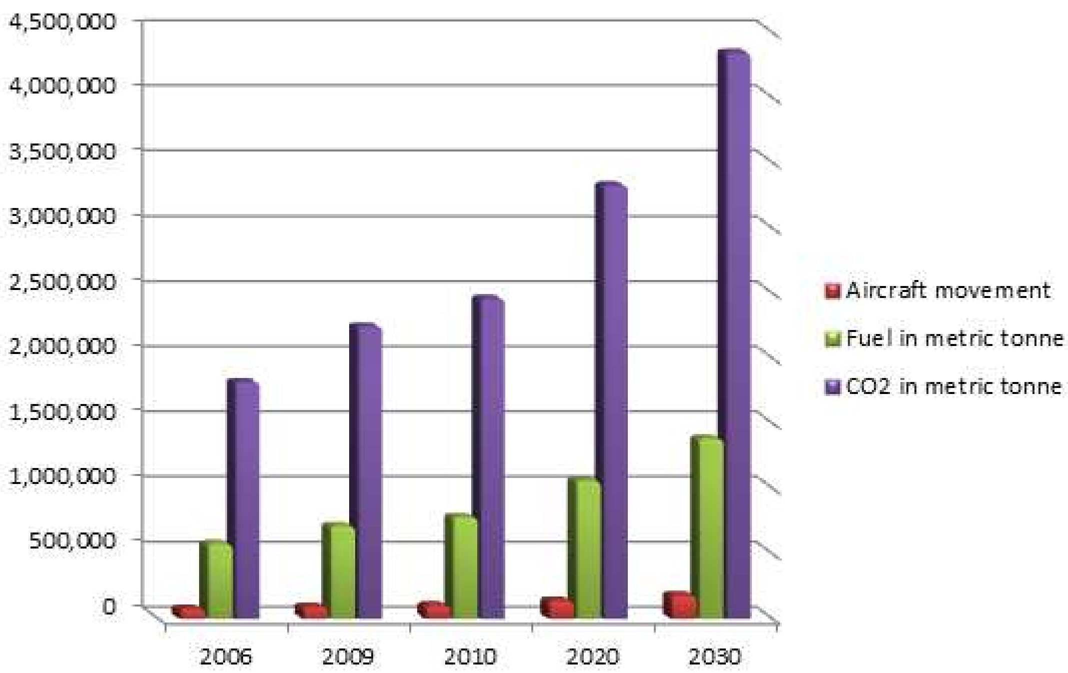


Figure 9.2: Future growths in air traffic movement, fuel consumption and CO_2 emissions

9.4 Comparison between UK airports and ADIA

The Aviation Environmental Federation (AEF) has carried out a simple estimate of CO_2 growth in emission using the DfT's passenger forecasts and fuel efficiency.

9.4.1 UK CO_2 emission forecast

Based on the AFE estimate the total UK CO_2 emission for the year 2005 and 2050 are presented in Figure 9.3. Table 9.3 presents the CO_2 forecast by sector, which is very useful for comparison purposes with ADIA results. Moreover, in 2006 ADIA generated 1.8 Mt of CO_2, whilst Heathrow generated 18.2Mt, Gatwick 4.8 Mt and Stansted 1.4 Mt in 2005. The comparison between ADIA, Heathrow, Gatwick and Stansted airports shows that ADIA aircraft movements is 16% of Heathrow, 30% of Gatwick and 40% of Stansted movement. CO_2 emission at ADIA is 10% of Heathrow, 40% of Gatwick and 30% of Stansted which has been reflected in Tier 3 methodology, this is due to the long distance international flights which connect the East and Europe through ADIA.

Furthermore, the ADIA CO_2 forecast for 2030 is 4.8 Mt and Heathrow is 24.9Mt, Gatwick 5.4 Mt. Figure 9.4 presents the comparison between ADIA and UK airports. ADIA's ambitions to expand may result in a major issue for the policy maker to ADIA and Abu Dhabi government.

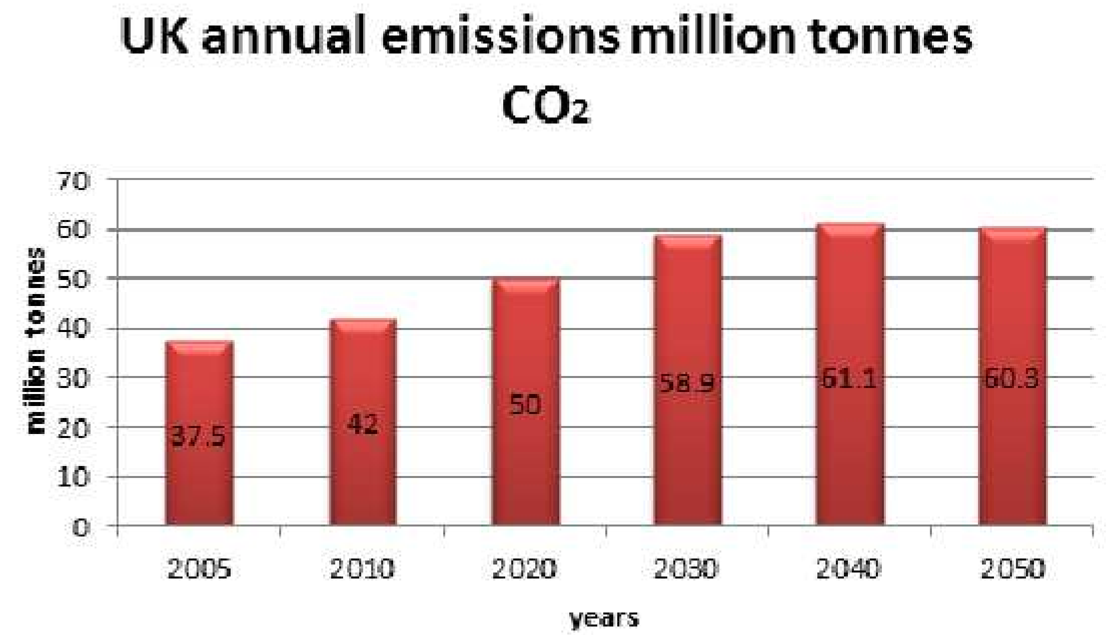


Figure 9.3: UK CO_2 aviation emissions between 2005 and 2050

(Source: AEFhttp://www.aef.org.uk/?p=242)

Table 9.3 CO_2 forecast for Different Sources in UK (Mt/Yr)

Source	**Reference Year**	
	2005	2030
Heathrow	18.2	24.9
Gatwick	4.8	5.4
Stansted	1.4	3.3
Luton	0.6	0.9
London City	0.2	0.3
Other UK	9.1	18.2
Ground	1.4	2.2
Freight only flights	0.6	2.4
UK total	37.5	58.9

(Source: AEF- http://www.aef.org.uk/?p=242)

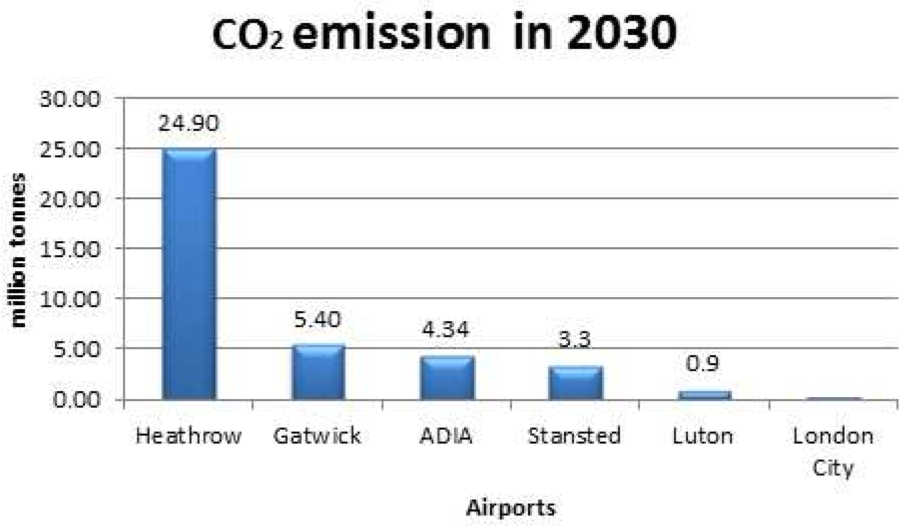


Figure 9.4: Comparison between ADIA and UK airports for CO_2 emission in 2030

According to figure 5.16 in chapter 5, 65% of the aircraft movement in 2004 was transit, and it was mentioned that most flights are long haul flights.

CHAPTER 10

GENERAL DISSCUSION

This chapter discusses the results obtained from 3 different aspects: firstly, the evaluation of the scientific reliability and validity of the research, secondly, the practical implication and originality of the research and lastly, the limitations of the research and areas for improvement.

10.1 Evaluation of the Scientific Reliability and Validity of the Research

10.1.1 Emissions inventory for ADIA

The first objective of this thesis was to conduct an emission inventory for ADIA. This work started with a literature review of air pollution emissions from the aviation sector, with an overview of how emissions inventories are compiled with particular emphasis on airports emissions (Chapter 2 the first and second sections). The emission inventory were conducted using EDMS, as explained earlier in Chapter 4 and Appendix one, the major finding of the emission inventory was illustrated in detail in Chapter 6.

The aircraft movements for the year 2006 produce the highest total of NO_x airport-related emission. It was clearly identified that the climb out phase produced the maximum NO_X during the LTO cycle. Moreover, emission inventories results were compared with different US airports.

Another comparison was conducted between Heathrow Airport, ADIA and Gatwick Airport. Results data were further examined to find out why the NO_X emissions from aircrafts were high at ADIA by conducting a small exercise to check the methodology used. This included the main factors that influence the emissions from an aircraft engine, such as time in mode and the fuel rate and the emission factors for the above mentioned three airports (LHR, ADIA, LGW). Three different types of aircraft were used and the findings were discussed in Chapter 6. Furthermore, the high NOx emissions came from some old aircraft from different airlines as illustrated in Chapter 4 in the tables of ADIA fleet mix.

NO_X projection and future emission reduction scenario

Future projections reveal an increase of NO_X emissions in 2030 up to 3,096 Mt, due to the increase in aircraft movement. No aircraft technology enhancements were taken into consideration in this projection which is a major factor in future projection. Following the setting of the first standards to reduce emissions by the ICAO, enormous improvements have been made (ICAO, 2010) (mentioned in Chapter 3), as part of the ICAO/CAEP mid and long-term technology goals for aircraft engines, the most favourable scenario proposes a robust 100% reduction of NOx emissions from the current NOx emission levels to the NOx emissions levels set by CAEP/7, using advanced aircraft technology and operational improvements (ICAO, 2010). In this study, assumptions were made for NOx emission below 3000ft; the first assumption would be 50% reduction in NO_X emissions for the year 2020, while the second assumption would be 60 % reduction in NO_X emissions for the year 2030. These assumptions were derived from CAEP/4 goals for NOx emission reduction. And by applying this into table 6.8 in chapter 6 future projections will be as presented in Table 10.1. Therefore, for the year 2020, instead of 2,371 metric tonne, it will be 1186 metric tonne, and for the year 2030, instead of 3,096 metric tonne, it will be 1238 metric tonne, while aircraft movement is projected to be 181,000 movements. The NO_X emission for the year 2030 after the reduction is expected to be 1238 metric tonne, less than then 2006 level, which was 1290 metric tonne. The reason to choose these CAEP/4 goals is to have a moderate assumption as well it matches the projected period, were CAPE/7 target longer period up 2050 and provides more stringency of NOx emissions standards.

Table 10.1 ADIA NOx emissions reductions assumptions through improvement in aircraft and engine technology

Year	Aircraft movement	NOx emission MT	Reduction %	Emission After Reduction Metric Tonne
2010	102,300	1,750	No assumption	-
2020	138,600	2,371	50	1186
2030	181,000	3,096	60	1238

10.1.2 Air quality status at ADIA and the surrounding areas.

The second objective of this study was to determine the area influenced by air traffic and to determine the level of impact of the current airport operations on the air quality around ADIA.

NO_2 measurements were carried out using passive diffusion tube methods in order to find out the spatial distribution of NO_2 in the vicinity of ADIA.

An experiment was conducted by the author in order to verify if covering the diffusion tube samplers with aluminium foil minimizes the impact of direct sunlight on the samplers. Three trials were conducted in September 2006 and in the first experiment, a total of 15 diffusion tubes were exposed for one week at three sites. At each site five diffusion tubes were kept, out of which 2 tubes were wrapped with aluminium foil around the cap, while the other two and one blank tube were left unwrapped. A comparison of wrapped and unwrapped diffusion tube samplers was given. As a result, wrapping diffusion tubes with aluminium foil did not give improved results. Further diffusion tube testing under extreme high temperature failed, due to such extreme weather conditions.

The performance of diffusion tubes have been examined in many studies, such as those by Kasper-Giebl and Puxbaum (1999), Ferm and Svanberg, (1998), and many more as discussed in the literature review in Chapter 2 section 2.4 but none of them carried out testing in extreme weather conditions like the UAE. Therefore, diffusion tubes are not a suitable device to be used in the UAE, as they may underestimate the NO_2 concentrations, as illustrated in the results in Chapter 7.

Air pollutant data sets were received from airport authorities of ADIA. Air quality parameters included, O_3, PM_{10}, CO, NO_x and SO_2. The pollutant measurements using standard measurement techniques were carried out for 9 months i.e., from 15 November 2005 to 15th July 2006 by the Supervision Committee for Abu Dhabi International Airport (SCADIA). Data sets were subjected to further interpretation of trends of pollutants with respect to diurnal variations, as well as seasonal changes with respect to O_3, NO, NO_2 and NOx. The NO_2: NOx relationships were determined from the measured concentrations of these parameters.

By examining NO_2 pollution rose, the major source of NO_2 is the road network around the airport. More measurement is required in the area around the airport together with assessment of emissions.

The maximum 1-hour mean concentration of ozone during the monitoring period was 156 µg/m^3, and did not exceed the FEA ozone standard of 200 µg/m^3 /1-hour. However, the maximum 8 hours average O_3 value of 126 ppb exceeded the 8 hour ozone standard specified by WHO, FEA, and the U.K. air quality standard and WHO guidelines. The NO_2 concentrations did not exceed the FEA, UK standards or the WHO guidelines. Particulate matter is a major air pollution problem in the area under investigation, aggravated by some natural sources like sandstorms. Further monitoring for PM_{10} is required.

10.1.3 Air pollution modelling and prediction of the air quality at ADIA

The modelling run used only airport emissions (mainly aircraft). No background concentrations from other sources were available. Therefore the comparison between monitored monthly average NO_x concentrations and those predicted by EDMS were generally showing low modelled concentrations as compared with measured concentration. And this is expected because other sources such as roads were not included.

10.1.4 Estimation of CO_2 emissions from ADIA

Tier 3 was used to calculate the total fuel consumption for ADIA. Table 9.1 presents the calculation for each flight and the result for one. This calculation is used in this study for all international passengers or carriers. To validate the results Tier 1 was utilized which essentially depends on fuel consumption per year or fuel sold by the airport. Table 4.11 presents aviation fuel consumption for the year 2006, which is equivalent to 626,767 tonne per year and by multiplying this number by the CO_2 emission factor, the CO_2 emission for the year 2006 is calculated as 1,974,314 tonne. No significant difference was found between the Tier 1 and Tier 3 methodologies.

***Uncertainty*: -** There is uncertainty relating to using a one day sample of air traffic data as shown in (chapter 4 the methodology) to generate an annual estimate. This is because during pilgrim (haj) seasons ADIA tend to have more aircrafts to transport passengers to KSA airports. Furthermore, the annual fleet mix given in Table 4.6 presents a diverse mix of airplanes such as military aircraft as well as helicopters and many light aircrafts. Similar uncertainties were shown in a study conducted by Pejovic, et al., (2008) (mentioned in Chapter 2) for Heathrow airport, using real traffic data for one week and the study concluded that one week cannot be used for one year estimate .

CO_2 projection and future emission reduction scenario

ADIA future expansion will result in more CO_2. The present study reveals that in 2030 the ADIA forecast growth in flights; the annual CO_2 emission will increase to 4.8 Mt.

This section describes a range of abatement technology to reduce aviation fuel consumption and eventually emission reductions. It was mentioned in Chapter 3 section 3.2.1 that the IPCC introduced different reduction measures such as aircraft and engine technology options. According to the (IPCC, 2007) compared with the standards in the 1970s, subsonic aircraft that are currently being manufactured are approximately 70% more effective in terms of fuel per passenger-kilometre. A decrease in emissions could be facilitated by further development of the effectiveness of fuel and in the design of aircraft. By 2015, it is predicted that fuel will be 20% more effective. By 2050, it is estimated that fuel will be 40-50% more effective (IPCC, 2007).

As part of the long-term planning for the industry, the 37th session of the ICAO Assembly in October 2010 set out standards to which all its 190 Member States were expected to aspire in terms of reducing CO_2 emissions for international civil aviation(chapter 3 section 3.2.1) (ICAO, 2010). The ICAO is working closely with Member States, providing guidance material and a plan for obtaining, interpreting and identifying aviation CO_2 emissions.

The optimum scenario in the case of CO_2 reductions relies on advanced aircraft technology and advanced operational improvement relating to the NextGen and SESAR initiatives (ICAO, 2010). It includes an optimistic fuel burn improvement of 15% per annum for all aircraft brought into the fleet between 2016 and 2026 (ICAO, 2010).

If these actions are implemented, technology can help cut emission even as the industry grows. According to forecasts made by (BAA 2010) and mentioned in chapter 3. First a 26% cut through improvement in engine air frame design up 2020. Second, a 25% cut through radical technology such as open-rotor engines introduced after 2020. And by applying this to table 9.6 in Chapter 9 future projections will be as presented in Table 10.1. Therefore, for the year 2020, instead of 3,326,594 metric tonne, it will be 26 % less, which will result in 2,461,679 metric tonne, and for the year 2030, instead of 4,344,250 metric tonne it will be 25% less, which will result in 3,258,188 metric tonne, while aircraft movement is projected to be 181,000 movements.

Another forecast for ADIA is a 20% reduction for the year 2020 and a 30% reduction for the year 2030. These forecasts were derived from CAEP/ 4 goals reduction for the period of 2005 to 2035. Table 10.3 presents the results for these forecasts. Therefore, for the year 2020, instead of 3,326,594 metric tonne it will be 20 % less which will be

2,661,275 metric tonne, and for the year 2030, instead of 4,344,250 metric tonne it will be 30% less which will be 3,040,975 metric tonne, while aircraft movement is projected to be 181,000 movements.

As result a major CO_2 emission reduction will be generated through the improvement in aircraft engines and different scenarios can be generated depending on the assumption of how fast these improved and cleaner aircraft could be used at ADIA.

Table 10.2 ADIA CO_2 emissions reductions assumptions through improvement in aircraft and engine technology.

Year	Reduction assumptions	CO_2 emission in Metric tonne
2010	No assumptions	2,455,343
2020	26%	2,461,679
2030	25%	3,258,188

Table 10.3 ADIA CO_2 emissions reductions assumptions through improvement in aircraft and engine technology.

