Integrating air quality and climate change strategies in Oman

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This thesis is dedicated to my lovely family: my husband Khalid and my children, Tasneem, Elaf, Alwaleed, and Ahmed, for the beauty they bring to my life.

For my Oman and its prosperous future.

Abstract:

Air pollution and climate change are two of the main environmental problems being faced at the moment across the globe and both have a major and costly impact on human health. Oman needs to avoid the negative scenario which could result, and this can best be done by the integration of air quality control and climate change mitigation strategies. This integration would improve air quality and meet climate goals and would be cost-effective as well as beneficial. This thesis investigates the potential for integrated climate and air quality strategies in Oman, and incorporates the mitigation of SLCPs, a group of pollutants that has not yet been considered in the country. The implications of the mitigation strategies on human health and the climate are analysed and the current air quality and climate change policies are examined. The thesis also develops the first emission inventory to be based on national data for the country, using the data for 2010; it presents Oman's emissions of carbon dioxide, methane, carbon monoxide, sulphur dioxide, nitrogen oxides, non-methane volatile organic compounds, ammonia, particulate matter, black carbon and organic carbon. The emission inventory estimated total emissions of CO_2 of 50 Mt, CH_4 of 565 kt, SO_2 of 160 kt, NMVOCs of 142 kt, NO_x of 137 kt, primary $PM_{2.5}$ of 61 kt, CO of 51 kt, NH_3 of 18 kt, BC of 4 kt, and OC of 0.9 kt. The main sources of pollution in 2010 were emissions from electricity generation, oil and gas extraction, road transport and the manufacturing industry.

Twelve emission scenarios are developed and analysed in this thesis: the Business As Usual (BAU) scenario and eleven mitigation scenarios. The mitigation scenarios are as follows:

- the renewable energy scenario and the zero coal scenario, both for the electricity generation sector
- the fugitive reduction scenario and the zero flaring scenario, both for the oil and gas sector
- the efficient industry scenario and the clean fuel scenario in the manufacturing industry
- the electric vehicle scenario, public transport scenario and paved road scenario for the road transport sector
- the efficient air conditioning scenario for the residential sector and
- the efficient air conditioning scenario for commercial and public services.

If all the measures covered in all these scenarios were implemented, this thesis estimates that 191 Mt of CO_2 would be avoided in 2050, as well as 840 kt of CH_4, 144 kt of a SO_2, 92 kt of NMVOCs, 211 kt of NO_x, 34 kt of primary $PM_{2.5}$ emissions, 81 kt of CO, 3 kt of NH_3, 3 t of BC, and 3 t of OC.

This thesis has estimated that in 2010, approximately 711 cases of premature death in Oman could be attributed to PM2.5; this figure would rise to 1810 cases in 2030, and to more than

4400 cases in 2050, according to the BAU scenario. Soil dust is the largest source of PM2.5 in all years, but the other main sources contributing to it are transport (81%), industrial process emissions (10%), and the oil and gas industry (5%). This thesis confirms the urgent need to develop an integrated air quality and climate change policy.

This thesis also assesses the current legal framework that could be used to reduce emissions in Oman. Current policy was examined to understand the level of effort being made to reduce air pollution, SLCPs and GHGs. Despite public concern in Oman over these issues, especially climate change, little action has so far been taken to reduce emissions. Semi-structured interviews were held with representatives of government, industry, NGOs, media and the judiciary. From the interviews it was clear that the level of interest among the different sectors of the Omani establishment does not reflect – and is indeed much lower than - the level of concern felt by the public about these issues. This is shown by the lack of ambitious targets in Oman's NDC and by the low level of attention paid to air pollution. This thesis shows that unless action is taken, the impact of air pollution will get worse, not only because of increasing pollution but also because of an aging and growing population. The measures in the different scenarios developed could lead to a 60% reduction in CO_2 and a 33% reduction in methane, and also greatly reduce the negative impact on health. The analysis has also shown that this could lead to a net reduction of 7 % in warming by 2050, and offset the released warming from reducing SO_2 and NO_x emissions to protect human health. For this to happen, the current legislative framework could be used, but a positive outcome will depend on two key factors. First, all stakeholders need to become far more aware of the issues involved, as at present these are not widely understood; and second, there is need for further policy development and legislation and also for investment in capacity and infrastructure.

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Acronyms:

AGCM	Atmospheric General Circulation Model
AGTP	Absolute Global Temperature Potential
AGW	Anthropogenic Global Warming
ALRI	Acute Lower Respiratory Infections
AOGCM	Atmosphere-Ocean General Circulation Model
AP	Air pollution
ARD	Acute Respiratory Diseases
ARTP	Absolute Regional Temperature Potential
Be'ah	Oman Environmental Services Holding Company S.A.O.C
BC	Black Carbon
BM	Buraimy Municipality
CC	Climate Change
COP	Conference of the Parties
COPD	Chronic Obstructive Pulmonary Disease
CTM	Chemical Transport Model
CVD	Cardio Vascular Diseases
DALYs	Disability Adjusted Life-Years
DM	Dhofar Municipality
EF	Emission Factor
EI	Emission Inventory
EMME	Eastern Mediterranean and the Middle East
ERF	Exposure Response Function
Eurostat	Statistical Office of the European Communities
FAO	Food and Agriculture Organization
FRF	Forcing Response Function
GBD	Global Burden of Disease
GCC	Gulf Cooperation Council
GCC-STAT	Statistical Centre for the Cooperation Council for the Arab Countries of the Gulf
GDP	Gross Domestic Product
GEOS	Goddard Earth Observing System
GHG	Green House Gases
Haya	Oman Wastewater Services Company SAOC
HFCs	Hydrofluorocarbons
IARC	International Agency for Research on Cancer
IEA	International Energy Agency
IER	Integrated Exposure Response
IHD	Ischemic Heart Disease
IMF	International Monetary Fund
INDCs	Intended Nationally Determined Contributions
ISAAC	International Study of Asthma and Allergies in Children
IPCC	Intergovernmental Panel on Climate Change
KSA	Kingdom of Saudi Arabia
LC	Lung Cancer
LEAP-IBC	Long-range Energy Alternative Planning
LTO	Landing and Taking Off
MAF	Ministry of Agriculture and Fisheries
MDPP	Million Date Palme Project,
ME	Middle East
MECA	Ministry of Environment and Climate affaire
MENA	Middle East and North Africa
MIS	Main Interconnected System