Year	Reduction Assumptions %	aircraft movement	Fuel in metric	CO_2 emission in Metric Tonne	Emission After Reduction Metric Tonne
2010	No assumption	102,300	779,474	2,455,343	-
2020	20	138,600	1,056,061	3,326,594	2661275
2030	30	181,000	1,379,127	4,344,250	3040975

10.2 Practical Implication and Originality

This study highlights the importance of considering the aviation air pollution in the Emirate of Abu Dhabi and the UAE in general for the first time.

This study contributes to the Abu Dhabi Air Quality Management Study (mentioned in Chapter 5) which includes emission inventories for all the industrial sectors in emirate. However the aviation sector was not included; therefore the importance of this thesis is in bridging the gap that currently exists.

This study contributes to Abu Dhabi Climate change policy plan,(mentioned in Chapter 5) in which the aviation sector was not mentioned; therefore the importance of this thesis is filling the gap by covering the aviation activities in Abu Dhabi Emirate by calculating CO_2 emission from ADIA, and lays the foundation for further studies. Furthermore, a complete CO_2 emission inventory is required for all the airport activities, including stationary source, GSE and APUs.

The Abu Dhabi strategy needs to include the aviation activities as part of the environmental policy towards achieving sustainable development for the aviation sector in the emirate. This Study contributes to the strategy by providing the required information on ADIA air pollution studies, which includes emission inventory, monitoring and CO_2 emission estimation for all flights departing from ADIA to different destinations.

A similar study should be conducted for Al Ain International Airport which is the second airport in the emirate of Abu Dhabi and the other six international airports which are as follows: - Dubai International Airport, Dubai World Airport also known as Al Maktoum International Airport, Sharjah International Airport, Ras Al Khaima

International Airport, Fujairah International Airport and Ajman International Airport which is currently under development.

10.3 Limitation and Area of Improvement

Diffusion tubes are not a suitable device to be used in the meteorological conditions of the UAE, because they may underestimate the NO_2 concentrations. Wrapping diffusion tubes with aluminium foil did not give improved results. Further diffusion tubes testing under extreme high temperature is recommended to explain why they failed.

An alternative suggestion is to try out use of the Message device (mentioned in chapter 2) to give a spatial picture of NO_2 concentration around the airport. These sensors were successfully used in the Message project (Cambridge University, 2009) to measure gas concentrations such as CO, NO, NO_2 with time and GPS positions and send the monitoring data over GPRS phone to archive them centrally.

Area of improvement: A complete emission inventory for aircraft maintenance, the roads network around the airport is needed along with airport, pickup and drop-off areas. Further, it should be a detailed one, including the type of vehicles, LDV, HDV, age of the vehicle. This emission inventory is also needed, in order to conduct further modelling and further spatial monitoring to validate modelling results.

EDMS model only NO_x, therefore an extension to NO_2 modelling is required. The EDMS model does not include a chemistry module. Therefore, NO_2 concentrations can be calculated from the modelled NO_X concentrations using a simple correlation method, such as the study which was was conducted in collaboration with UK DfT as part of an air quality status investigation near Heathrow Airport. Britter, et al., (2005), which recommended that NO_2 concentration near roads, is made of two parts: 1) NO_2 from road traffic and 2) NO_2 from background concentration. The road traffic contribution to NO_2 can be defined as a constant proportion (approximately 16%) of road traffic NO_X. Though, the actual NO_2 proportion depends upon the total amount of NO_X. Therefore a variable factor is preferable in local air quality assessment, namely, the oxidant partitioning model (Jenkins, 2004 a) making an empirical relationship (which was mentioned in Chapter 2 section 2.6.) It was established that consideration of O_3, NO and NO_2 as a set of chemically coupled species offers further information to assist the prediction and interpretation of how the level of NO_2 varies with that of NOx. The method includes defining (i) linear expressions describing how the level of "oxidant", O_X varies with the level of NOx, and (ii) algebraic expressions describing how the fractional contribution of NO_2 to O_X (i.e. NO_2/O_X) varies with NOx. The product of these two quantities results in the dependence of NO_2 levels as a function of NOx (AQEG, 2004).

A complete CO_2 emission inventory is required for all the airport activities such as activities on the airfield and in around the terminals, stationary source, GSE and APUs.

CHAPTER 11

SUMMARY AND CONCLUSIONS

A series of conclusions can be derived from the wide range of topics covered in this thesis and their significance lies in that they are the results of the first study of aviation air pollution in the Emirate of Abu Dhabi and the UAE.

The conclusions presented in this chapter have been set out in accordance with the objectives of the thesis as defined in chapter 1 and reiterated as follows:

Objective A: To establish emissions inventory for ADIA.

Objective B: To evaluate air quality status at the airport and surrounding areas by analysing air pollution data and to conduct NO_2 diffusion tube measurement campaign to find out NO_2 spatial distribution.

Objective C: To carry out air pollution modelling to predict the air quality at ADIA.

Objective D: To calculate aircraft CO_2 emissions from ADIA, to illustrate ADIA aeronautical activities contribution to global warming issues.

Objective E: To set up recommendations in support of an air quality policy for ADIA.

11.1 Objective A: To establish an emissions inventory for ADIA.

1. The emission inventory illustrates that aircraft movements produce approximately 89% of total NO_x airport-related emission, while GSE can be attributed to the remaining 11%.
2. GSE has maximum emission from CO sources at the airport due to incomplete combustion process.
3. CO emission by the aircraft accounts for 30% of the total emissions. Stationary sources account for 4% of the total emissions followed by GSE/APU (66%) and training fires are negligible.
4. For SOx, aircraft are the major contributors accounting for 83% of the total emissions followed by GSE/APU, 17%, stationary sources.
5. The highest contribution to particulate matter was through aircraft at ADIA as they contributed 59 % for PM_{10} level. Stationary sources account for just 1% and fires contribute 3%, but GSE/APU contribution is larger at 37%.
6. Aircraft engine emission during the LTO cycle climb out phase produced the largest NO_x.
7. On the comparisons between Heathrow Airport, ADIA and Gatwick Airport, the total aircraft movement was the highest at Heathrow (LHR) 469,763 movements for the year 2002, followed by Gatwick (LGW) 244, 989 movements for the year 2002 and the lowest at ADIA with 75,000 movements for the year 2006. On the other hand, the total aircraft NO_x emission from LHR were 5318 metric tonnes/year, followed by LGW 1589.79 metric tonnes /year and the lowest was at ADAI, with 1290.44 metric tonne/year. However, ADIA aircraft emission was close to LGW.

8. Future projection reveals an increase of NO_x emissions in 2030 up to 3,096 Mt due to the increase in aircraft movement. No aircraft technology enhancement was taken into consideration in this projection.

11.2 Objective B: To evaluate air quality status at the airport and surrounding areas by analysing air pollution data and to conduct a NO_2 diffusion tube measurement campaign to find out NO_2 spatial distribution.

1. The maximum 1-hour mean concentration of ozone during the monitoring period was 156 µg/m^3 and did not exceed the FEA ozone standard of 200 µg/m^3 /1-hour. However, the maximum 8 hours average O_3 value of 126 ppb exceeded the 8 hour ozone standard specified by WHO, FEA, and the U.K. air quality standard and WHO guidelines.
2. The NO_2 concentrations did not exceed the FEA, UK standards or the WHO guidelines.
3. Particulate matter is a major air pollution problem in the area as per present investigation and it is aggravated by some natural sources like sandstorms. Further monitoring for PM_{10} is required.
4. A revision for the air quality standards is highly necessary to match with WHO guidelines and EU.
5. Based on the NO_2 pollution rose, it was found that the major source of NO_2 is the road network around the airport.
6. Diffusion tubes are not a suitable device to be used in the meteorological conditions of the UAE, because they may underestimate the NO_2 concentrations.

7. Wrapping diffusion tubes with aluminium foil did not give improved results. Further diffusion tubes testing under extremely high temperatures is highly recommended to ascertain the reason for the failure.
8. An alternative suggestion is to try out the use of the Message device to give a spatial picture of NO_2 concentration around the airport. These sensors were successfully used in the Message project (Cambridge University, 2009) to measure gas concentrations such as CO, NO, NO_2 with time and GPS position and send the monitoring data over GPRS phone to archive them centrally.

11.3 Objective C: To carry out air pollution modelling to predict the air quality at ADIA.

1. The modelling run used only airport emissions (mainly aircraft). No background concentrations from other sources were available. Therefore, the comparison between monitored monthly average NO_x concentrations and those predicted by EDMS generally showed low modelled concentrations as compared to measured concentration. These results were expected because other sources, such as roads, were not included.
2. There is a need for a complete emission inventory for the surrounding areas and roads around ADIA in order to conduct further modelling and further spatial monitoring to validate modelling results. Future projection is also needed
3. The EDMS only models NO_x, therefore an extension is required for NO_2 modelling.
4. The incorporation of background concentration is required.

11.4 Objective D: To calculate aircraft CO_2 emissions from ADIA, to illustrate the contribution of ADIA's aeronautical activities to global warming issues.

1. The total CO_2 emission per year is 1.8 metric tonne.
2. No significant difference is found between the Tier 1 and Tier 3 methodologies.
3. ADIA future expansion will result in more CO_2 emission. The present study reveals that in 2030 for the ADIA forecast growth in flights, the annual CO_2 emission will increase to 4.8 Mt.
4. Emission reduction scenarios showed major reduction could be generated through employing new generation of aircraft which has new engine technology.

11.5 Objective E: To set up recommendations in support of an air quality policy for ADIA.

11.5.1 Recommendations for ADIA

The major sources of air emissions at ADIA include road traffic, airport vehicles and the ground running of aircraft. Many of these operations are essential to the efficient operation of the airport. The challenge for ADIA is to work with its business partners such as the airlines, the ground handling agents ADAS, and relevant government agencies such as the Department of Transport (DOT) and Abu Dhabi Environmental Agency (AED) to keep these emissions at acceptable levels.

A long term strategy is required to balance the needs for the environment with economic growth and social responsibilities. The goal of sustainable development is to enable all people throughout the world to satisfy their basic needs and enjoy a better quality of life without compromising the quality of life for future generations (Defra, 2005). Aviation air quality policy for ADIA should meet the needs of society for air travel and transport, while removing or minimising any negative impacts on the local and global environment. The strategy should provide the mechanisms for monitoring and reporting air quality and climate change to AED. It is recommended that a continuous emission inventory programme is conducted on a yearly basis, as a first step towards sustainable aviation. Fundamental to this is the adoption of an emission reduction scheme that enforces an emission reduction policy to all airlines operating at ADIA and monitors aircraft from the different airlines in order to prevent the use of old aircraft in ADIA in order to reduce emission .

This emission inventory is also needed on a yearly basis to observe any increase and to adopt mitigation measures to reduce it, including public transport to reduce emission from cars. This can be accomplished in collaboration with the department of transport (DOT), EAD, ADAC and Abu Dhabi traffic police.

ADIA should contribute to the air quality measurement a programme which is run by the Abu Dhabi Environmental agency and aid research to improve the assessment of aircraft and airport emissions enabling a better understanding of their actual contribution to local air quality close to airports. Therefore, an air quality measurement programme should be implemented by ADIA with several monitoring stations in and around the airport in cooperation with EAD.

At the same time ADIA needs to deliver continued improvements in airport ground vehicles, the supply of ground power services, operational practice and the availability of cleaner fuels, in order to reduce NOx emissions.

Ground Service Equipment (GSE) which service airplanes should use alternative fuels such as compressed natural gas and electricity. The use of these fuels will result in lower emissions and an improved quality in the vicinity of the passenger terminal aircraft parking apron. Electrical GSE will reduce CO_2 emission at ground level in the airport.

Alternative fuels are not available for commercial aircrafts at the present time, therefore decreasing the engine burn time is the primary mitigation strategy to reduce emissions .Electric power and air conditioning should be supplied while airplanes are parked at the gate, in order to eliminate the need to run on-board auxiliary power units.

Reducing emissions associated with trips to and from the airport can help improve local air quality similar to the US EPA policy; this can be achieved by using ADIA city terminal which is located in central Abu Dhabi, passengers could check in to the city terminal and then travel by buses to the airport, giving bus services the first priority, including designating priority bus lanes on the main approach routes to the airport and providing traffic signal arrangement for buses. Such measures would result in fewer individual journeys being made to and from the airport.

11.5.2 Recommendations on emirate level

The Abu Dhabi Environmental Agency is the authority concerned with regulating the air quality and climate change issues in the emirate. In the same way, the Department of Transport (DOT), regulates the aviation sector and is also responsible for the entire road network in the emirates, regulating all other modes of transportation involved therein. ADIA and Al Ain International Airport are owned by Abu Dhabi Aviation

Company ADAC which was established in 2007. Figure 11.1 presents the relationship between these organizations in implementing the aviation air quality policy. To allow the aviation industry to grow in a sustainable manner, air quality must be regulated with the cooperation of the various organization mentioned above.

Continuous monitoring is absolutely essential for the area around the airport. Abu Dhabi Airport Company (ADAC) and the Environmental Agency Abu Dhabi (EAD) should plan to implement a joint programme to determine the background concentration around that area.

Increased demand for air transport will create congestion on local transport systems. ADIA, in collaboration with DOT, should implement an integrated public transport system which including direct coach, bus and rail services. This will benefit both passengers and staff and reduce the environmental impact from to cars

It is also recommended that an organization, similar to the National Atmospheric Emission inventory in the UK, should be established, in order to have a yearly emission inventory for all the sectors and pollutants in Abu Dhabi Emirates based on consistent and documented procedures.

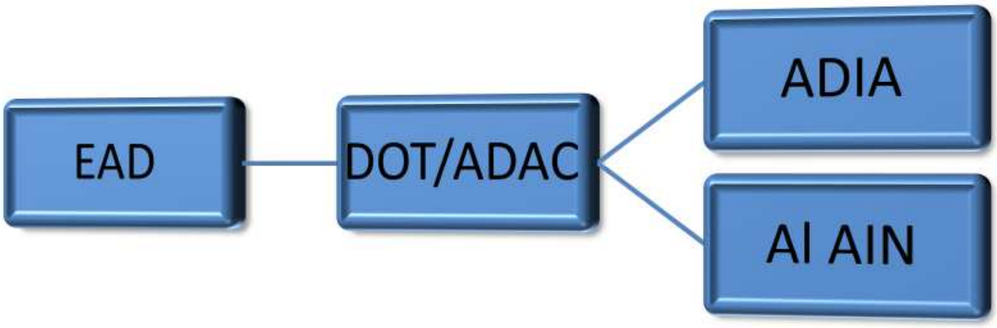


Figure11.1 The relationship between the Abu Dhabi environmental Agency and Department of Transport and Abu Dhabi Aviation company in implementing the aviation air quality policy.

As a non-Annex 1 country under the UNFCCC, the UAE is not obliged to follow explicit GHG reduction targets. However, the UAE is demonstrating its shared aims with the international community in tackling the threat to climate change, by establishing MASDER city, which is the" world's first carbon-neutral zero-emission city", by using renewable energy and MASDER Institute of Science and Technology. It is highly recommended that a fully comprehensive CO_2 emission inventory for all Abu Dhabi Emirates is conducted, including all sectors.

Such an inventory needs to involve the public by, for example, conducting a public awareness programme to illustrate climate change issues. Individual participation and responsibility should be encouraged by demonstrating how they can make a positive contribution to climate change by reducing their own CO_2 footprint. This programme should have its roots in environmental education in schools, with the media also playing a major role in disseminating information and a pro-active message to the people.

11.5.3 Recommendations at the Federal level

Various organisations in the UAE are involved at the federal level; first the Ministry of Environment and Water (MOEW), which is responsible for regulating air quality, and second, the General Civil Aviation Authority (GCAA) which was established 1996 to regulate the aviation sector in the UAE in compliance with ICAO standards.

The aviation air quality policy should be set by the GCAA and MOEW and it must include the cooperation of the UAE airlines, UAE airport operators, aircraft manufacturers and the air navigation service provider. Figure 11.3 presents the relationship between the GCAA and the MOEW and the different airports in the UAE, namely, Al Ain International Airport (AL AIN), Dubai International Airport (DXB), Dubai World Airport, also known as Al Maktoum International Airport (DWC), Sharjah International Airport (SHJ), Ras Al Khaima International Airport (RKT) and Fujairah International Airport (FJR) .

In order to achieve a good air quality level in the UAE, full cooperation between the organizations mentioned above is required. The GCAA is responsible for the ICAO and the IPCC guidelines for the aviation sector and with cooperation of the MOEW which is responsible for air quality monitoring in the UAE, both should set recommendations to the different airports in the UAE to conduct similar studies to this one currently under discussion. Each airport should follow this example and submit an emission inventory report and conduct an air quality monitoring programme ascertain the prevailing conditions around these airports. This should be followed by the setting of emission reduction targets and the establishment of a sustainable aviation council that includes the GCAA, MOEW, the aviation industry and the atmospheric sciences to implement the environmental aviation policy by monitoring and evaluating the future expansion of airports in the UAE. In order to eventually achieve an effective policy for the UAE, it is recommended that a similar approach to the UK white paper aviation policy is adopted.

The GCAA should work in collaboration with UAE airlines and airports to implement the IPCC suggestions to reduce the impact of aviation emissions. This includes: - changes in aircraft and engine technology, fuel, operational practices and regulatory and economic measures.

In order to deal with the large amounts of NOx emissions at ground level from landside vehicles including cars, taxis, coaches, and freight, an approach similar to that of The Voluntary Airport Low Emission (VALE) programme developed in the US by the FAA should be adopted by the GCAA. The voluntary programme should include the conversion of airport vehicles and ground support equipment to low emission technologies, the modification of airport infrastructure for alternative fuels and the provision of terminal gate electricity and air for parked aircraft.

The current legislative framework governing air quality in the UAE is set by MOEW as mentioned in chapter 3.The air quality standards is required to match with WHO guidelines and EU objectives and it should be designed to protect health and the environment.

The MOEW is recommended to sets emissions standards for on-road and non-road engines, similar to the US EPA.

Finally, it is recommended that the GCAA with UAE airports, coordinate their efforts with the Ministry of Energy to calculate the GHG's in order to participate in the Third National Communication to the United Nation Framework Convention on Climate Change because in the first 2 reports the aviation sector was not included.

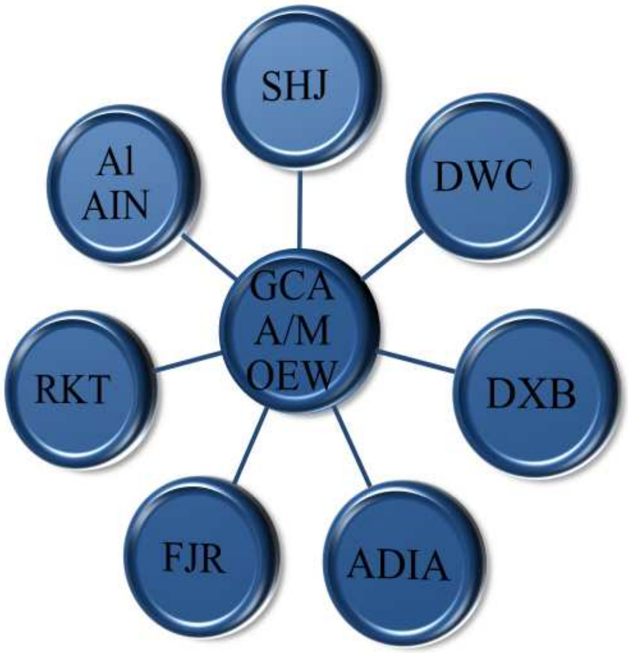


Figure11.2: The relationship between the GCAA and the MOEW and the different UAE airports in implementing the aviation air quality policy

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Appendix 1

Establishing an Airport Emission Inventory

Using Emission Dispersion Modelling System Model

Establishing an Airport Emission Inventory

Using EDMS Model

A. Create a new study for ADIA airport by selecting the parameters (airport ID, mixing height, altitude, year, and average yearly temperature) that are specific to the airport which contribute to the computation of the vehicle, parking lot, and roadway emissions and dispersion analysis. In addition, metric unit measurements have been chosen. At the same time, the airport coordinates were provided in the domain window.

B. Provide EDMS by using aircraft profiles to compute the emissions inventory, the aircraft types have been selected to be used in the study that are collected from ADIA Air Traffic Control (ATC) Division as one day data that have been multiplied by 365 days and aircraft engine types which have been chosen from ICAO 2007 manuals, see Figures 2 that show an APU data besides, aircraft type, engine, APU, times in mode, GSE, and engine emissions.

C. The yearly LTO cycles for each aircraft have been filled according to the assumption of one day as identical days through the whole year. Off course, this assumption was not preferable due to the lack of data from the provider.

D. Fill the aircraft average annual taxi time.

E. Maintain adding each aircraft/engine type, LTO cycle, taxi time to the model.

F. The EDMS model assigns default values for Takeoff Time (typically 0.3 minutes), Climb out Time (typically 5 minutes), and Approach Time (typically 6 minutes).

G. The data of parking lots, roadways, stationary sources, and training fires are collected from ADIA Operation Division to complete the dialog boxes that associated with each of these subcategories.

H. Run the EDMS emission inventory program to obtain the results.

A-1 EDMS Operational Setting up Steps

A1-1Operational Steps of setting up the Scenario:

1. Select the directory where the study will be located.

2. Type “2010” in the file name box.

3. Press “Open”.

4. Select “Abu Dhabi Int'l” in the Airport ID drop down list box.

5. Highlight the default Mixing Height value as 3,000 ft.

6. Enter 90 in the Avg. Yearly Temp. box.

7. Choose Emissions & Dispersion that will produce an emissions and dispersion inventory.

8. Select “LTO Based” from the GSE Modeling Basis, and select MOBILE6.2 for the version of MOBILE.

9. Select the “Units of Measure” tab and choose metric units.

10. Return to the General tab. In the Study Info box, enter trail for the study.

11. Press “OK”. This saves the changes entered and closes the setup window.

12. Answer “Yes” to the warning about changing the mixing height that will change the time in mode for aircraft.

13. Answer “Yes” to the warning about changing the average yearly temperature which affects the motor vehicle emission factors

Figure A-1 Study set up window

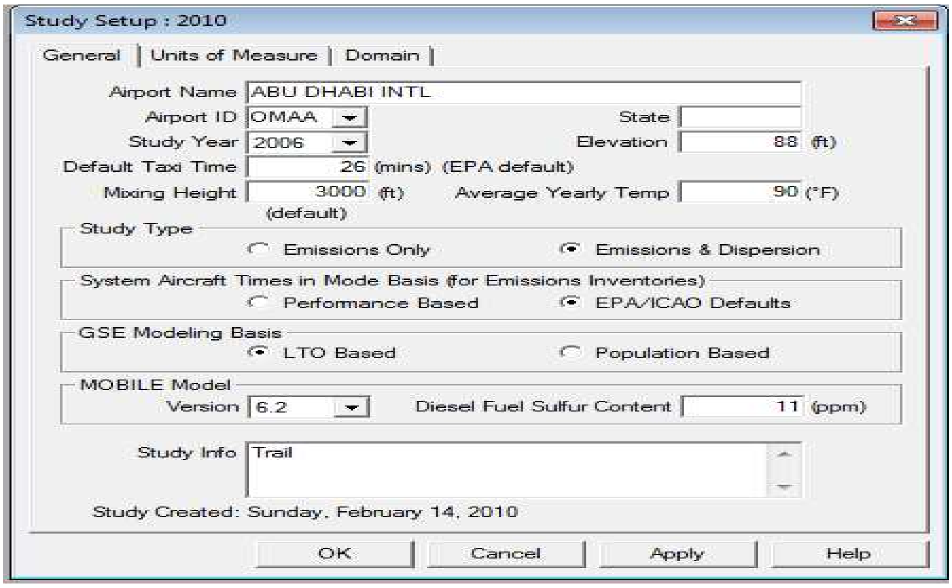
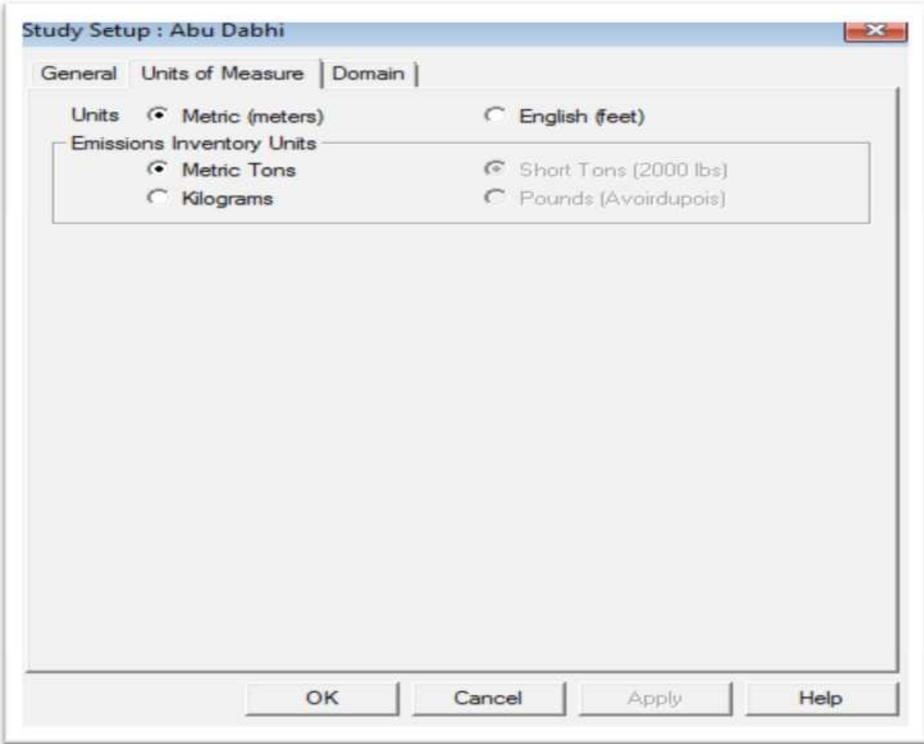


Figure A-2 Choice of emission output unite



A1-2 Operational Steps of Adding Gates:

Table presents ADIA Gates and the following steps are required for data input

1. Select Gates from the Airport menu that brings up a window which allows to specify information about the gates to be added to the study.

2. Press “Add New” and create a gate called “Main”. Change the number of points in order to create gates for this study.

3. Set the coordinates for the Main.

4. Press “Apply”. This saves the information for gate that just created.

6. Press” OK”.

Figure A-3 Gate assignment window

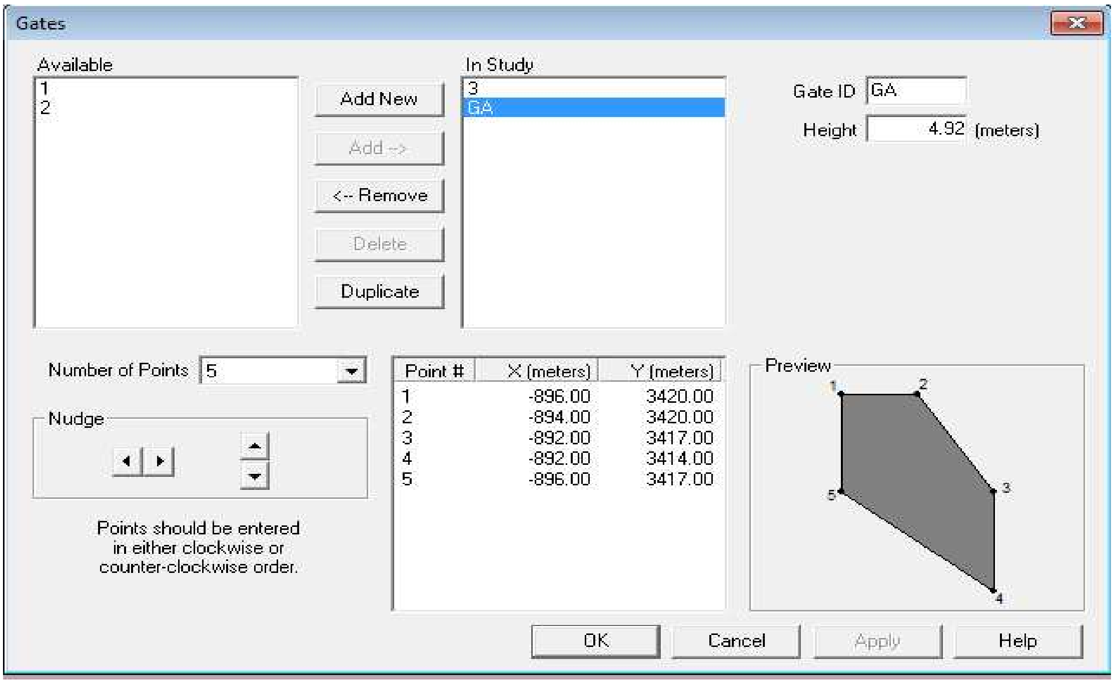


Table A-1 ADIA gates coordinates

Gates	X	Y
1	$24^0$25'37.79"N	$54^0$38'51.01"E
2	$24^0$25'41.80"N	$54^0$38'52.46"E
3	$24^0$25'44.01"N	$54^0$38'52.03"E
4	$24^0$25'44.86"N	$54^0$38'47.71"E
5	$24^0$25'43.52"N	$54^0$38'46.32"E

A1-3 Operational Steps of Aircraft Taxiways:

1. Select Taxiways from the Airport menu. This brings up the Aircraft Taxiways window that specifies the location of the taxiways which will be considered in our study.

2. Press "Add New" and create a new taxiway.

3. Set the average speed of aircraft on taxiway which 20.

4. Set the coordinates of the taxiway.

This specifies the location of the taxiway.

5. Press "Apply".

6. Repeat steps 2-4 for each of the five taxiways.

7. Press "OK"

Figure A-4 Taxiway assignment window

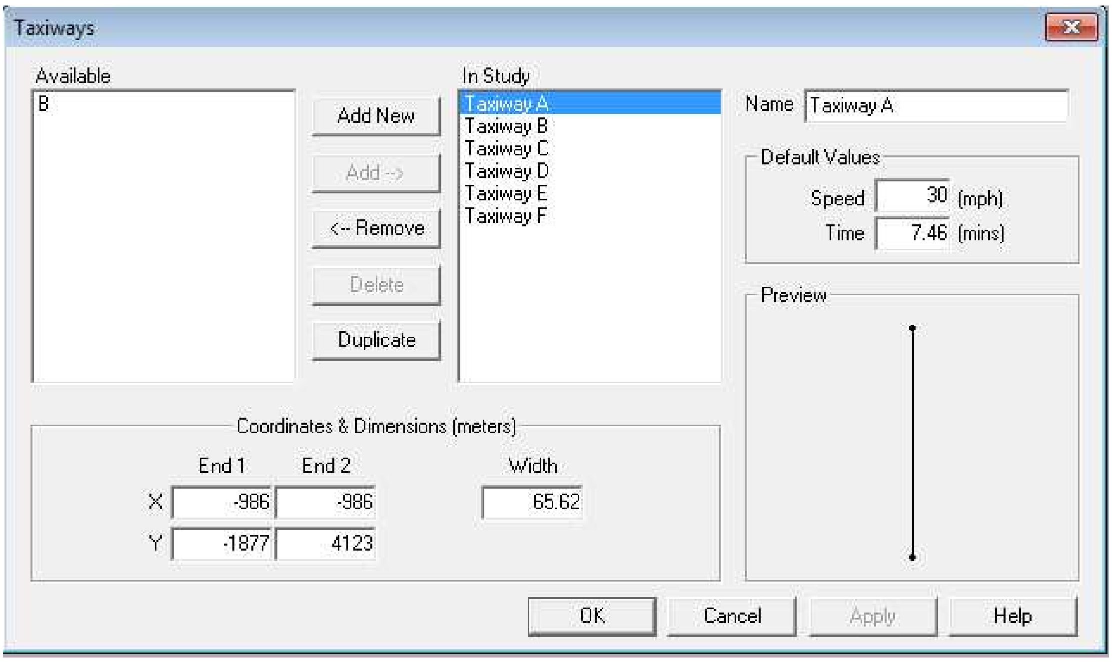


Table A-2ADIA taxiway coordinates

Taxi way	X1 -Coordinate	Y1-coordinate	X2 -Coordinate	Y2-coordinate
13-B	24^{0}26'35.72"N	54^{0}38'09.48"E	24^{0}26'35.72"N	54^{0}38'06.18"E
B-16	24^{0}26'35.72"N	54^{0}38'06.18"E	24^{0}26'17.45"N	54^{0}38'23.87"E
16-15	24^{0}26'17.45"N	54^{0}38'23.87"E	24^{0}26'05.45"N	54^{0}38'40.70"E
15-14	24^{0}26'05.45"N	54^{0}38'40.70"E	24^{0}25'58.17"N	54^{0}38'50.38"E
14-12	24^{0}25'58.17"N	54^{0}38'50.38"E	24^{0}25'52.40N	54^{0}38'48.24"E
12-Apron 1	24^{0}25'52.40"N	54^{0}38'48.24"E	24^{0}25'45.17"N	54^{0}38'42.20"E
12- Apron 2	24^{0}25'52.40"N	54^{0}38'48.24"E	24^{0}25'46.79"N	54^{0}38'43.46"E
12- Apron 3	24^{0}25'52.40"N	54^{0}38'48.24"E	24^{0}25'47.29"N	54^{0}38'46.73"E
31-1	24^{0}25'14.24"N	54^{0}39'58.47"E	24^{0}2514.60"N	54^{0}39'52.25"E
1-5	24^{0}2514.60"N	54^{0}39'52.25"E	24^{0}25'10.72"N	54^{0}39'45.77"E
5-FBO	24^{0}25'10.72"N	54^{0}39'45.77"E	24^{0}24'59.52"N	54^{0}39'35.63"E
1-2	24^{0}25'14.60"N	54^{0}39'52.25"E	24^{0}25'25.74"N	54^{0}39'36.60"E
2-3	24^{0}25'25.74"N	54^{0}39'36.60"E	24^{0}25'22.97"N	54^{0}39'30.90"E
3-4 Cargo Apron	24^{0}25'22.97"N	54^{0}39'30.90"E	24^{0}25'20.21"N	54^{0}39'30.90"E
2-6	24^{0}25'25.74"N	54^{0}39'36.60"E	24^{0}25'25.74"N	54^{0}39'18.29"E
6-7	24^{0}25'25.74"N	54^{0}39'18.29E	24^{0}25'46.23"N	54^{0}39'05.01"E
7- Apron4	24^{0}25'46.23"N	54^{0}39'05.01E	24^{0}25'41.40"N	54^{0}39'00.06"E

A1-4 Operational Steps of Runways:

Table presents ADIA coordinated for runway 13-31 and the following steps are required for data input.

1. Select Runways from the Airport menu, where the location and length of the runways in our study can be specified.

2. Add two new runways called “13-31”.

3. Set the coordinates for runway 13-31.

4. Set the queue coordinates for runway13-31.

”5. Set the Peak Queue Time for the runway to 4 minutes at peak.

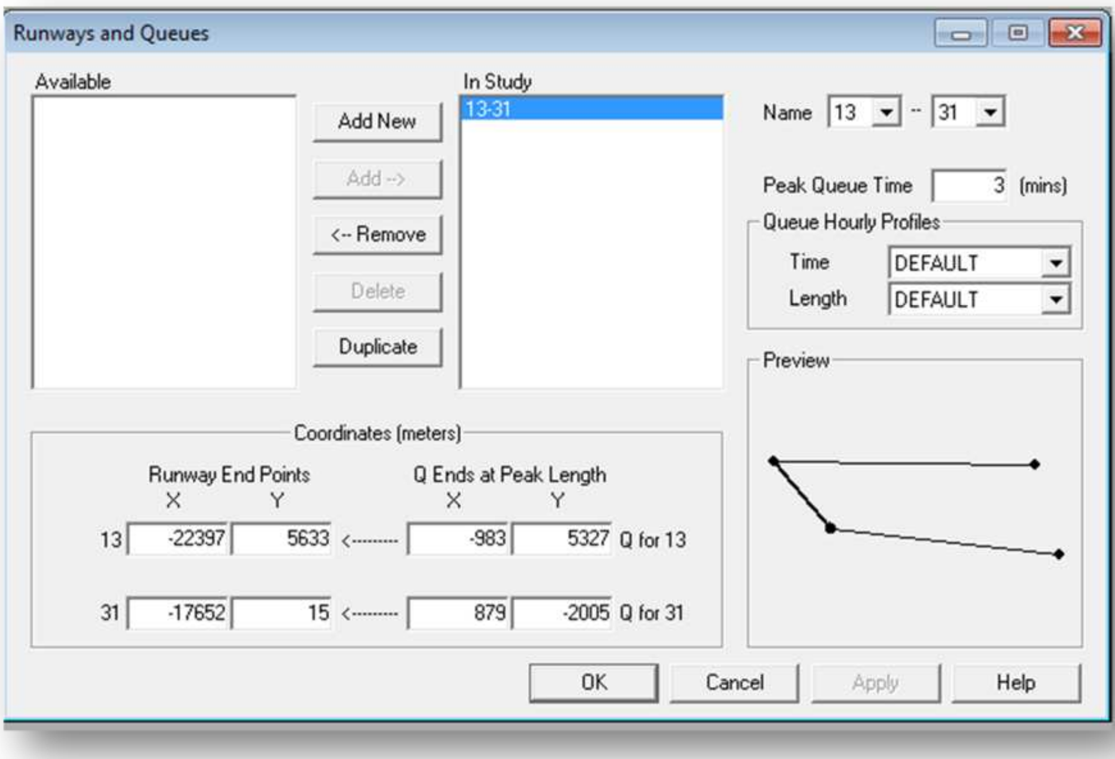
6. Press “Apply”. The values are saved.

7. Press “OK”.

Table A-3 ADIA runway coordinates

Runway	X	Y	X Peak Queue Time	Y Peak Queue Time
13	24^{0}26'39,09"N	54^{0}38'07,98"E	24^{0}26'38.04"N	54^{0}38'07.54"E
31	24^{0}25'17.75"N	54^{0}40'00,08"E	24^{0}25'19.15"N	54^{0}40'00.75"E

Figure A-5 Runway assignment window



A1-5 Operational Steps of Buildings:

1. Select Buildings from the Airport menu. This brings up the Buildings window where the location of the building in our study can be determined.