MM	Muscat Municipality
MOCI	Ministry of Commerce and Industry
MOG	Ministry of Oil and Gas
MORMWR	Ministry of Regional Municipality and Water Resources
MSW	Municipal Solid Waste
MWM	Mawarid Mining
NASA	National Aeronautics and Space Administration
NCDC	National Climatic Data Centre
NDC	Nationally Determined Contributions
NCSI	National Centre for Statistical Information,
NMHC	Non-Methane Hydrocarbon
NMVOC	Non-Methane Volatile Organic Compounds
OCC	Oman Cement Company
OECD	Organization for Economic Cooperation and Development
OGCM	Ocean General Circulation Model
OLNG	Oman Liquid Natural Gas
OMC	Oman Mining Company
OOC	Oman Oil Company
OPEC	Petroleum Exporting Countries
OPWP	The Oman Power and Water Procurement Company,
ORPIC	Oil Refineries and Petroleum Industries Company,
PACA	Public Authority for Civil Aviation
PAEW	Public Authority for Electricity and Water
PAM	Public Authority for Mining
PEIE	Public Establishment for Industrial Estates
PM	Particulate Matter
RCC	Raysut Cement Company
RCP	Representative Concentration Pathway
RF	Radiative forcing
ROP	Royal Oman Police
ROWA	Regional Office for West Asia
RR	Relative Risk
SES	Socio-economic Status
SIZ	Sohar Industrial Zone
SLCF	Short Lived Climate Forcers
SLCPs	Short Lived Climate Pollutants
SLR	Sea Level Rise
SM	Sohar Municipality
UAE	United Arab Emirates
UN	United Nation
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
VOC	Volatile Organic Compounds
WB	World Bank
WBT	Wet Bulb Temperature
WHO	World Health Organization
WMO	World Meteorological Organization

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Author's declaration

I declare that this thesis is a presentation of original work and I am the sole author. This work has not previously been presented for an award at this, or any other, university. All sources are acknowledged as References.

1 Introduction

1.1 Overview

This thesis investigates the potential for integrated climate and air quality strategies in Oman, and incorporates the mitigation of SLCPs; this latter possibility has not yet been considered in the country. Through this analysis, the thesis will investigate the implications of the mitigation strategies on human health and climate.

Throughout this study the current impacts of air pollution and climate change in Oman will be discussed, in order to discover the severity of their effect on the health of people in this country, and how these effects compare with the impacts experienced on a global scale. It will highlight indications that climate change is being experienced by the region and examine the seriousness of the impact of such changes. It will also seek to discover whether or not any health issues in the region are related to those changes, and, if so, how these compare to the situation in other parts of the globe.

The thesis also examines the extent to which air pollution and climate change are being addressed in Oman; it does this by analysing current policies and by assessing the emphasis placed on these environmental issues by policy makers, industry and civil society. It outlines a number of measures that could be taken to address both air pollution and climate change, proposes a number of mitigation scenarios and considers the extent to which these could be implemented in Oman and what would be necessary for them to be included in national policy.

The Sultanate of Oman is located in the southeast of the Arabian Peninsula, with a population of 2,773 million (2010)[1] and an economy predominantly dependent on oil.

Based on the annual report (No. 2) on population statistics in the Gulf Cooperation Council (GCC) countries, issued by the Statistical Centre for the Cooperation Council for the Arab Gulf States 2018, Oman's population is growing fast between 2010 and 2016 compared with other GCC countries such as Qatar, Bahrain, and Kuwait as shown in figure 1.1[2].

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[1] Actual Results of General Census of Population, Housing and Establishment.

[2] https://www.gccstat.org/en/

Oman has a total area of around 309,000 km^2. Approximately 82% of the total area is sandy desert; mountains occupy 15% and coastal areas represent only 3% of the total area. The total arable land is around 2.2 million hectares, or 7% of total area; of this, 173,000 acres are actually under cultivation, making the per capita cultivated land about 0.07 acres. The coastline stretches for over 3,165 km along the Arabian/Persian Sea, the Gulf of Oman, and the Indian Ocean. Oman is one of the world's hottest and most arid regions, which poses many challenges to human settlement, including shortage of water and also desertification (UNEP/ROWA, 1993). Along the coast, the climate tends to be more humid, while it is extremely hot and dry in the interior deserts. The southern region of Dhofar attracts a summer monsoon that arrives from the Indian Ocean and is called Alkhareef by the locals (Al Shueile, 2015). Appendix A1 gives a diagrammatic representation of Sultanate of Oman. The country is one of the most water scarce in the world and climate change is likely to worsen drought and desertification, threaten water security and disrupt agricultural production. Rising temperatures increase, the risk of heat-related morbidity and mortality. Furthermore, the incidence and severity of natural disasters, such as the cyclones experienced in recent years, are expected to rise[3].

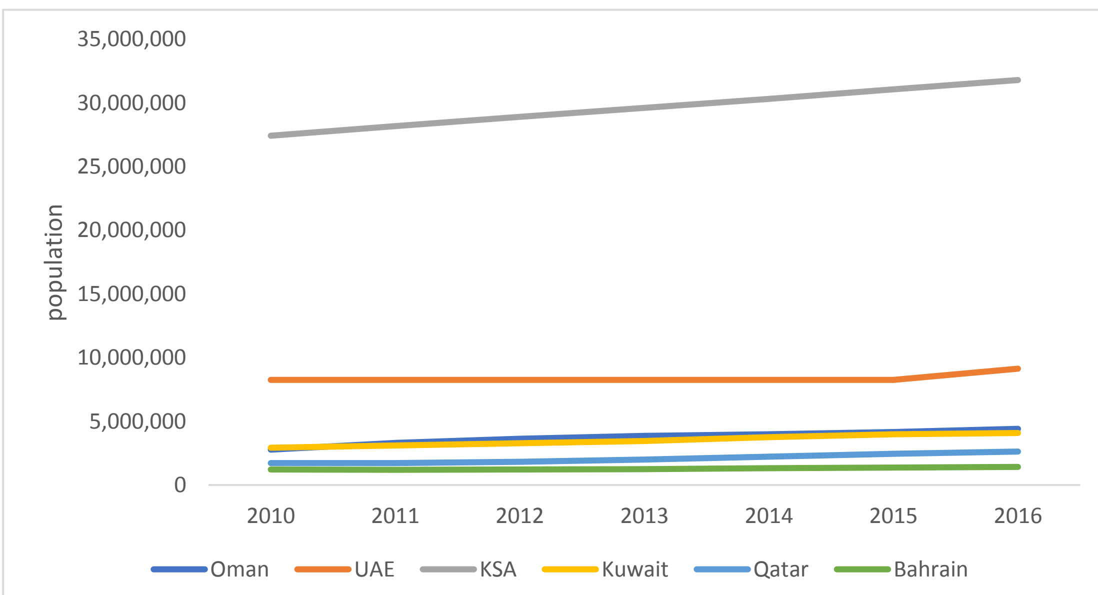

Figure 1-1 The GCC countries population growth (2010 – 2016) based on the Statistical Centre for the GCC, 2018

[3] Climate and health country profile, 2015 OMAN - WHO (http://www.who.int/globalchange/en/

1.2 Air pollution:

Air pollution – both ambient (outdoor) and household (indoor) – represents the biggest environmental risk to health at a global level. New data from WHO shows that nine out of ten people in the world breathe air containing high levels of pollutants. Updated estimates reveal an alarming death toll of seven million people every year caused by ambient (outdoor) and household air pollution (WHO, 2019). Air pollution affects all regions, all socio-economic categories and age groups. Although people living in the same area breathe the same air, there are remarkable geographical differences in exposure to air pollution. WHO states that out of every ten people, only one person lives in a clean city which considered 'safe' by the WHO Air Quality Guidelines. Air Quality Guidelines refer to concentrations recorded over a given time period, which are considered to be acceptable in terms of what is scientifically known about the effects of each pollutant on health and on the environment. To be considered safe is to be within those acceptable limits. For example, the WHO has set the AQ guideline for $PM_{2.5}$ at 10 µg m^{-3}. Air pollution continues to increase at an alarming rate, and influences both people's health and the economies of nations (WHO, 2016).

Although certain health impacts of air pollution have recently been the focus of researchers in Oman and other GCC countries, there are still very few studies dealing with the region that examine the relationship between health impacts, such as premature deaths, and air pollution. The first environmental epidemiological study in Oman, showed an increased risk of respiratory and allergic disease in a population living near an industrial complex (Al-wahaibi and Zeka, 2015; Alwahaibi and Zeka, 2016).

Li et al. (2010) quantified the national burden of disease attributed to particulate matter (PM) and ozone (O_3) in ambient air in the United Arab Emirates (UAE). They estimated that approximately 7% (95%, Confidence Interval (CI): 2–17%) of the total deaths in the UAE in the year 2007 were attributable to PM in ambient air; this figure compared with about 1% (95%, CI: 0.2–2%) of the total deaths attributed to ground-level O_3 exposure for the same year. This estimate is higher than the total global percentage of premature deaths caused by PM, where outdoor air pollution accounts for approximately 1.2% of total mortality in urban areas worldwide (Cohen *et al.*, 2006).

These worryingly high rates of premature death due to ambient air pollution in the UAE are likely to be typical of the GCC region as a whole, and are not widely known or examined in depth, which suggests that additional policies are likely to be required to address the problem. One aim of this thesis, then, is to provide robust evidence for the extent of the air pollution problem, primarily in

Oman but also in the rest of the GCC region. It also seeks to assess the current and future impacts on health and climate, to increase awareness and so help to provide a stimulus for political action to address the issue.

1.2.1 Global health impacts

According to the WHO, every year seven million premature deaths worldwide are linked to air pollution, amounting for one in eight of total global deaths (WHO, 2017). This makes air pollution the world's largest single environmental health risk, ranking alongside major health risks such as smoking, high cholesterol, high blood sugar and obesity (Figure 1-1).

It has been estimated that in 2010 air pollution caused 223 000 deaths from lung cancer worldwide (Anenberg et al., 2012; Lim et al., 2012; Stohl et al. 2015). The specialized cancer agency of the World Health Organization, the International Agency for Research on Cancer (IARC), announced on 17 October 2013 that it had classified outdoor air pollution as carcinogenic to humans. Particulate matter (PM), a major component of outdoor air pollution, was evaluated separately and was also classified as carcinogenic to humans by the IARC[4].