2. Add new building called “Terminal Building”, etc.

3. Set the coordinates for “Terminal Building”, “General Aviation", and Cargo which specifies the location of the building at the airport.

4. Press “Apply”.

5. Press “OK”.

A Table A-4 ADIA building coordinates

Terminal Building	X	Y
	24^{0}25'37.79"N	54^{0}38'51.01"E
	24^{0}25'41.80N	54^{0}38'52.46"E
	24^{0}25'44.01"N	54^{0}38'52.03"E
	24^{0}25'44.86"N	54^{0}38'47.71"E
	24^{0}25'43.52"N	54^{0}38'46.32"E
General Aviation /FBO	**X**	**Y**
	24^{0}25'12.83"N	54^{0}39'31.05"E
	24^{0}25'11.06"N	54^{0}39'33.35"E
	24^{0}25'08.06"N	54^{0}39'30.66"E
	24^{0}25'09.47"N	54^{0}39'28.74"E
CARGO	**X**	**Y**
	24^{0}25'28.63"N	54^{0}29'06.77"E
	24025'11.12"N	54039'33.35"E
	24025'08.06"N	54039'30.66" E
	24^{0}25'09.47"N	54^{0}39'28.74"E

Operational Steps of Adding Aircraft:

1. Select Aircraft from the Emissions menu which brings up the Aircraft Operations & Assignments window with the Operations tab activated, which allows to specify information about the aircraft and their associated ground support equipment.

2. Provide descriptive identifications for each aircraft.

3. Select the aircraft to be used in the study by clicking on the aircraft name as listed

in the Available list and engine name as listed in the available engines list, then pressing Add. For each aircraft select the APU Assignments, Operation Time, and Gate assignments.

4. Enter the number of yearly operations.

5. Select the hourly, daily, and monthly profiles of each aircraft.

6. Choose the **“**Time In Mode“ tab and for each aircraft, and it is set as ICAO standards .

7. Set the approach angle to the runway is 3°.

8. For each aircraft entered, set total taxi and queue time to 7 minutes that is assuming that all aircraft at the airport spend on average 4 minutes taxiing to the runway, and 3 minutes waiting to takeoff.

9. Choose the “GSE Assignments” tab for ground support equipment which are being

modeled for each aircraft in the study.

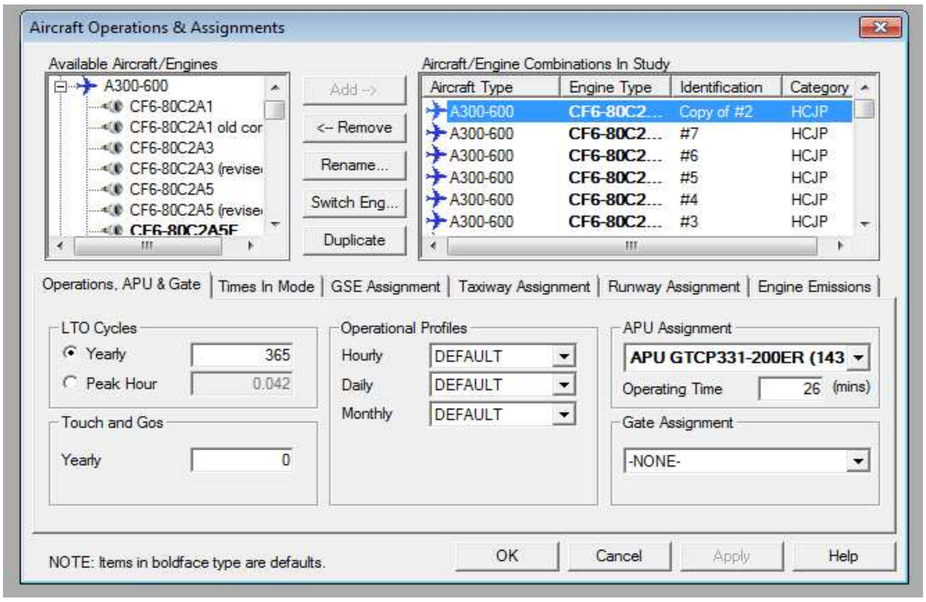
10. Select the “Taxiway Assignment” tab which allows to assign each aircraft to specific

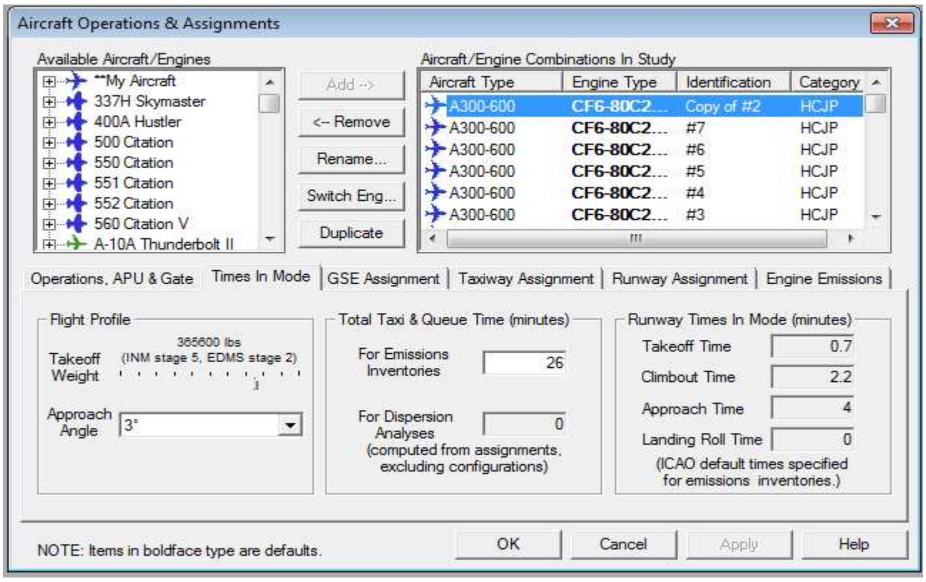
taxiways.

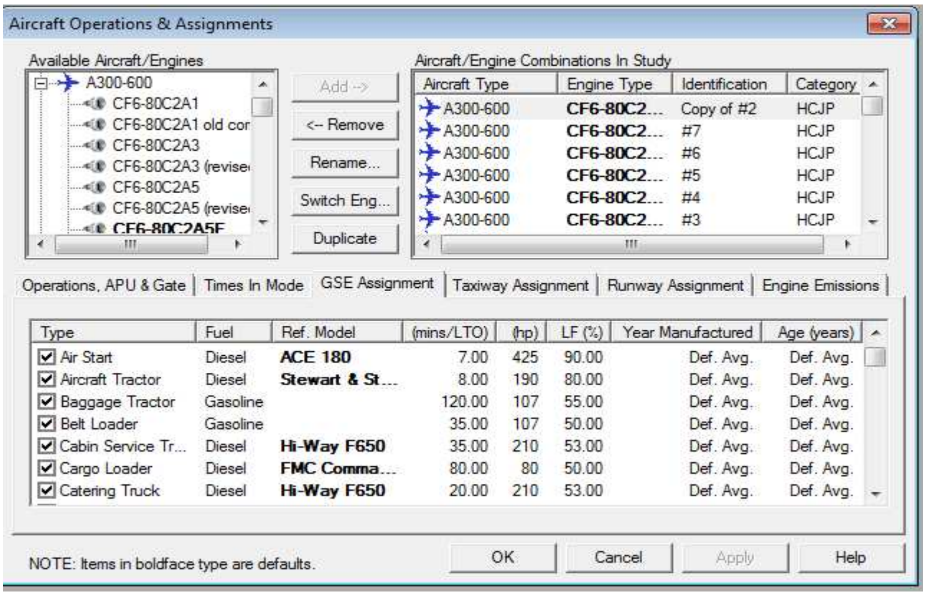
11. Select the corresponding taxiway assignments.

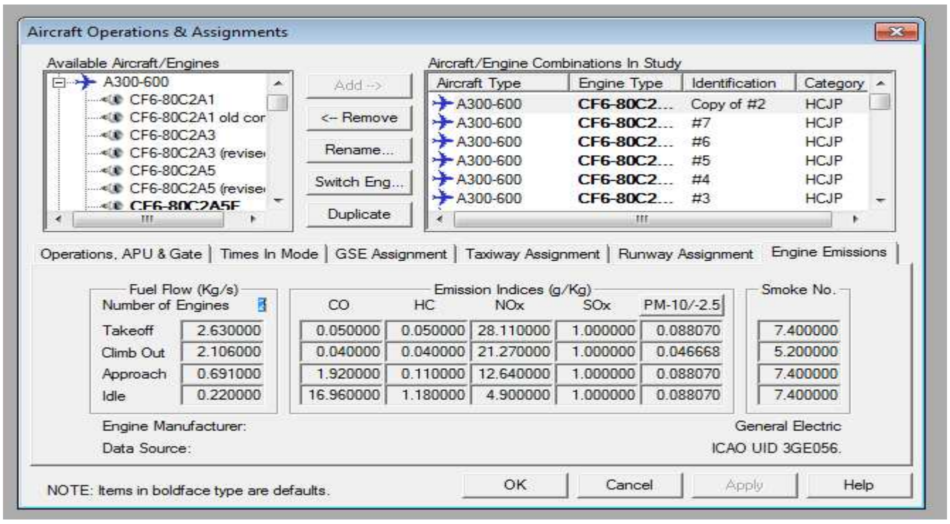
12. Press “Apply” This saves all of the changes made to this window

Figure A-6 Aircraft assignment windows






Aircraft Operations & Assignments
Available Aircraft/Engines
A300-600
CF6-80C2A1
CF6-80C2A1 old cor
CF6-80C2A3
CF6-80C2A3 (revise
CF6-80C2A5
CF6-80C2A5 (revise
CF6-80C2A5F
Add -->
<-- Remove
Rename...
Switch Eng...
Duplicate
Aircraft/Engine Combinations In Study
Aircraft Type | Engine Type | Identification | Category
A300-600 | CF6-80C2... | Copy of #2 | HCJP
A300-600 | CF6-80C2... | #7 | HCJP
A300-600 | CF6-80C2... | #6 | HCJP
A300-600 | CF6-80C2... | #5 | HCJP
A300-600 | CF6-80C2... | #4 | HCJP
A300-600 | CF6-80C2... | #3 | HCJP
Operations, APU & Gate | Times In Mode | GSE Assignment | Taxiway Assignment | Runway Assignment | Engine Emissions
Type | Fuel | Ref. Model | (mins/LTO) | (hp) | LF (%) | Year Manufactured | Age (years)
Air Start | Diesel | ACE 180 | 7.00 | 425 | 90.00 | Def. Avg. | Def. Avg.
Aircraft Tractor | Diesel | Stewart & St... | 8.00 | 190 | 80.00 | Def. Avg. | Def. Avg.
Baggage Tractor | Gasoline | | 120.00 | 107 | 55.00 | Def. Avg. | Def. Avg.
Belt Loader | Gasoline | | 35.00 | 107 | 50.00 | Def. Avg. | Def. Avg.
Cabin Service Tr... | Diesel | Hi-Way F650 | 35.00 | 210 | 53.00 | Def. Avg. | Def. Avg.
Cargo Loader | Diesel | FMC Comma... | 80.00 | 80 | 50.00 | Def. Avg. | Def. Avg.
Catering Truck | Diesel | Hi-Way F650 | 20.00 | 210 | 53.00 | Def. Avg. | Def. Avg.
NOTE: Items in boldface type are defaults.
OK
Cancel
Apply
Help


Aircraft Operations & Assignments
Available Aircraft/Engines
A300-600
CF6-80C2A1
CF6-80C2A1 old cor
CF6-80C2A3
CF6-80C2A3 (revise
CF6-80C2A5
CF6-80C2A5 (revise
CF6-80C2A5F
Add -->
<-- Remove
Rename...
Switch Eng...
Duplicate
Aircraft/Engine Combinations In Study
Aircraft Type | Engine Type | Identification | Category
A300-600 | CF6-80C2... | Copy of #2 | HCJP
A300-600 | CF6-80C2... | #7 | HCJP
A300-600 | CF6-80C2... | #6 | HCJP
A300-600 | CF6-80C2... | #5 | HCJP
A300-600 | CF6-80C2... | #4 | HCJP
A300-600 | CF6-80C2... | #3 | HCJP
Operations, APU & Gate | Times In Mode | GSE Assignment | Taxiway Assignment | Runway Assignment | Engine Emissions
Fuel Flow (Kg/s)
Number of Engines 2
Emission Indices (g/Kg)
CO | HC | NOx | SOx | PM-10/-2.5
Smoke No.
Takeoff 2.630000 | 0.050000 | 0.050000 | 28.110000 | 1.000000 | 0.088070 | 7.400000
Climb Out 2.106000 | 0.040000 | 0.040000 | 21.270000 | 1.000000 | 0.046668 | 5.200000
Approach 0.691000 | 1.920000 | 0.110000 | 12.640000 | 1.000000 | 0.088070 | 7.400000
Idle 0.220000 | 16.960000 | 1.180000 | 4.900000 | 1.000000 | 0.088070 | 7.400000
Engine Manufacturer: General Electric
Data Source: ICAO UID 3GE056.
NOTE: Items in boldface type are defaults.
OK
Cancel
Apply
Help

A1-6Operational Steps of Parking Facilities:

1. Select Parking Facilities from the Emissions menu.

2. Press "Add New" and create a new

parking facility called "Parking Garage".

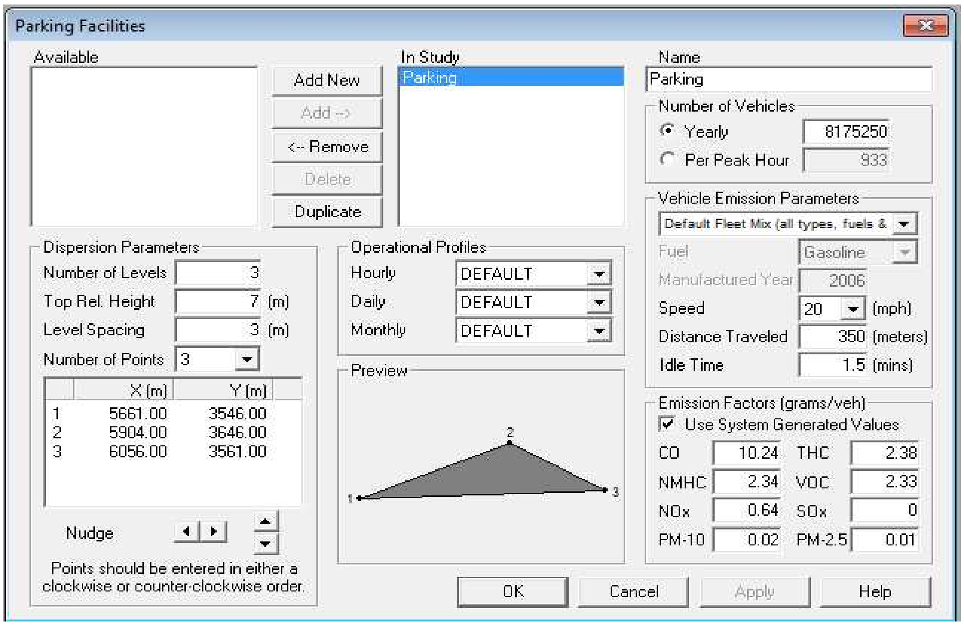
3. Set the Yearly number of vehicles to 825000.

4. Set the Speed in Lot to 20 Kph which affects the emissions factors.

5. Press "OK".

Table A-7 Parking facilities assignment window

Car Park	**X**	**Y**
	$24^0$25'27.64"N	$54^0$38'43.35"E
	$24^0$25'34.64"N	$54^0$38'38.11"E
	$24^0$25'35.52"N	$54^0$38'44.46"E



A1-7 Operational Steps of Roadways: Not applicable due to the lack of roadways data.

A1-8 Operational Steps of Stationary Sources:

1. Select Stationary Sources from the Emissions menu that emissions information about stationary sources can be added.

2. Add a new source called "Airport Backup Power" of category Emergency Generator.

3. Select Type: Gasoline Fuel

4. Under "Dispersion Parameters" select "Point" and enter the coordinates of the power unit.

5. Set the Base Elevation and the Diameter to Supply emissions and dispersion parameters for the generator.

6. Finally, enter the Yearly hours operated as 96 hours, Press "Apply".

7. Press "OK".

A1-9 Operational Steps of Training Fires:

1. Select Training Fires from the Emissions menu.

2. Add a new training fire called “TF 1”, with a Fuel Type of Propane, and Yearly gallons of fuel used 12000. Then, Press “Apply”.

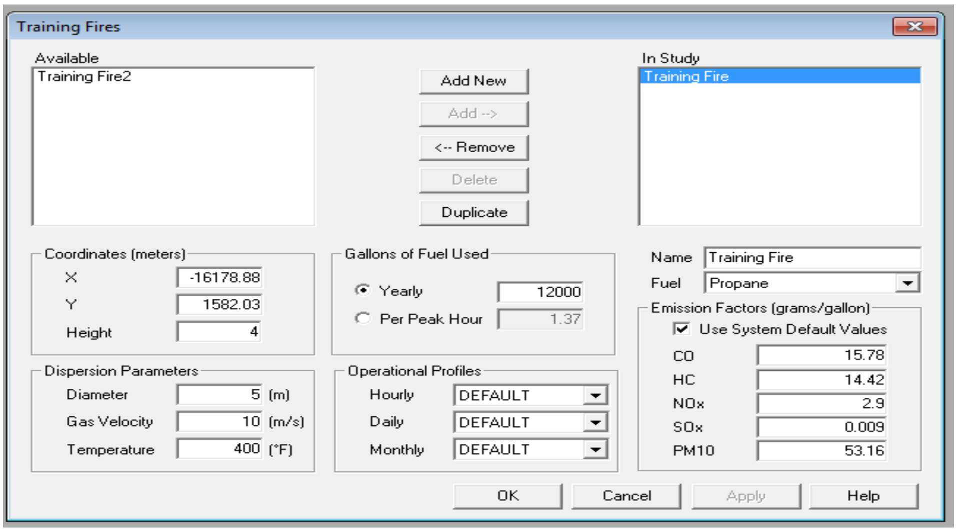
3. Enter the training fire coordinates and a Height .