Premature deaths linked to air pollution are increasing every year. Many studies have been conducted worldwide investigating the impact of air pollution on health (Fang et al. 2013; Cohen et al. 2006; Silva et al. 2013; Suite 2012; Leveque 2015) ; all agree that the impact of air pollution on health is one of the most important concerns facing the world's nations, developing and developed countries alike.

[4]https://www.rehva.eu/rehva-journal/chapter/outdoor-air-pollution-a-leading-environmental-cause-of-cancer-deaths-iarc-scientific-publication-no-161-air-pollution-and-cancer

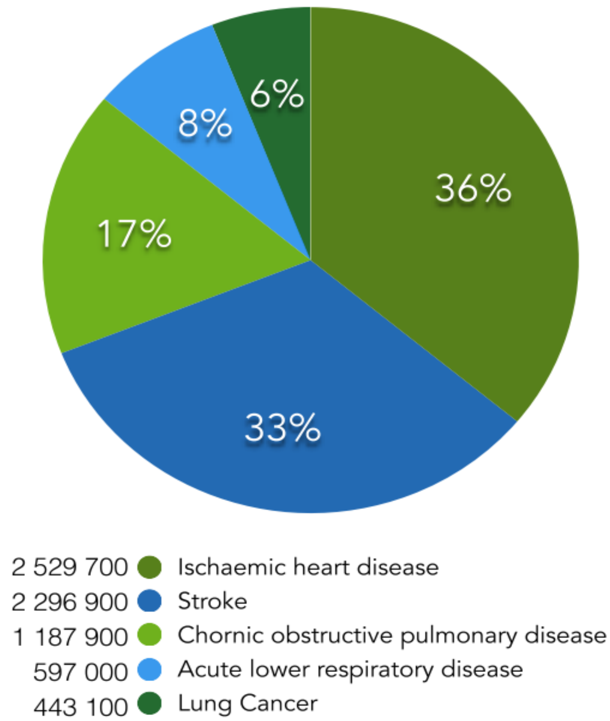

Figure 1-2: Deaths attributable globally to the joint effects of household air pollution and ambient air pollution by disease, 2012 (WHO 2017)

1.2.1 Air pollution and health in Oman and the GCC region

The Global Burden of Disease project (GBD) calculates the health impacts of air pollution and of other causes of disease. They have classified the air pollution which poses a health risk to humans into three main categories: household air pollution, ambient particulate matter, and ozone (WHO, 2016). The GBD project reports the impacts of these for each country of the world (See IHME website).

In the Gulf Cooperation Council (GCC)[5] region, there has recently been growing attention to environmental issues in general, and to air pollution in particular. At the same time, according to the GBD, there has been a tremendous increase in the number of premature deaths related to air pollution in the GCC countries, where 5,809 people died prematurely due to ambient particulate matter pollution in 1990, a figure which rose to 12,651 deaths in 2015 (IHME, 2016). For example, in Bahrain, Kuwait, and Qatar, the GBD estimates that there are 773 deaths annually due to fine particulate matter less than 2.5 microns in diameter ($PM_{2.5}$) (Eastnorth et al., 2016).

[5] Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, and United Arab Emirates

Figure 1-2 compares the percentage of total death caused by the three main types of air pollution from the GBD assessments: household air pollution, ambient particulate matter, and ambient ozone, and gives data for the six GCC countries, namely Bahrain, Kuwait, Oman, Qatar, Saudi Arabia and the Emirates. It is clear that ambient $PM_{2.5}$ is the dominant type of air pollution in the region, and is more dangerous to health than ambient ozone or indoor air pollution. It was found that, in the GCC countries, indoor air quality was much less of a problem than that of ambient air quality (Gevao et al., 2007; Al-rashidi et al., 2012; Yeatts et al., 2012, Omidvarborna et al., 2018, Cohen et al., 2013).

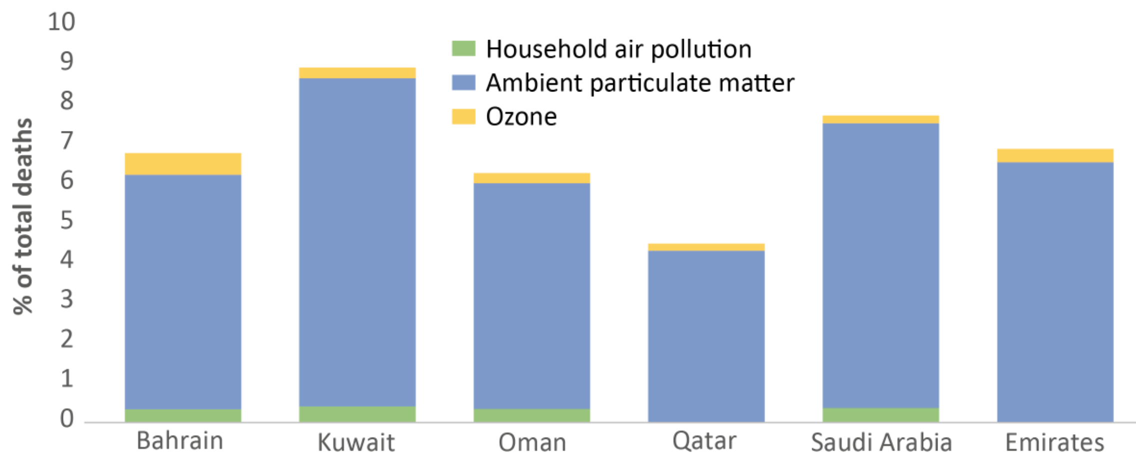

Figure 1-3: Percentage of total death attributable to air pollution in 2013 for different GCC Countries (IHME, 2016)

On a global scale, developing countries are major contributors to air pollution due to their growing economies; these are linked to the emergence of emissions-generating sectors such as energy, transport and industry (Galeotti and Lanza, 1999; Kumar et al., 2015). The Middle East and North Africa (MENA) region, which includes Algeria, Bahrain, Egypt, Jordan, Iran, Iraq, Kuwait, Lebanon, Libya, Morocco, Oman, Palestine, Qatar, the Kingdom of Saudi Arabia (KSA), Syria, Tunisia, Turkey, the United Arab Emirates (UAE) and Yemen, is one of the major contributors worldwide to climate change emissions and their impact on global health (El Fadel et al., 2013).

The severity of the region's air pollution and how it compares with that elsewhere can be shown by comparing the mortality rate attributed to household and ambient air pollution; this is normally expressed as the number of deaths per 100,000 population. The WHO estimated that in 2012, there were 7.5 deaths per 100,000 population attributed to household and ambient air pollution in the UAE, 9.0 in Qatar, 11.1 in Bahrain, 13.5 in Oman, 14.2 in Kuwait, and 28.1 in KSA. These numbers can be compared with those in developed countries like the UK, with 25.7 deaths per 100,000, people, and the USA, with 12.1 deaths. The highest mortality rate in 2012, according to estimates by the WHO, was in China, with 163.1 deaths, while the lowest was in Brunei Darussalam, 0.2, and Australia and Sweden, both with 0.4. Figure 1-3 illustrates these findings (WHO, 2016).

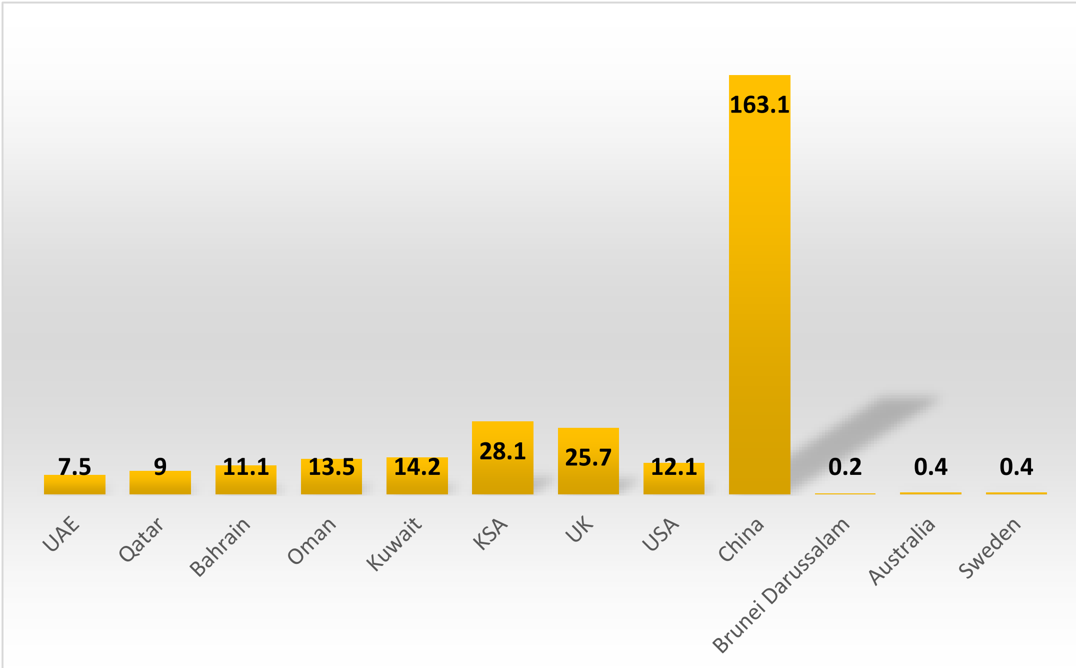

Figure 1-4: Mortality rate attributed to household and ambient air pollution (per 100,000 population), 2012 (WHO, 2016)

A study conducted by Willis et al. (2010) focusing on the pollution-related health risks in the UAE found that outdoor and indoor air pollution posed the greatest risks to health, outranking other sources of pollution such as soil and groundwater, drinking water contamination, ambient noise, and electromagnetic fields from power lines. A study by Gibson and Farah (2012) quantifying illness and premature deaths in the UAE as a result of environmental pollutants, found that outdoor air pollution ranked highest in terms of risk priority. The recent 2014 Ambient Air Pollution database updated by the World Health Organization (WHO) ranked Doha as the twelfth most polluted city in the world, based on the annual mean concentration of fine particulate matter ($PM_{2.5}$ and PM_{10}), according to a report by the Qatar Statistics Authority (2013) (Farahat, 2016).

A number of air pollution and health studies have been carried out in Oman, usually in industrial zones that are expected to be the most polluted areas. Most of those studies are motivated by the health and safety requirements of the Public Establishment for Industrial Estates (PEIE) which regulates those companies and industries. At times, however, the studies are conducted in response to demands for investigation from the population living around that area of industrial activity.