4. Press “OK”.

Table A-6 ADIA stationary sources coordinates

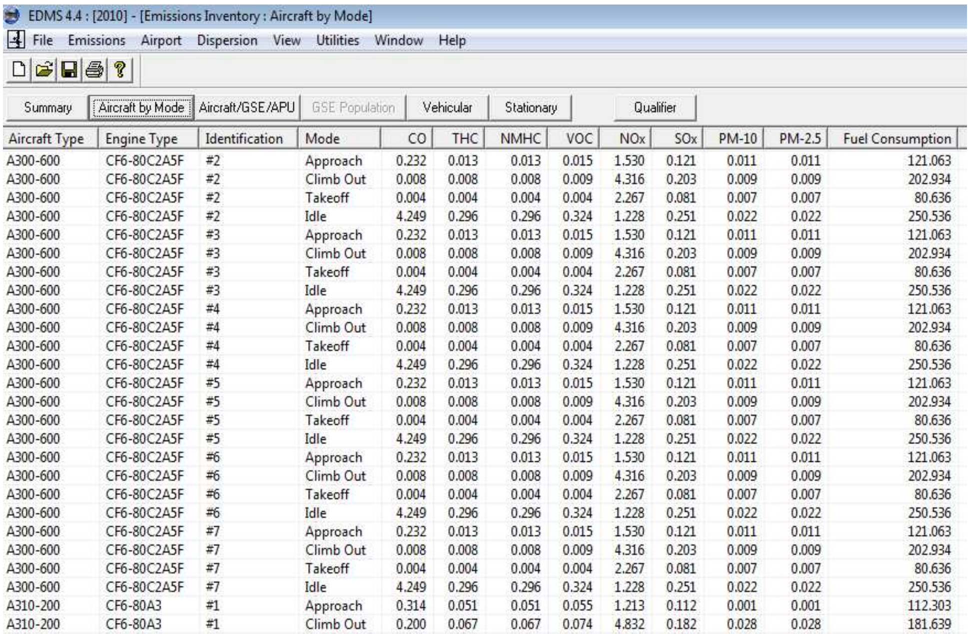
Stationary sources	X	Y
North Training Fire	24^{0}26'08.76"N	54^{0}38'31.96"
Emergency Power Generation	25^{0}25'14.48"N	54^{0}38'57.06"

Figure A-8 Training fire assignment window



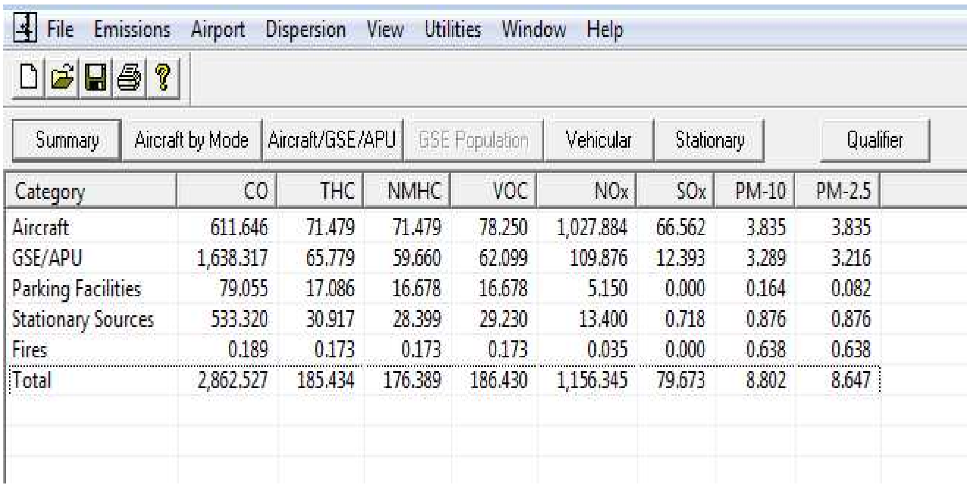
A1-10Results of Run Emission Inventory

Figure A-9 emission result by aircraft mode window



Aircraft Type	Engine Type	Identification	Mode	CO	THC	NMHC	VOC	NOx	SOx	PM-10	PM-2.5	Fuel Consumption
A300-600	CF6-80C2A5F	#2	Approach	0.232	0.013	0.013	0.015	1.530	0.121	0.011	0.011	121.063
A300-600	CF6-80C2A5F	#2	Climb Out	0.008	0.008	0.008	0.009	4.316	0.203	0.009	0.009	202.934
A300-600	CF6-80C2A5F	#2	Takeoff	0.004	0.004	0.004	0.004	2.267	0.081	0.007	0.007	80.636
A300-600	CF6-80C2A5F	#2	Idle	4.249	0.296	0.296	0.324	1.228	0.251	0.022	0.022	250.536
A300-600	CF6-80C2A5F	#3	Approach	0.232	0.013	0.013	0.015	1.530	0.121	0.011	0.011	121.063
A300-600	CF6-80C2A5F	#3	Climb Out	0.008	0.008	0.008	0.009	4.316	0.203	0.009	0.009	202.934
A300-600	CF6-80C2A5F	#3	Takeoff	0.004	0.004	0.004	0.004	2.267	0.081	0.007	0.007	80.636
A300-600	CF6-80C2A5F	#3	Idle	4.249	0.296	0.296	0.324	1.228	0.251	0.022	0.022	250.536
A300-600	CF6-80C2A5F	#4	Approach	0.232	0.013	0.013	0.015	1.530	0.121	0.011	0.011	121.063
A300-600	CF6-80C2A5F	#4	Climb Out	0.008	0.008	0.008	0.009	4.316	0.203	0.009	0.009	202.934
A300-600	CF6-80C2A5F	#4	Takeoff	0.004	0.004	0.004	0.004	2.267	0.081	0.007	0.007	80.636
A300-600	CF6-80C2A5F	#4	Idle	4.249	0.296	0.296	0.324	1.228	0.251	0.022	0.022	250.536
A300-600	CF6-80C2A5F	#5	Approach	0.232	0.013	0.013	0.015	1.530	0.121	0.011	0.011	121.063
A300-600	CF6-80C2A5F	#5	Climb Out	0.008	0.008	0.008	0.009	4.316	0.203	0.009	0.009	202.934
A300-600	CF6-80C2A5F	#5	Takeoff	0.004	0.004	0.004	0.004	2.267	0.081	0.007	0.007	80.636
A300-600	CF6-80C2A5F	#5	Idle	4.249	0.296	0.296	0.324	1.228	0.251	0.022	0.022	250.536
A300-600	CF6-80C2A5F	#6	Approach	0.232	0.013	0.013	0.015	1.530	0.121	0.011	0.011	121.063
A300-600	CF6-80C2A5F	#6	Climb Out	0.008	0.008	0.008	0.009	4.316	0.203	0.009	0.009	202.934
A300-600	CF6-80C2A5F	#6	Takeoff	0.004	0.004	0.004	0.004	2.267	0.081	0.007	0.007	80.636
A300-600	CF6-80C2A5F	#6	Idle	4.249	0.296	0.296	0.324	1.228	0.251	0.022	0.022	250.536
A300-600	CF6-80C2A5F	#7	Approach	0.232	0.013	0.013	0.015	1.530	0.121	0.011	0.011	121.063
A300-600	CF6-80C2A5F	#7	Climb Out	0.008	0.008	0.008	0.009	4.316	0.203	0.009	0.009	202.934
A300-600	CF6-80C2A5F	#7	Takeoff	0.004	0.004	0.004	0.004	2.267	0.081	0.007	0.007	80.636
A300-600	CF6-80C2A5F	#7	Idle	4.249	0.296	0.296	0.324	1.228	0.251	0.022	0.022	250.536
A310-200	CF6-80A3	#1	Approach	0.314	0.051	0.051	0.055	1.213	0.112	0.001	0.001	112.303
A310-200	CF6-80A3	#1	Climb Out	0.200	0.067	0.067	0.074	4.832	0.182	0.028	0.028	181.639

Figure A-10 emission result summary



Category	CO	THC	NMHC	VOC	NOx	SOx	PM-10	PM-2.5
Aircraft	611.646	71.479	71.479	78.250	1,027.884	66.562	3.835	3.835
GSE/APU	1,638.317	65.779	59.660	62.099	109.876	12.393	3.289	3.216
Parking Facilities	79.055	17.086	16.678	16.678	5.150	0.000	0.164	0.082
Stationary Sources	533.320	30.917	28.399	29.230	13.400	0.718	0.876	0.876
Fires	0.189	0.173	0.173	0.173	0.035	0.000	0.638	0.638
Total	2,862.527	185.434	176.389	186.430	1,156.345	79.673	8.802	8.647

A-2 Dispersion Calculation

For dispersion calculation receptors location are needed, table A-7 presents receptors ID and location

Table A-7 ADIA receptors coordinate

Receptors	Diffusion tube number	POINT_X	POINT_Y
AUH 1	IMX07	24^{O}27'04.88"N	54^{O}37'53.67"E
AUH 2	IMX06	24^{O}26'24.27"N	54^{O}40'22.90"E
AUH 3	IMX04	24^{O}25'13.38"N	54^{O}39'34.24"E
AUH 4	IMX26	24^{O}26'44.06"N	54^{O}37'00.76"E
AUH 5	IMX22	24^{O}25'38.00"N	54^{O}37'46.02"E

A2-1 Meteorology

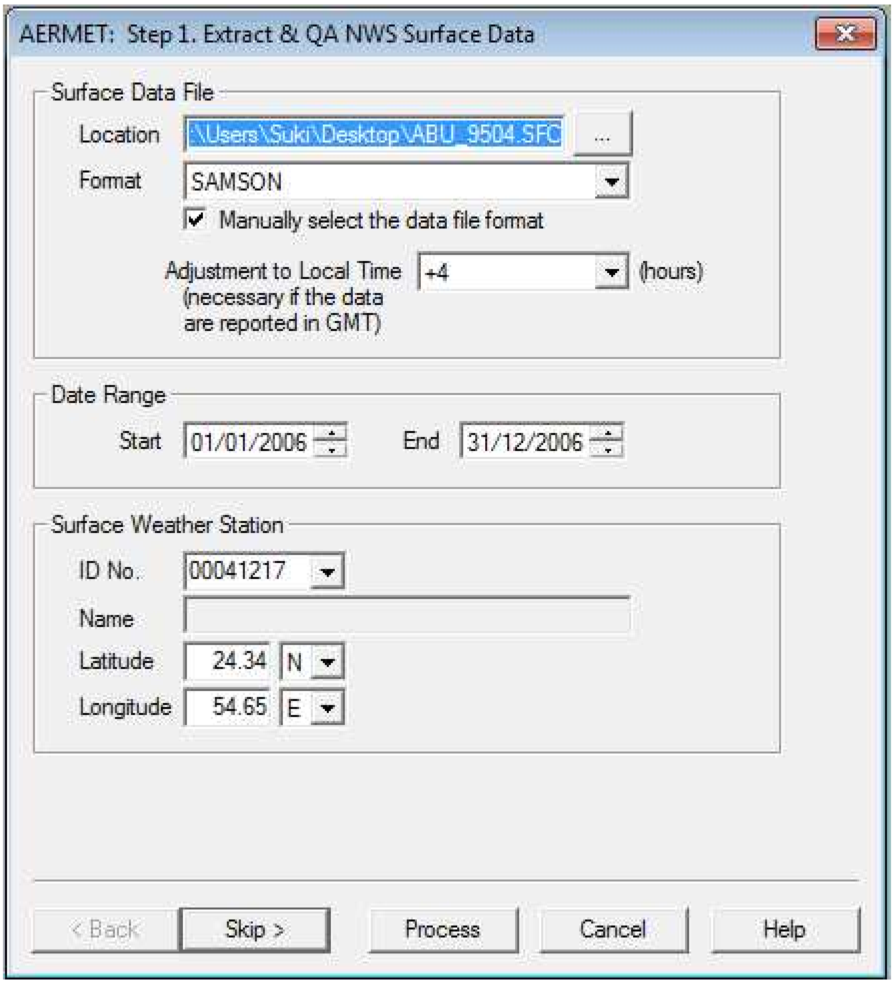
AERMOD requires both surface and upper-air weather data for dispersion. This section describes how to load and merge this data for a dispersion run.

A2-1-1The AERMET Wizard

The AERMET wizard provides a step-by-step interface that takes surface and upper-air data and merges it for AERMOD use.

AERMET Wizard Step 1. Surface Weather Data fig (A-11)

Figure A-11 weather set up window-Step1



The first step in the AERMET Wizard is to extract the surface weather data that will be used in the study.

1. Select AERMET Wizard from the Dispersion menu. This brings up the AERMET Wizard.

2. Press the button marked "…" (located after the Location input box) to select the surface weather file .This selects the surface weather file that we will use for this study. Note: This is a fictitious set of weather data. It should not be used for regulatory analyses.

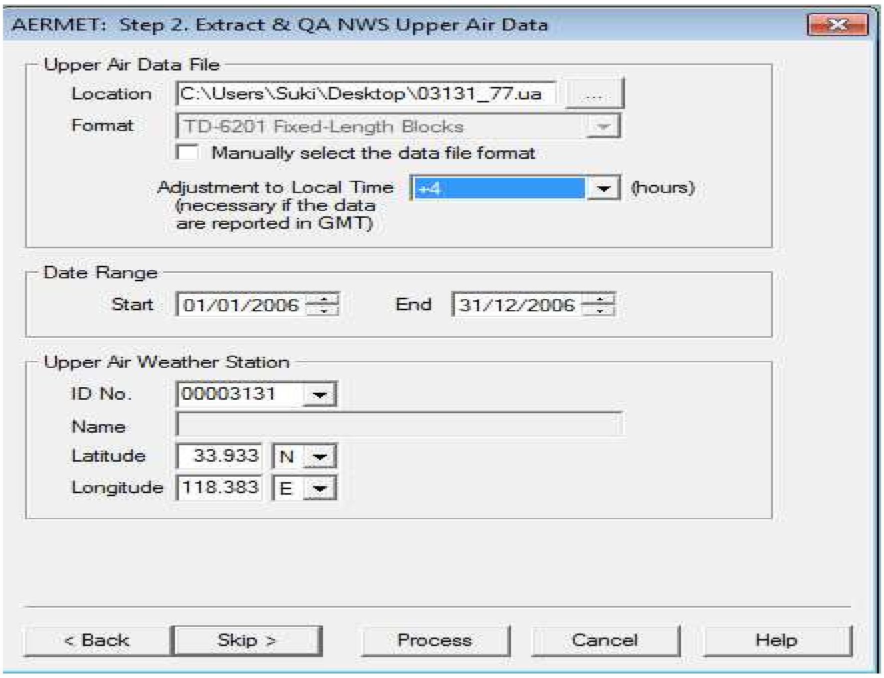
3. Set the start and end dates to 01/1/2006 to 31/12/06.

4. press process , then the AERMET wizard will extract the surface weather data and the upper-air data screen will appear.

A2-1-2 AERMET Wizard Step 2. Upper Air Data.

The next step will be to extract the upper-air soundings that will be merged with the surface weather data. In order to do that the following steps should be followed:-

Figure A-12 weather set up window-Step2



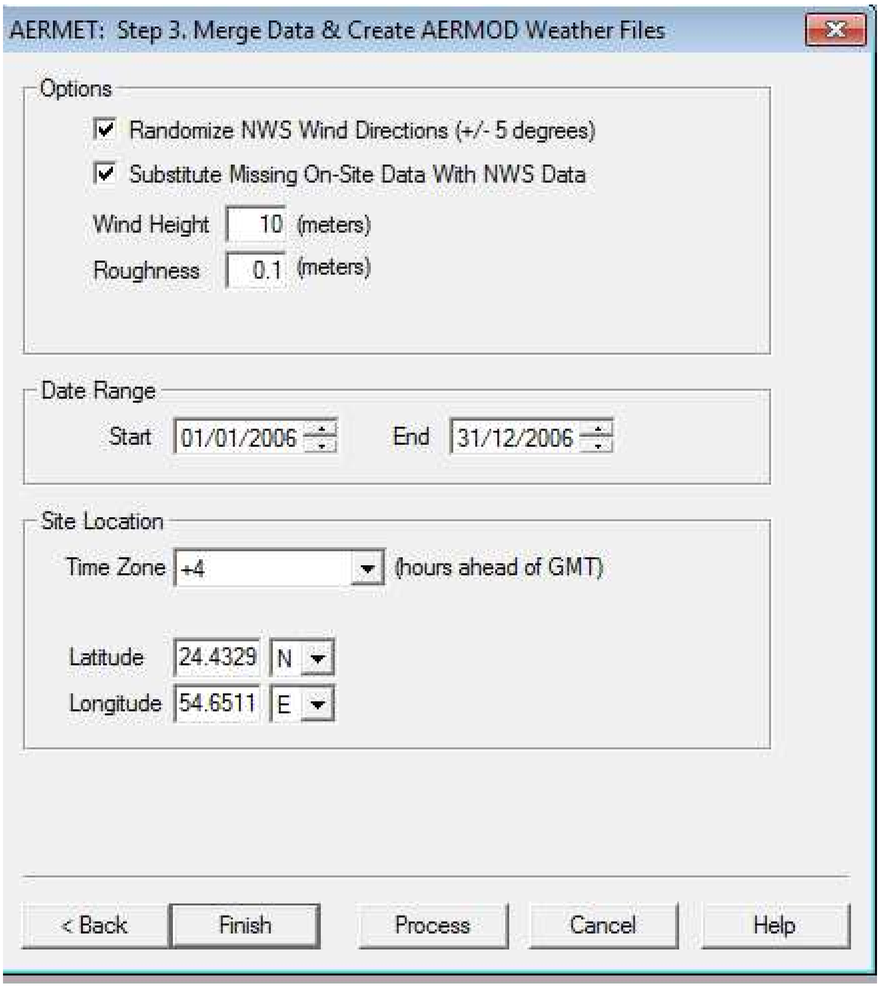
1. Press the button marked "…" to select the upper-air weather file

2. Set the start and end dates to 1/1/2006.

3. Enter 54.24 N for the latitude and 24.52.E for the longitude. Provide the location of the weather station.

4. Press "Process". The AERMET wizard will extract the upper-air weather data and the merge screen will appear.

Figure A-13 weather set up window-Step3



A2-1-3 AERMET Wizard Step 3. Merge data.

Next, the tow files (surface weather and Upper air) need to merge data and create AERMOD weather files by taking the merged surface and upper-air weather data and converting it into surface (.sfc) and profile (.pfl) weather files that AERMOD can read.

1.Set the start and end dates

2. Press “Finish”. The AERMET wizard will merge the data and convert the weather data into surface and profile files for use with AERMOD.

A2-2 Generating AERMOD Input Files

The next step is to generate the input files that will be used by AERMOD to calculate the concentrations. See Figure

1. From the Dispersion menu, choose the Generate AERMOD Input Files option.

This brings up the generate AERMOD input files window.

2. Set the Title to “NO_X 2006”.

3. Set the pollutant to NO_X and the averaging period set to 1 hour.

4. Press “Next”. Advance to Step 2 of AERMOD processing.

5. Select “Use AERMAP Generated Files” and select the two AERMAP files created in the

previous step and press “Next". The AERMOD run will include AERMAP terrain

data and we are ready to move to Step 3 of AERMOD processing.

6. Press the “…” button next to the Surface file line and choose the “.sfc” file that has been created with the AERMET wizard.