Oman has recently embraced a rapid industrialization drive aimed at enriching its economy and decreasing its dependency on fossil fuel. As a result, many industrial parks have been constructed, one of which is the Sohar Industrial Zone (SIZ); these parks include petrochemical industrial complexes. Al-wahaibi & Zeka (2015) examined the acute health impacts on adults of ≥20 years old living near the Sohar Industrial Zone for the period from 2006 to 2010; the emissions here are mainly of sulphur dioxide (SO_2), nitrogen oxides (NO_x) and volatile organic compounds (VOC). Findings suggested that those living closer to the industrial park were two or three times more likely to visit health care facilities because of acute respiratory tract diseases, asthma, conjunctivitis and dermatitis than those living in the control zone, with greater exposure effects observed amongst people aged ≥50. Similar results were found in an evaluation of the health effects on children aged <20 years old living near the Sohar Industrial Zone; the study covered the same period of time, with greater asthma-related health effects being noticed in the ≤14-year-old group (Alwahaibi and Zeka 2016).

Sabah Abdul-Wahab, and Sappurd Ali (2015) assessed the impact on workplace and ambient air quality due to the release of sulphur dioxide (SO_2) into the atmosphere at the Al-Noor gas production station, located in the southern desert of the Sultanate of Oman. The estimated results were compared with the air quality standards/guidelines set by Oman's regulatory authorities as well as those set by the World Health Organization (WHO). It was concluded that the SO_2 levels were high enough for sensitive individuals in the workplace of the Al-Noor station to experience adverse health effects due to short-term exposure to SO_2.

Another study was conducted in the Oman Liquid Natural Gas (OLNG) plant in Muscat, to assess the potential impact of the environmental air quality arising from the plant. The pollutants studied included methane (CH_4), NMVOCs, carbon monoxide (CO), nitrogen oxides (NO and NO_2), and suspended dust. The results indicated that the mean concentrations of all pollutants were too low to cause any significant impact on air quality, except for that of non-methane hydrocarbon. This means that non-methane hydrocarbons are the main air pollutants likely to have an impact on the environment directly around Oman Liquid Natural Gas plants (Abdul-Wahab, 2005).

With the continuing development of industrialization in Oman, atmospheric emissions from different industrial sources are likely to increase, unless action is taken; this discussion will be part of the assessment of future emission trends and their impact in Chapters 4 and 5.

1.2.1.1 Outdoor air Pollution - Ambient particulate matter (PM)

Airborne particulate matter is made up of a collection of solid and/or liquid materials of various sizes; these range from a few nanometres in diameter (about the size of a virus) to around 100 micrometres (100 µm, about the thickness of a human hair). Airborne particulate matter consists of primary components, which are released directly from the source into the atmosphere, and also secondary components, which are formed in the atmosphere by chemical reactions. Particulate matter comes from both human-made and natural sources. It contains a range of chemical compounds whose composition provides clues to their origin. Particulate matter is classified according to its size with this classification used in concentration measurements. For example, PM_{10} refers to the concentration of particles that are less than or equal to 10 µm in diameter while $PM_{2.5}$ describes the concentration of particles that are less than or equal to 2.5 µm in diameter. Anthropogenic PM sources can be broadly divided into three types: transportation-related sources, energy and industry-related sources and construction and activities related to construction like crushing, screening, cutting and drilling. In addition to anthropogenic sources, natural sources also play an important role in determining ambient levels of PM. The majority of the PM studies set in arid areas estimate that natural sources such as dust storms contribute far more than anthropogenic emissions (Tsiouri et al., 2014). In the Middle East, dust storms are a major contributor to the degradation of air quality by increasing PM. Some of this will be due to poor land management and is therefore anthropogenic in origin. This specific issue is important to the GCC and will be highlighted in more detail at the end of this section, where there will also be a review of studies related to it.

Various studies have looked at the health impacts of PM in the GCC region. Leveque (2015) reviewed the association between particulate matter (PM) and cardiovascular diseases (CVD) in selected countries of the Middle East region, including the GCC countries. He noted in his findings that "ambient PM pollution is considered a potential risk factor for platelet activation and atherosclerosis and has been found to be linked with an increased risk for mortality and hospital admissions due to CVD".

Looking at the United Arab Emirates (UAE), MacDonald Gibson et al. (2013) assessed the burden of disease attributable to six routes of exposure to risks in the environment: outdoor air, indoor air, drinking water, coastal water, occupational environments, and climate change. For every exposure route, the researchers integrated UAE environmental monitoring and public health data in a spatially resolved Monte Carlo simulation model to estimate the annual disease burden attributable to selected pollutants. The assessment included the entire UAE population (4.5 million for the year of analysis, 2008). The study found that outdoor air pollution was the leading contributor to mortality, with 651 attributable deaths (95% confidence interval [CI] 143–1,440), or 7.3% of all deaths. Indoor air pollution and occupational exposures were the second and third leading contributors to mortality, with 153 (95% CI 85–216) and 46 attributable deaths (95% CI 26–72) respectively.

Li et al. (2010) quantified the national burden of disease attributable to particulate matter (PM) and ozone (O_3) in the ambient air in the United Arab Emirates (UAE). They found that, in the year 2007, approximately 545 (95% CI: 132–1224) excess deaths in the UAE were attributable to PM in ambient air, with these excess deaths representing approximately 7% (95% CI: 2–17%) of the total deaths that year. Also for the year 2007, the researchers attributed approximately 62 premature deaths (95% CI: 17–127) to ground-level O_3. These figures can be compared with those given by the GBD for the impact of PM on health in the country. The GBD estimates that there were 19 deaths/100,000 people in the UAE in 2005, equivalent to 855 deaths, as the population was 4.5 million in that year. For 2010, there were 20 deaths/100,000 people, which or 1,700 deaths in total, as the population had then grown to 8.3 million.

Nasser et al. (2015) carried out an extensive review of the published literature pertaining to the subject for the years 2000–2013, and found that the air pollution problem in developing countries is aggravated by the low utilization of public transport, the ageing vehicle fleet and the increasing number of personal cars. The concentration of particulate matter in the Middle East region is much higher than that given in the World Health Organization 2006 guidelines (i.e. that $PM_{2.5}$ = 10 µg m^{-3} as an annual average, and PM_{10} = 20 µg m^{-3}). By linking the numbers of visits and admissions to hospitals with the increase in the PM concentration, Nasser et al managed to uncovered a detrimental relationship between PM and CVD (cardio-vascular disease) within four Middle East countries: Iran, the Kingdom of Saudi Arabia, Qatar and the United Arab Emirates.

The military conflict in 1991 in the GCC region added substantially to the health risks in Saudi Arabia due to increased levels of airborne particulate matter. White et al. (2008) used a quantitative risk assessment methodology to estimate the increase in premature deaths among Saudi citizens associated with exposure to elevated PM_{10} air pollution levels from the 1991 Gulf War. Their results give a strong indication that the population of the Kingdom of Saudi Arabia suffered a substantial and adverse health impact from the environmental degradation associated with the Gulf War, where estimates show approximately 1,080 to 1,370 excess deaths from exposure to air pollution related to the war.

Figure 1-4 gives a general picture of annual mean ambient $PM_{2.5}$ concentrations in the GCC region and shows how it compares with the global picture. The GCC region experiences a $PM_{2.5}$ concentration well in excess of the WHO Guideline value, namely an annual mean of $PM_{2.5}$ of 10 µg m^{-3}. Clearly, from the map developed by the World Health Organization (WHO), the arid area of the GCC region has one of the highest concentrations of $PM_{2.5}$ globally. Although this may be partly due to the natural PM generated from the desert and from sand storm events, it is important also to understand the contribution of PM from anthropogenic sources in this region.

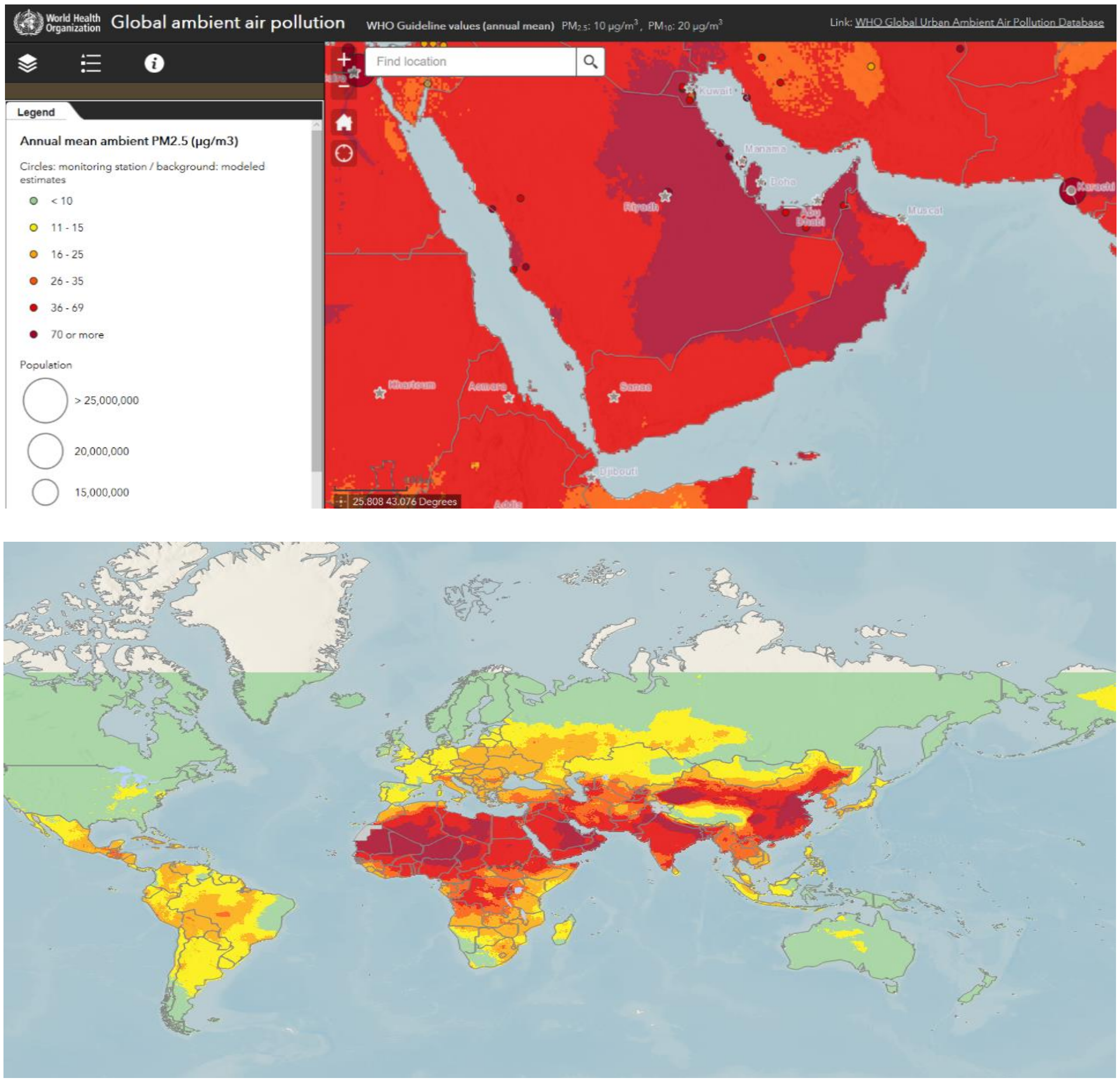

Figure 1-5: Global ambient pollution (WHO, 2016)

According to PM source apportionment studies, the largest source of PM in the GCC countries is sand dust. PM from natural sources in this region, mainly soil dust and sea salt, is characterized by elements abundant in the rocks and the soil of the earth's crust. Studies of occupational exposure have highlighted that chronic exposure to silica dusts (during dust storms) resulted in lung diseases

(Thalib and Al-taiar, 2012; Thomas, 2012; Al-jeelani, 2013; Givehchi et al., 2013; Manney et al., 2012), with Givehchi et al. (2013) reporting that the major source of dust was from the deserts of Iraq and Syria.