7. Again in the Meteorology section, press the “…” button next to the Profile File line and choose the “.pfl” file.

8. Press “Next” Advance to Step 4 of AERMOD processing.

9. Press “Generate”. The AERMOD input files will be generated and the window will be closed.

Figure A-14 AERMOD input file step 1

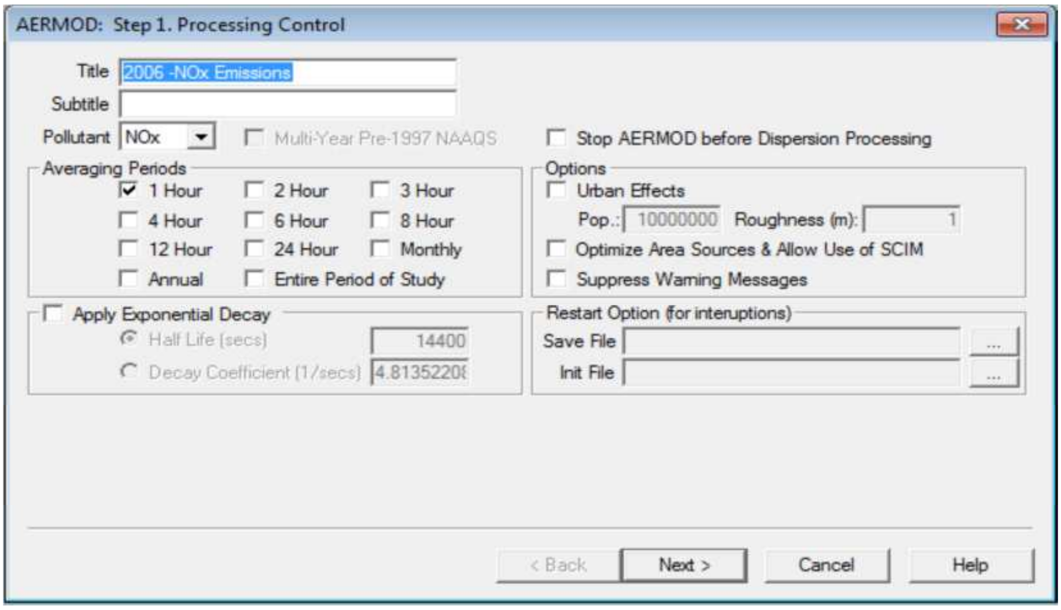


Figure A-15 AERMOD input file step 2

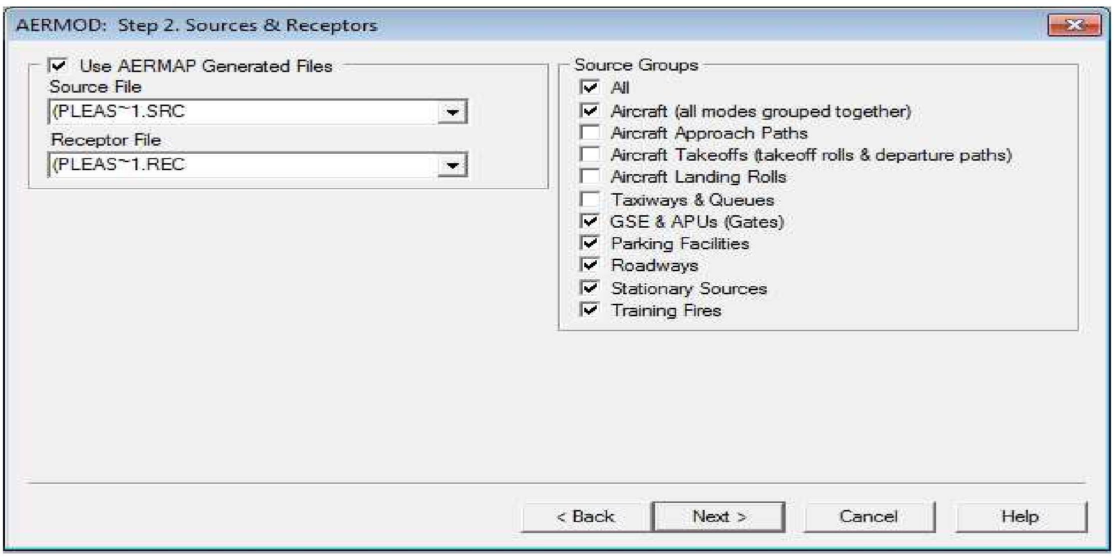


Figure A-16 AERMOD input file step 3

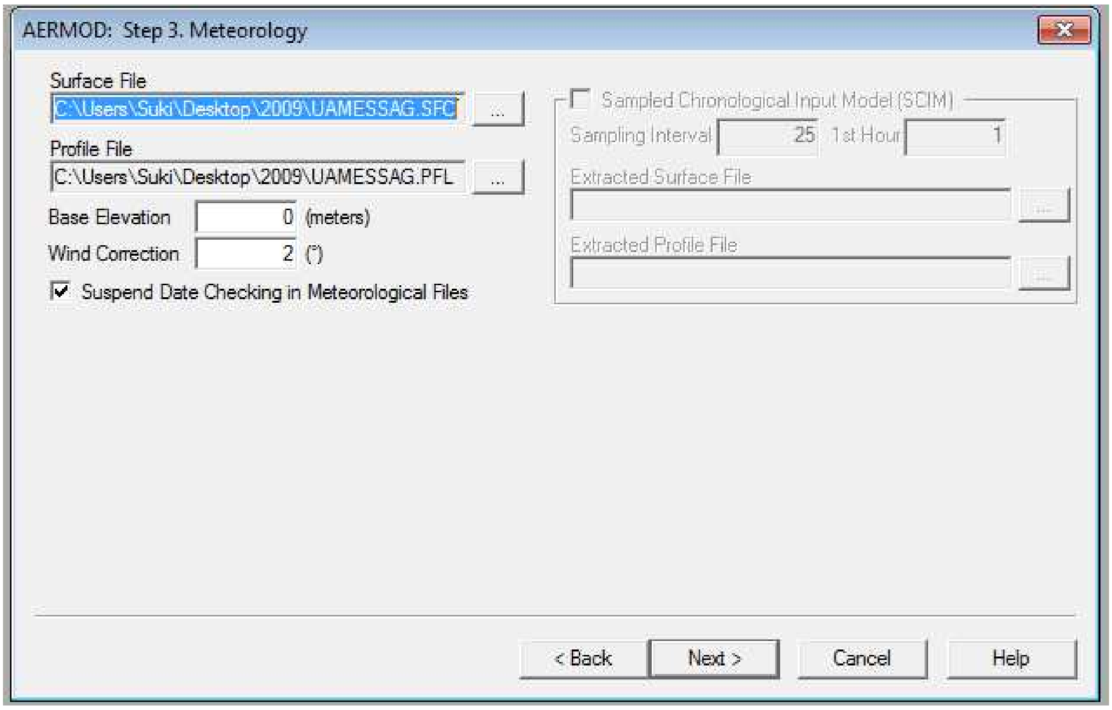


Figure A-17 AERMOD output reporting step 4

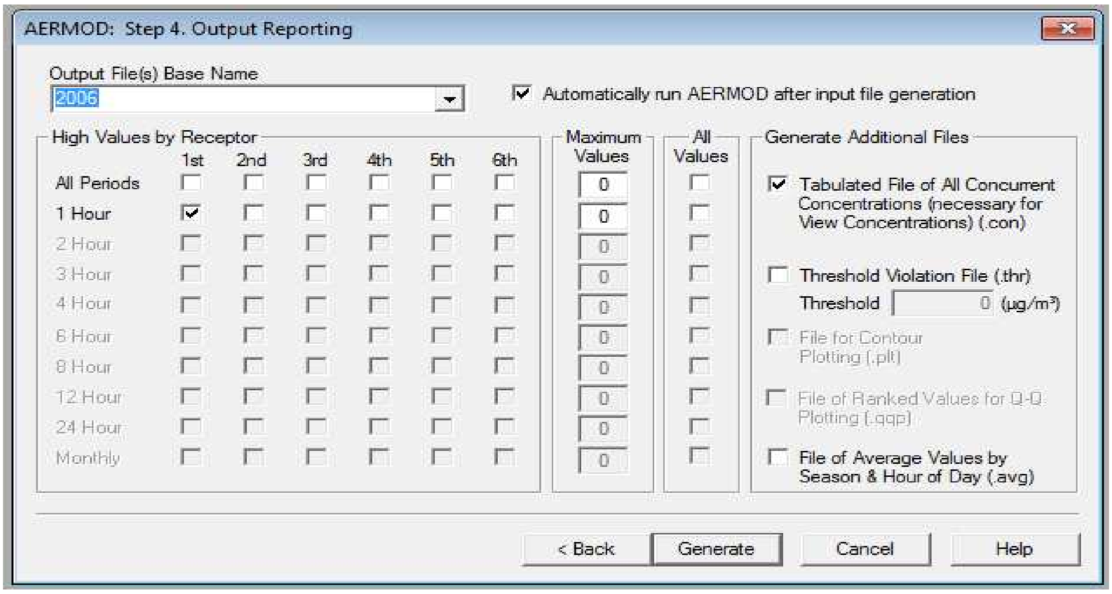
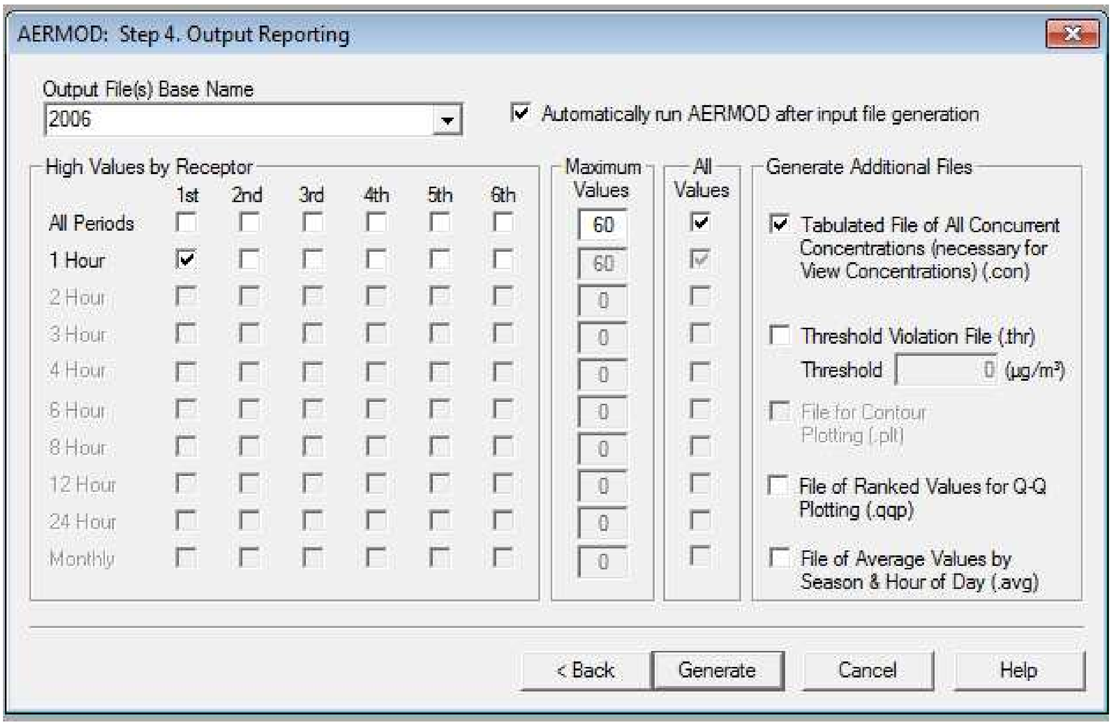
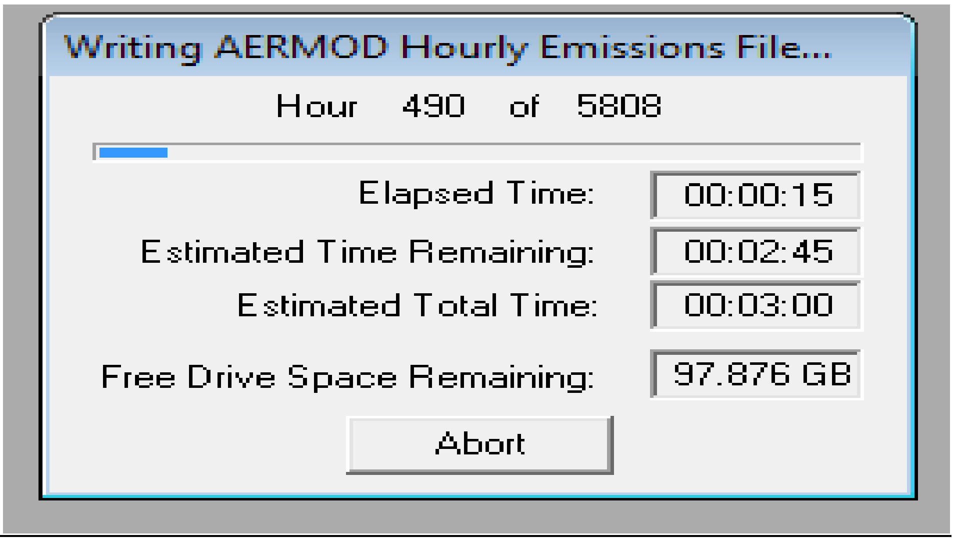


Figure A-18 AERMOD output reporting step 4





Appendix 2

NO_2 Measurements

A2-1 Diffusion Tubes Campaign

Figures 1 to 8 present the diffusion tubes campaigns (winter &Summer), it started by preparing the wooden posts which needed to be placed in the ground and then the diffusion tubes fixes at the top.

Figure 1 Diffusion tube placed on wooden post winter campaign

Figure 2 Diffusion tube placed on wooden post next to the runway, winter campaign

Figure 3 Diffusion tube wooden post being placed at the ground.

Figure 4 Diffusion tube wooden posts being placed by digging the post on the ground

Figure 5 Diffusion tube placed next to the monitoring station

Figure 6 Diffusion tubes being placed in the wooden post

Site	ppb	POINT_X	POINT_Y
IMX20	14	261019.74139700000	2704427.20414000000
IMX18	13	261513.33124699900	2704602.60699999000
IMX13	12	261783.07626300000	2704099.35136999000
IMX15	15	262225.94121700000	2703741.03335999000
IMX19	12	262576.20713400000	2702772.39999999000
IMX12	14	263236.96322400000	2702934.12344000000
IMX10	22	260866.81296499900	2703981.42322000000
IMX09	10	259054.95696099900	2705801.20552999000
IMX08	19	259159.07425599900	2705571.68041000000
IMX14	12	259987.62179899900	2705685.54729000000
IMX07	10	260928.10767500000	2705842.39870999000
IMX11	11	260671.01042100000	2704478.59142000000
IMX06	11	263868.25845600000	2703847.30114000000
IMX05	16	263964.69652900000	2702527.09717000000
IMX04	14	262531.42722800000	2702450.61180000000
IMX03	19	261886.28977000000	2702852.99134999000
IMX01	12	261307.66132900000	2703288.62539999000
IMX28	13	261118.11063200000	2703474.85064999000
IMX02	13	261167.30478000000	2701063.16218000000
IMX29	1	261006.29138600000	2709014.63901000000
IMX27	4	260213.71398599900	2707781.36125000000
IMX26	6	257859.89575800000	2705345.55225000000
IMX25	17	257149.30912399900	2704641.79817999000
IMX24	11	257398.69770200000	2703897.04872999000
IMX23	16	258283.51471300000	2703698.90438000000
IMX30	8	261985.92064500000	2707415.93807000000
IMX31	15	264412.57797799900	2704734.12289999000
IMX21	10	263391.94663500000	2706653.12246000000
IMX22	13	259161.49916100000	2703005.39915000000
IMX17	21	262411.18370400000	2703306.83375999000

Table 1 Value of NO_2 concentration determined at different sites and their coordinates for diffusion tube samples.

Table 2: Diffusion tube number, location and NO_2 concentration for June/ July measurement

Site No.	Location	Tubes	Blank Value (ppb)	Concentration	Average Value (ppb)
1	Runway/centre taxiway/Papa – November	IMB 6, 7, 8, 9 is blank	4	10,9,12,4	**3**
2	Runway parallel to the south fire station	IMB 13,14.15, 12 is blank	2	5,9,10,2	**3**
3	Eco aircraft stand	IMB 16,17,18,19 is blank	4	6,9,1,4	**2**
4	End of the Runway/ Amiri Flights side	IMB 1,2,3,4 is blank	4	7,9,6,4	**2**
5	End of the Runway/ Abu Dhabi Aviations side	IMB 21,22,23,24 is blank	2	6,5,5,2	**3**
6	Baseline/ the new developed area	IMB 20,10,5,11 is blank	3	5,6,5,3	**2**
7	Baseline/ the new developed area	IMX37 ,36,35,33 is blank	3	5,4,1,3	**1**
8	Next to the monitoring station	IMB25,26,27,28,29is Blank,IMX38,39 is blank	13	6,6,5,7,2,1,3	**4**
9	Baseline/ the new developed area/west	IMB 30,31,32,33 is blank	3	5,6,10,3	**3**
10	Baseline/ the new developed area /east	IMB 35,36,37,34 is blank	2	6,5,4,2	**3**
11	Khalifa City B *	IMB 38,39, 40,41 is blank	3	4,8,5,3	**2**
12	Baseline/ SCADIA Offices	IMB 42,43,44,45 is blank	3	7,7,5,3	**3**
13	Next to the ladies beach /outside the airport / under the flight path	IMB 54,46,48,47 is blank	3	4,3,5,3	**1**
14	Khalifa City A/ Etahad complex	IMB 49,51,53,50 is blank	4	6,6,8,4	**2**
15	Khalifa City A/HCT constriction site	56, 57,58,52 is blank IMB	4	6,4,6,4	**1**
16	Al Falah City / under the flight path	IMB 55,56 , IMX34, IMX 40 is blank	2	6,5,4,2	**3**
17	Al Falah City	IMB 59,BL1,BL2, BL3 is blank	2	5,9,8,2	5

Table 3: Difference in NO_2 values between wrapped and unwrapped diffusion tubes exposed for one week.

Site No.			Blank	Wrapped with foil		Not wrapped		Date Start of exposure	Termination of exposure
				.No	NO_2 (ppb)	.No	NO_2 (ppb)		
1.	Next to the weather radar Baseline/ the new developed area	11,12,13,14, 15	**Location**	**Tubes**	4,4	11,13	4,4	5/09/06	11/09/06
2.	Baseline/ the new developed area ,next to the fence	16,17,18,19, 20			4,6	16,18	5,4	5/09/06	11/09/06
3.	SCAIDA, baseline/ the new developed area/west	31,32,33,34, 35	0 ppb	31,33	4,4	32,34	4,5	5/09/06	11/09/06

Table 4: One week diffusion tubes trial to determine the difference in NO_2 concentrations using foil wrapping on the top of two 2 tubes at each site.

Site No.	**Location**	**Tubes**	**Blank**	**wrapped with foil**		**unwrapped**		**Start of exposure**	**Termination of exposure**
				.No	**NO_2 (ppb)**	.No	**NO_2 (ppb)**		
1	Next to the weather radar Baseline/ the new developed area	41,42,43,44,45	0ppb	41,42	11,11 ppb	43,44	18,19ppb	12/09/06	**19/09/06**
2	Baseline/ the new developed area ,next to the fence	46,47,48,49,50	0ppb	48,49	14,14	46,47	15,14	12/09/06	**19/09/06**
3	SCAIDA, baseline/ the new developed area/west	36,37,38,39,40	0ppb	36,37	16,12	38,39	13,14	12/09/06	**19/09/06**

Table 5: Diffusion tube sample location sites and results 2 weeks trial

Site No	Location	Tubes	Blank concentration	wrapped With foil		unwrapped		Start of exposure	Termination of exposure
				NO	NO_2	NO	NO_2		
1	Eco aircraft stand	1,2,3,4,5,	0 ppb	2,3	21,17	1,4	10,18	5/09/06	19/09/06
2	End of the Runway/ Amiri Flights side	6,7,8,9,10	0 ppb	6,7	16,12	8,9	10,11	5/09/06	19/09/06
3	End of the Runway/ Abu Dhabi Aviations side	21,22,23,24,25	0 ppb	22,24	14,14	21,23	11,9,	5/09/06	19/09/06
4	Police station opposite to terminal car park	26,27,28,29,30	0 ppb	26,27	11,15,	28,29	12,14	5/09/06	19/09/06

A2-3 Wind Rose Plotting Steps

Wind Rose Plot, which generates wind rose information and statistics that plots meteorological hourly surface data.

Step 1: Choose wind speed to view on wind rose plot.

Step 2: Choose knots as unit of measurement of wind speed.

Step 3: Choose the direction that the wind blows from.

Step 4: Import the meteorological data file.

Step 5: Select the date range for time period, full year data.

Step 6: Choose time range by clicking on specify time button.

Step 7: Surface Station information and ID number will appear automatically.

Step 8: Run

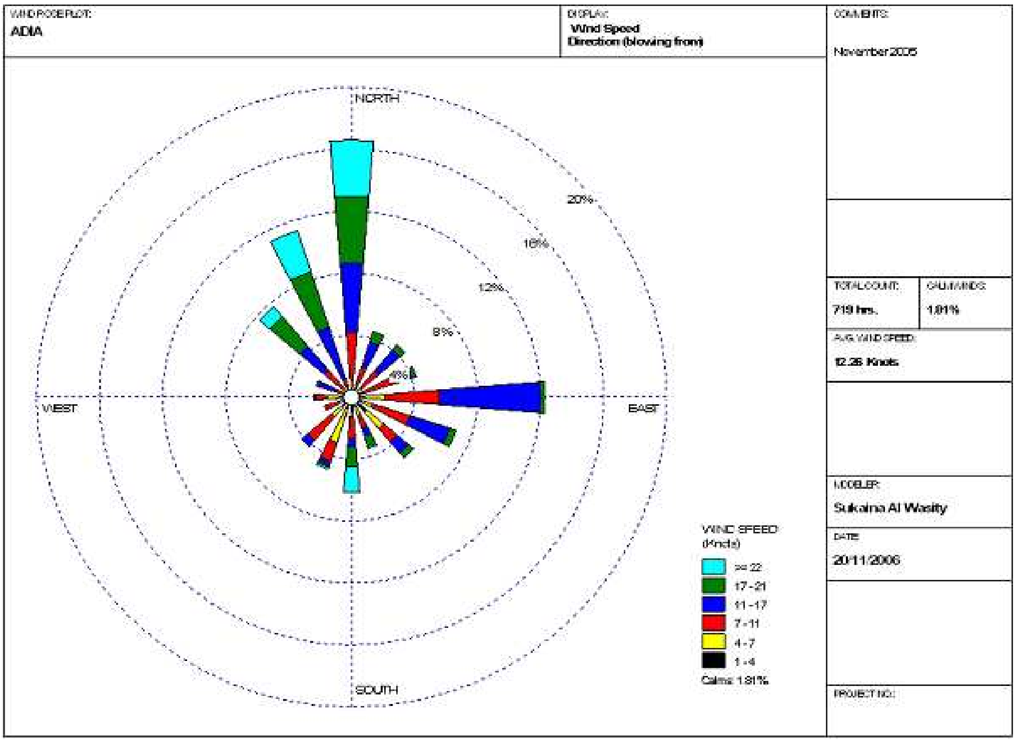
View of Outputs:

1. The wind rose view which displays the frequency distribution of occurrences of winds in each of 16 direction sectors.

2. The frequency count table that displays the number of occurrences of winds in each of 16 direction sectors.

3. The frequency distribution table displays the normalized frequency of occurrences of winds in each of 16 directions.

Figure 9: Wind rose for the month of November, 2005



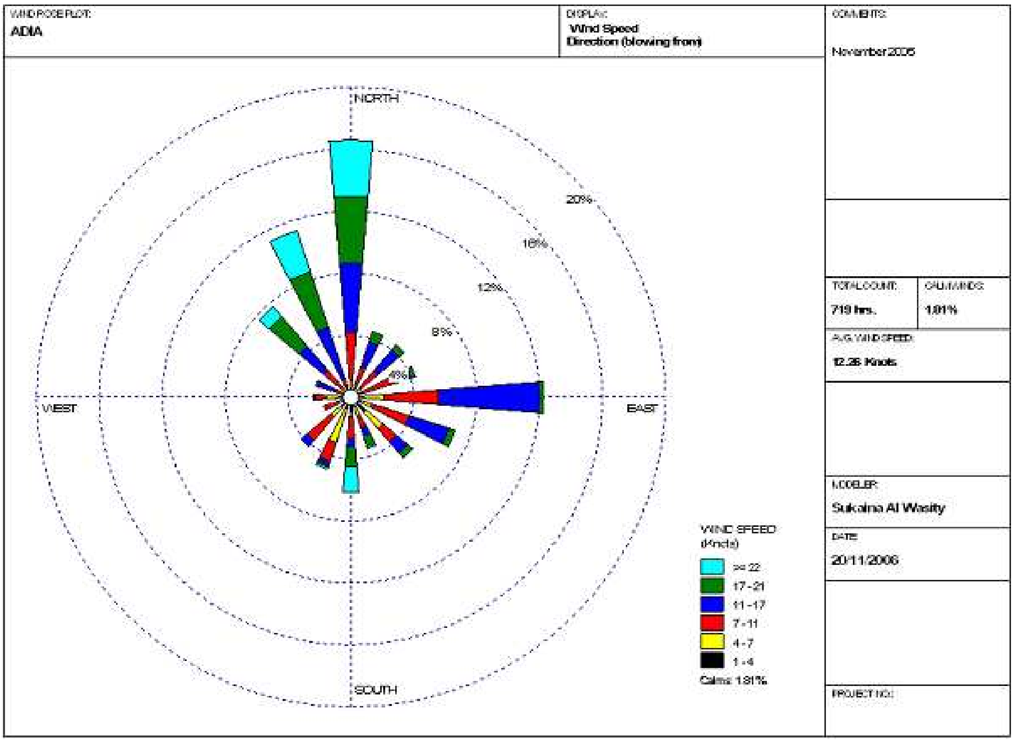


Figure 10: Wind rose for the month of December, 2005

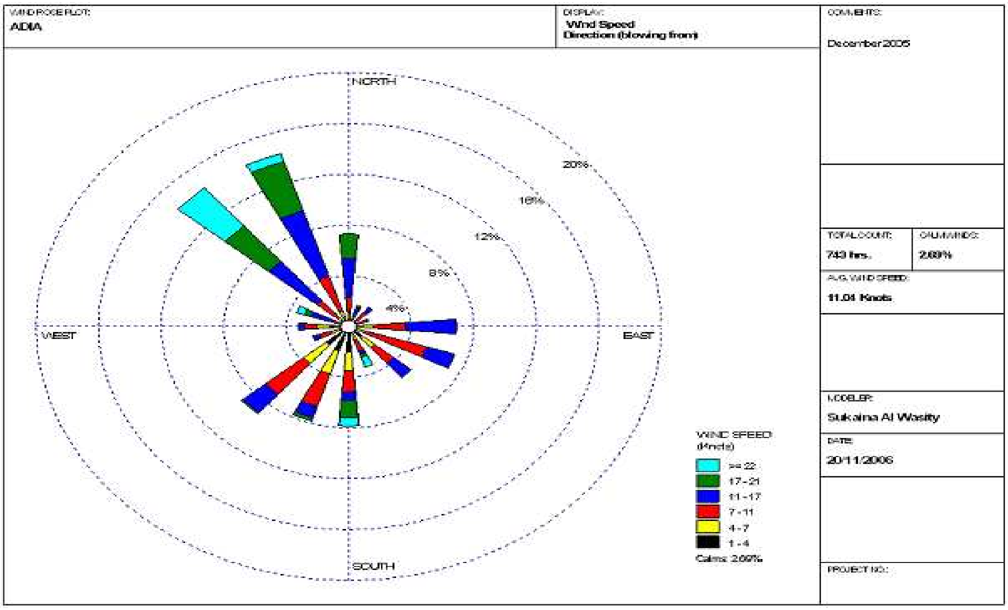


Figure 11: Wind rose for the month of February, 2006.

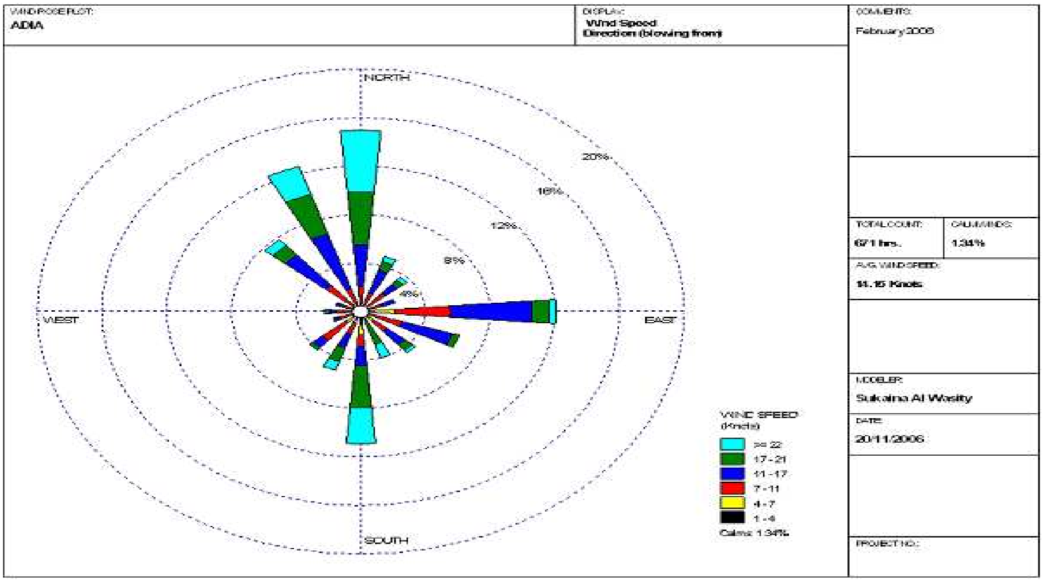


Figure 12: Wind rose for the month of March 2006.

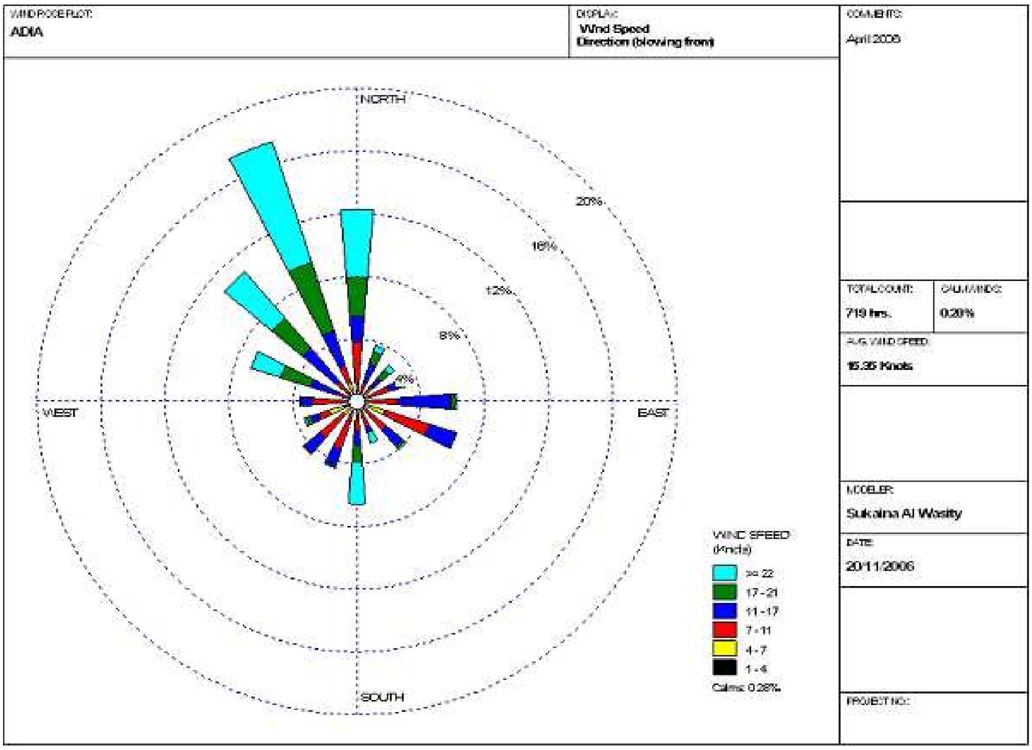


Figure 13: Wind rose for the month of April, 2006.

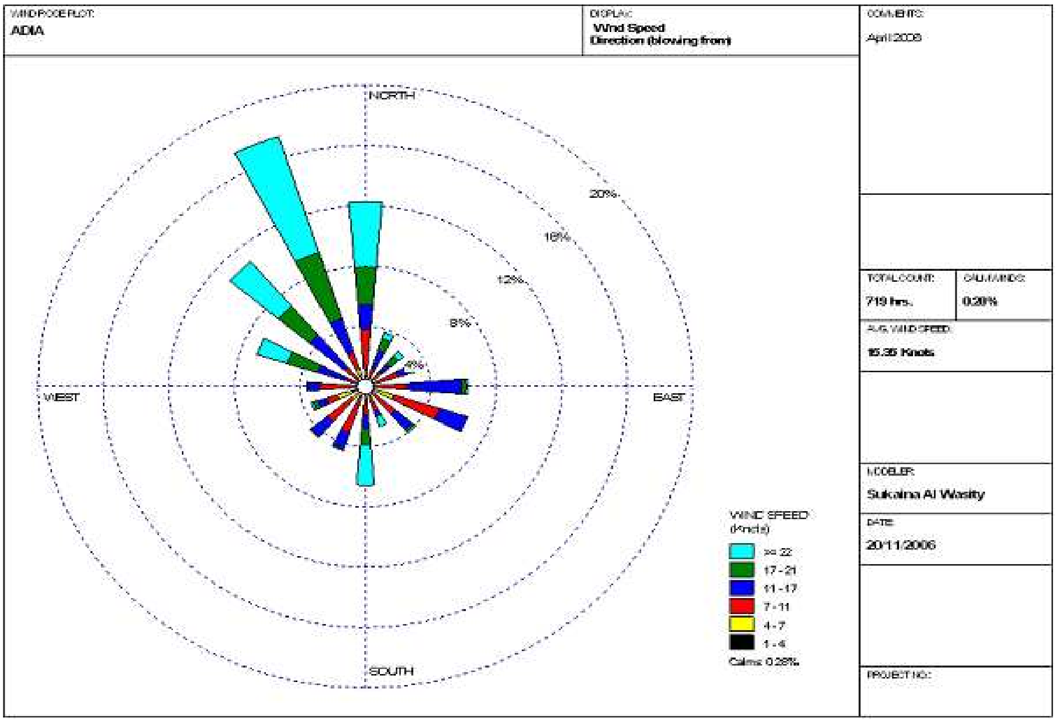


Figure 14: Wind rose for the month of May, 2006.

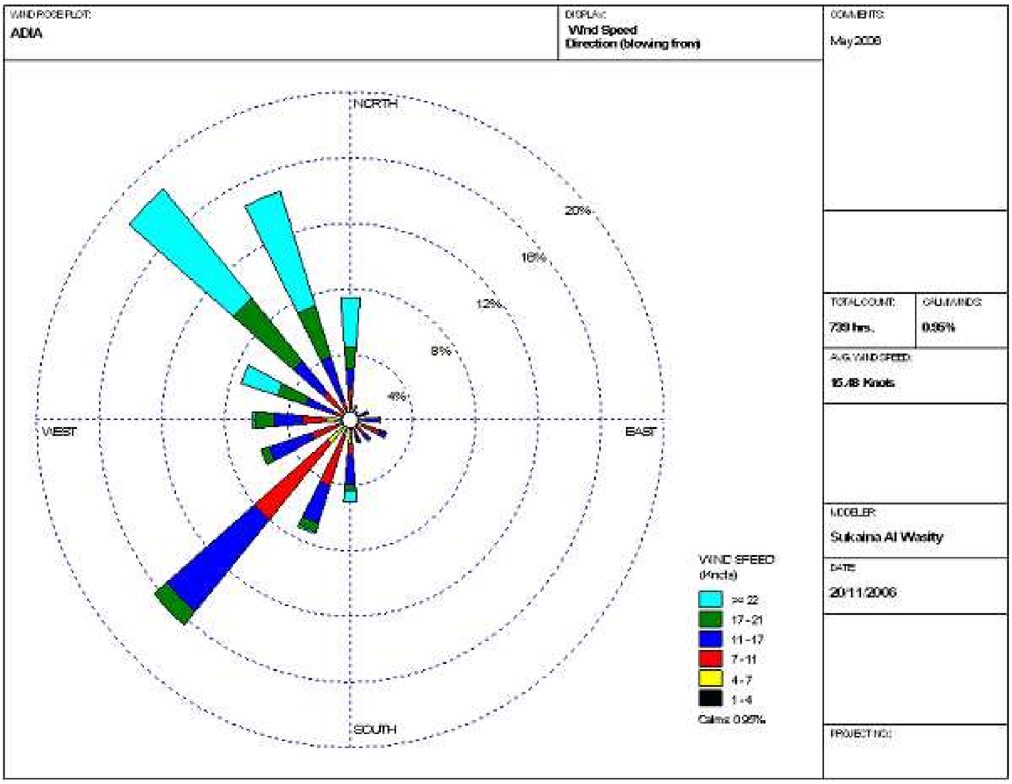


Figure 15: Wind rose for the month of June, 2006.

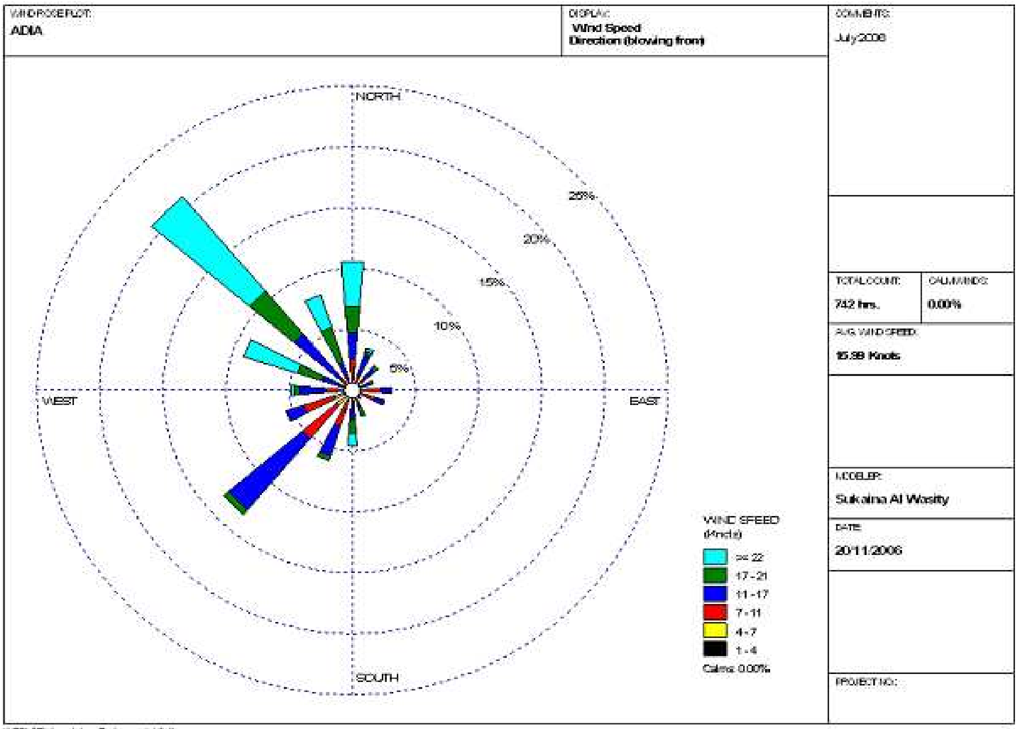


Figure 16: Wind rose for the month of July 2006.

A2.4 Pollution Rose methodology

Wind rose plot software from Lakes Environmental has been used to draw NO_2 pollution rose for ADIA that will create pollution rose lot that identical to OPENAIR plot.

The following steps were followed to create the pollution rose:

1. Import excel file that contains weather parameters and NO_2 concentration.

2. Set up the file to create SAMSON file to be read by the software program.

3. Add ADIA weather station information.

4. Create SAMSON file and save it the concerned directory.

5. Import SAMSON file to the pollution rose program.

6. User should run the and create the pollution rose, NO_2 Concentration Class frequency distribution graph, frequency distribution table, and frequency count table.

7. Save file as "emf" file.

A2-7 Monthly Diurnal Variation

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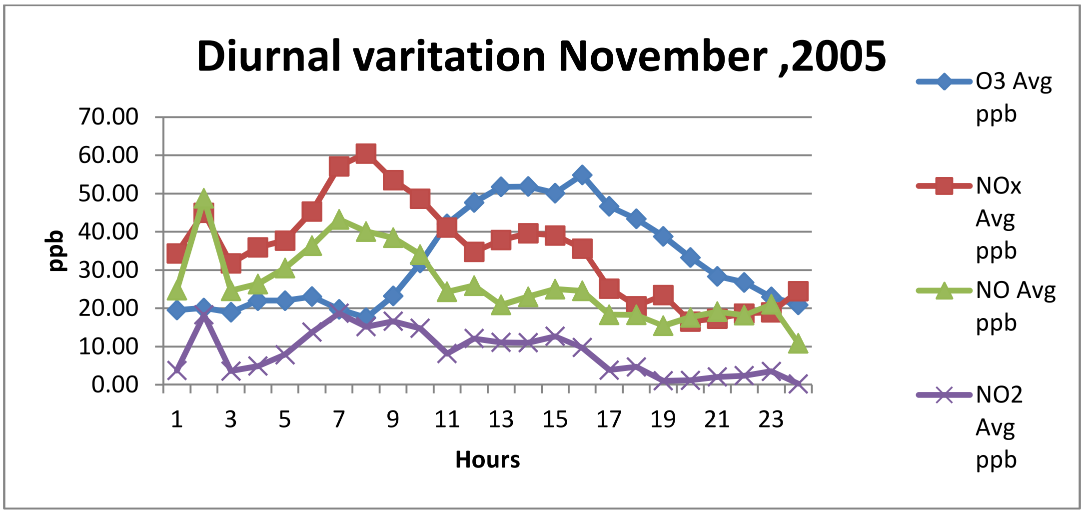

Figure 17: O_3, NO_2, NO, NO_x, diurnal variation for November

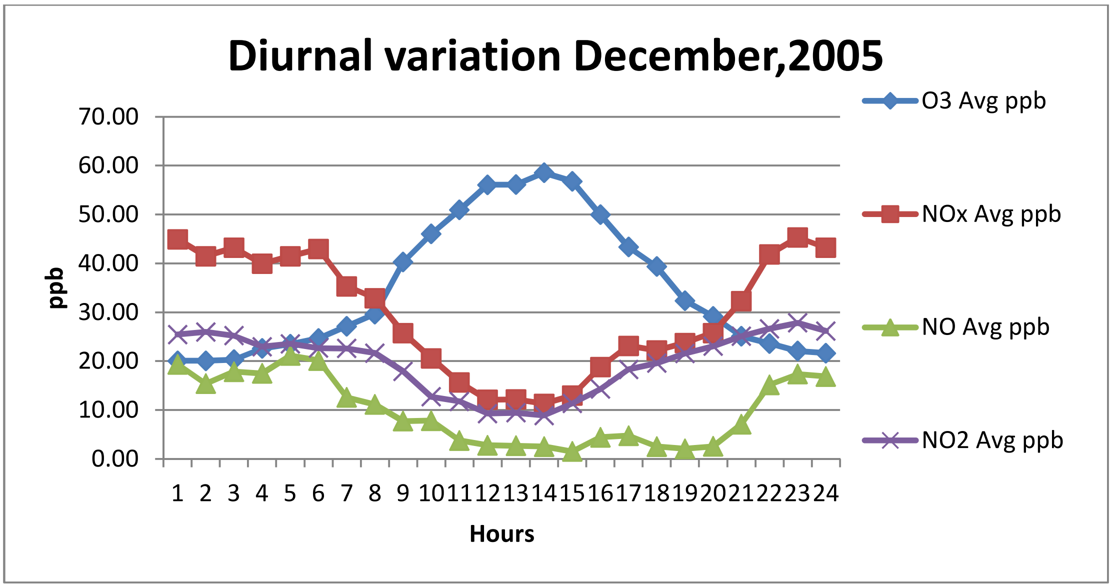

Figure 18: O_3, NO_2, NO, NO_x, diurnal variation for the month December

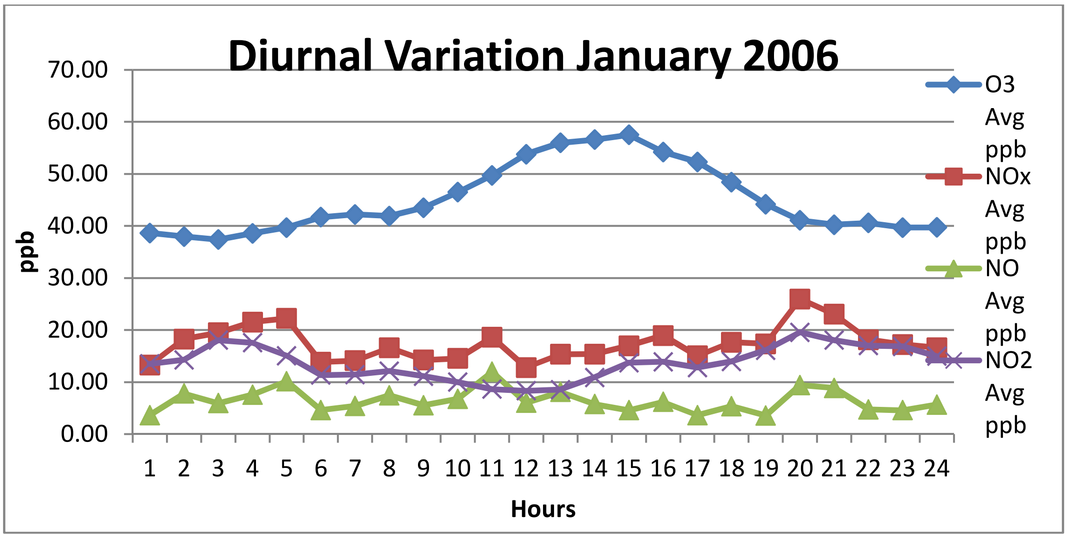

Figure 19: O_3, NO_2, NO, NO_x, diurnal variation for January

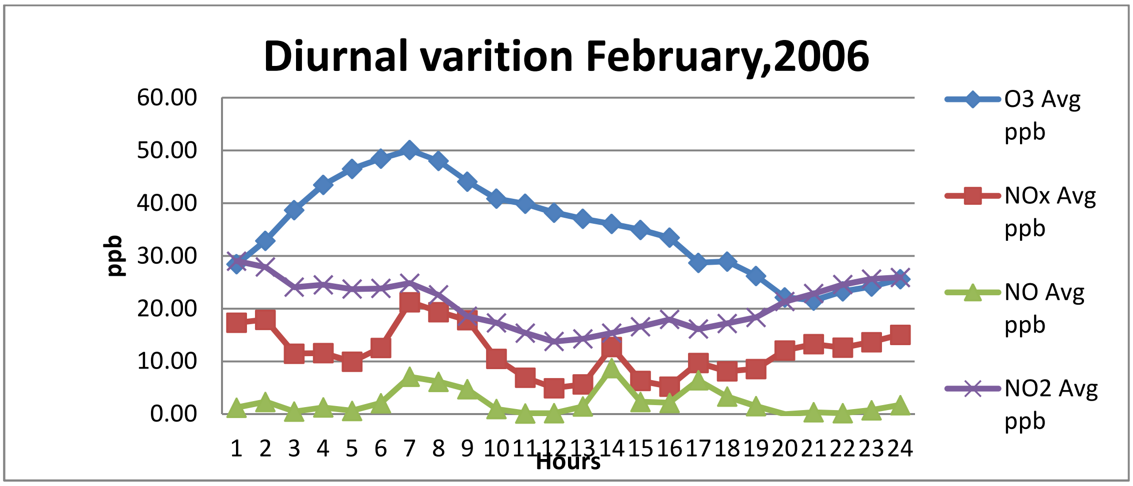

Figure 20: O_3, NO_2, NO, NOx, diurnal variation for February

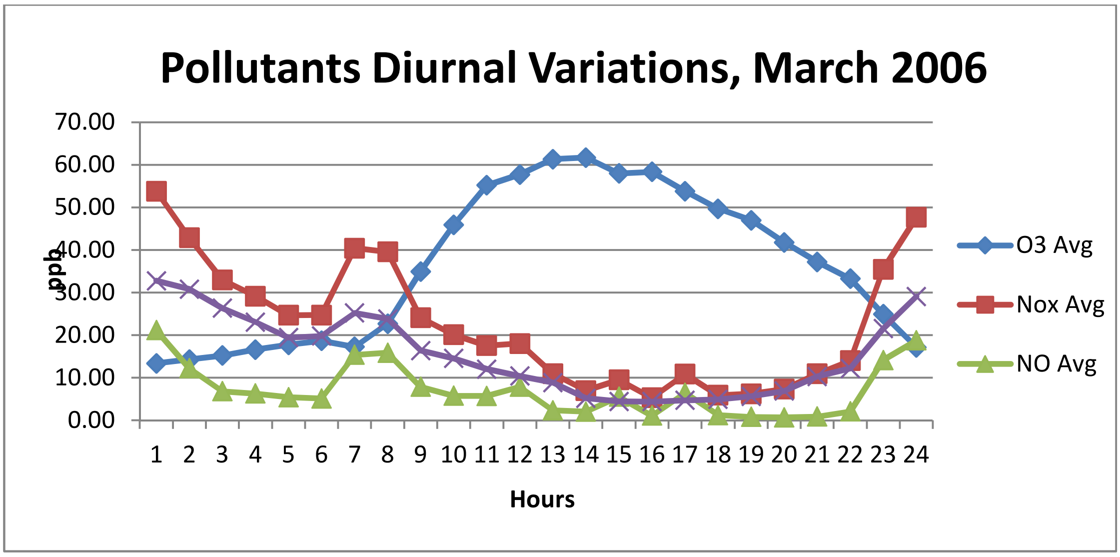

Figure 21: O_3, NO_2, NO, NO_x, diurnal variation for March (15-31) East station

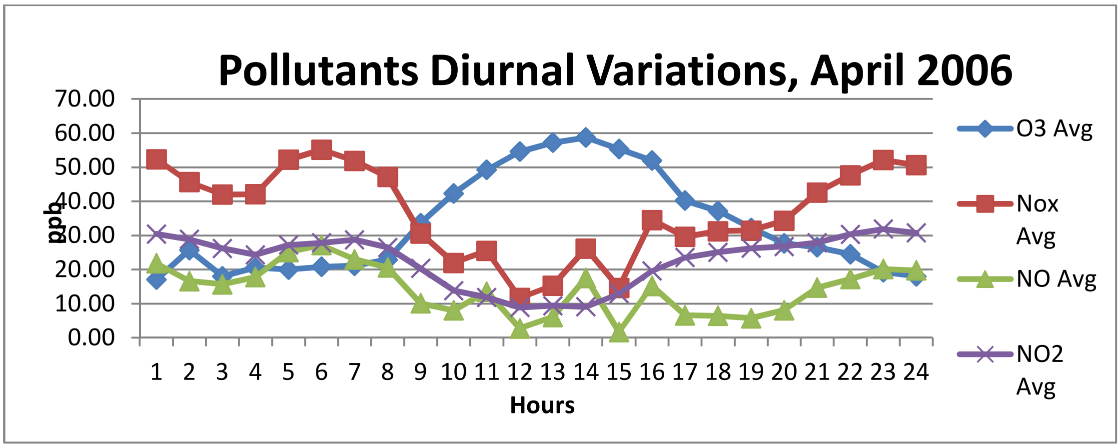

Figure 22: O_3, NO_2, NO, NOx, diurnal variation for April 2006

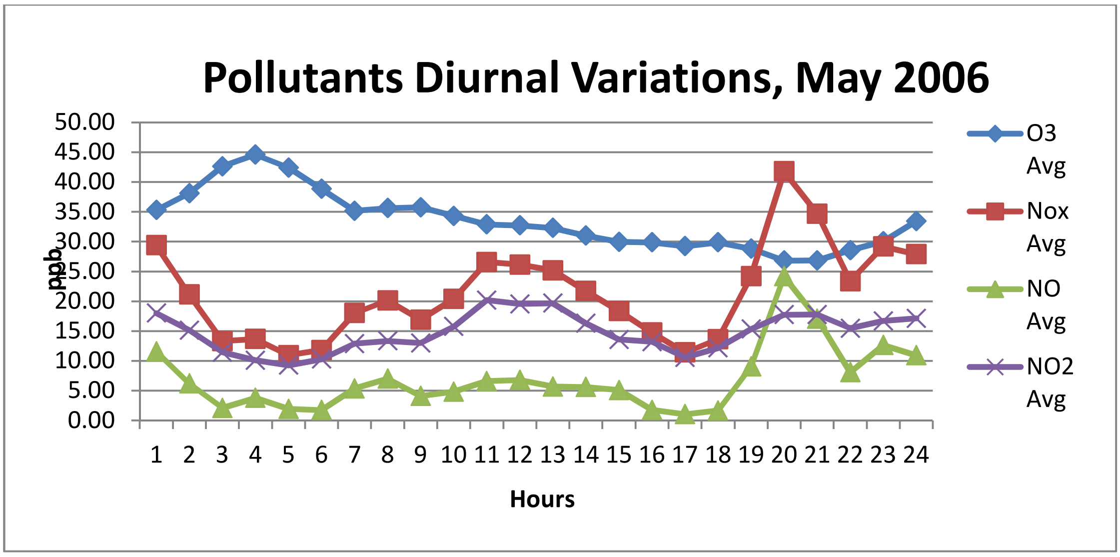

Figure23: O_3, NO_2, NO, NO_x, diurnal variation for May 2006

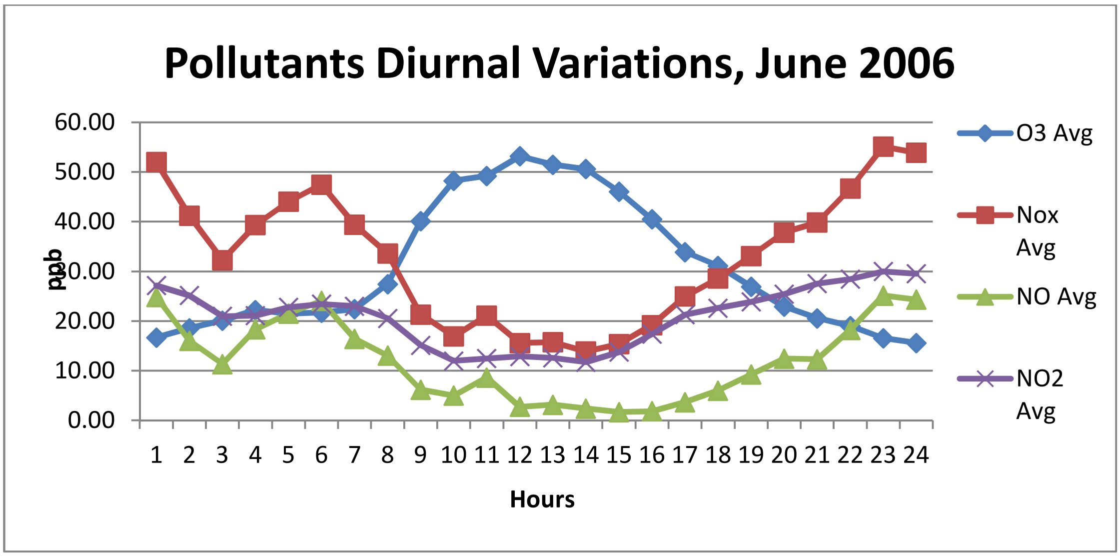

Figure 24: O_3, NO_2, NO, NO_x, diurnal variation for June 2006

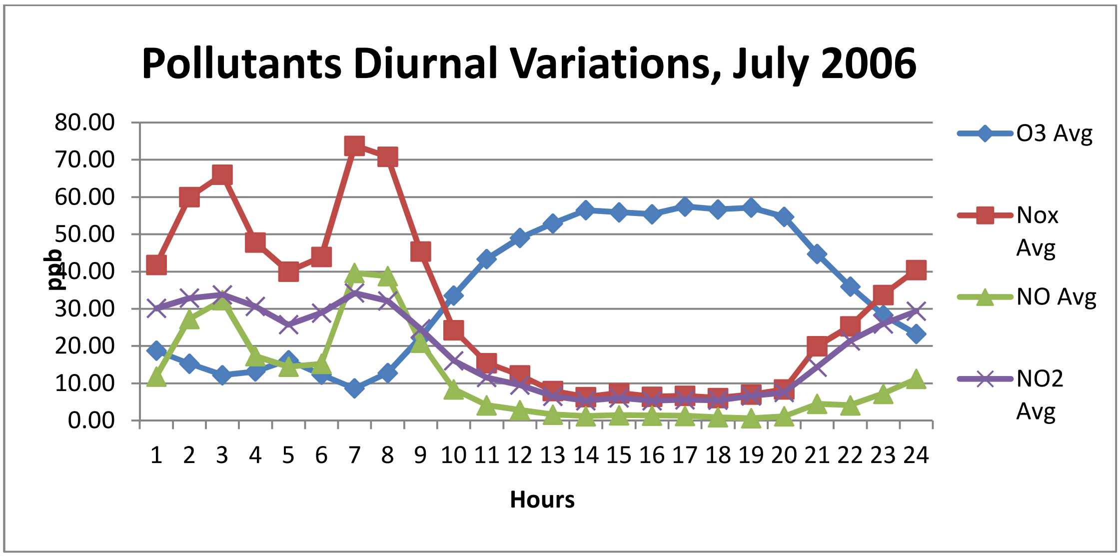

Figure 25:O_3, NO_2, NO, NO_x, diurnal variation for July 2006