Sand Storms:

Although this thesis is about policies and strategies for reducing air pollution emission from human activities, it also considers natural PM emissions which have a major impact in this region because of sand storms. The region has a huge and periodic problem with natural PM, most of which is entirely natural but some of which is due to land degradation and urban development, which also have an impact on health (Farahat et al. 2003; Thalib and Al-Taiar 2012; Ebrahimi et al. 2014; Givehchi et al. 2013; Hamza et al. 2011).

The Arabian Peninsula, located in the 'dust belt', is home to the Empty Quarter or the Rub' al Khali desert, a desert that contains half as much sand as the entire Sahara Desert. The Rub' al Khali extends over portions of the Kingdom of Saudi Arabia (KSA), the United Arab Emirates (UAE), Oman, and Yemen (Farahat, 2016). The aridity of the environment means that the Arabian Peninsula is frequently exposed to major dust storms, both annually and seasonally. Countries in the Arabian Peninsula, in particular, which experience wind-blown dust storms several times each year, are recognised as one of the principal sources of global dust (Washington et al., 2003). Dust storms help the transfer of aerosols, particulates, and pollutants from one area to another across the peninsula (Farahat, 2016) and they are associated with an enormous increase in hospital admissions for respiratory conditions. However, despite the frequent dust storms that GCC countries experience, little information is available on their impact on health in the region.

Dust storms are a very frequent phenomenon in the GCC countries (Figure 1-5). Airborne dust has been found to reduce visibility to below 11 km in Saudi Arabia and neighbouring countries for more than 30% of the summer months (Kutiel and Furman 2003; Washington et al., 2003).

Figure 1-6: A typical example of a dust storm in Saudi Arabia (source: http://photo.accuweather.com/, Riyadh;October 2009)(Tsiouri et al., 2014)

Draxler et al. (2001) have predicted that dust storm events over Kuwait occur for at least 18% of the year, and Alharbi (2009), in a study looking at the situation in Saudi Arabia between 2000 and 2003, reported 33 dust storm events over the capital city Riyadh; these mostly took place from March to August.

A number of monitoring studies dealing with the Middle East (ME) indicate that the occurrence of dust storms, and also the rapid increase in the urban population, are the key reasons for the high PM concentration levels in the region. In their review of monitoring studies, Tsiouri et al. (2014) noted that the levels of both annual mean PM_{10} and $PM_{2.5}$ concentrations exceed the World Health Organization (WHO) guidelines ($PM_{2.5}$ = 10 µg m^{-3}, PM_{10} = 20 µg m^{-3}) even during most of the non-dust-storm episodes, and, as expected, the PM pollution levels become even higher during dust storm episodes, as shown in Table (1-1). These results are confirmed by a study conducted by Leveque (2015) which found that the annual average values of PM pollutants in the Middle East region are much higher than those in the World Health Organization guidelines of 2006.

Table 1-1: Summary of the field campaigns studies in Middle East Sampling (Tsiouri et al., 2014)

Sampling period	PM types	PM concentration (μg m^{-3})	country	Author
2004-2005	PM_{10} $PM_{2.5}$	Annual mean: PM_{10}, 66–93 $PM_{2.5}$, 31–38	Kuwait	Brown et al. (2008)
2006-2007	PM_{10} $PM_{2.5}$	Annual mean highest levels: PM_{10} at Tallil, 303 $PM_{2.5}$ at Tikrit, 114	Qatar, UAE, Iraq, Kuwait	Engelbrecht et al. (2008; 2009); Engelbrecht and Jayanty 2013
2007-2009	PM_{10}	24-h average, 4–1, 426	UAE	Al-Katheeri et al. (2012)
2007-2010	PM_1	High concentrations	Kuwait	Bu-Olayan and Thomas (2011)
Jan-Sep 2001	PM_{10} $PM_{2.5}$	The 24-h overall mean: PM_{10}, 87.3±47.3 $PM_{2.5}$, 28.4±25.4	Saudi Arabia	Khodeir et al. (2012)

Several epidemiological studies conducted in the Arabia Peninsula show that areas impacted by desert dust storms, such as Middle East communities, seem to have a higher prevalence of asthma (Abal *et al.*, 2010) than that in European countries, particularly in the paediatric population, where dust storm events are significantly associated with an increased risk of admission to hospitals due to asthma and other respiratory diseases (Thalib and Al-Taiar, 2012), and to cardiovascular diseases linked to the adverse effects of PM (Farahat, 2016).

Dust storms can also have a considerable impact on the hydrological cycle, on climate variability, and on ambient air quality (Golitsyn & Gillette, 1993; Kaufman et al., 2002; Miller et al., 2004; Parungo et al., 1995; Prospero et al., 2002; Ramanathan et al., 2010; Tegen et al., 1996). This is because they cause significant perturbations in the radiation-energy balance of the earth's atmospheric system, as well as perturbations in atmospheric heating and stability (Alpert et al., 2004), in chemical and biological ecosystems (Singh et al., 2008), and in ambient air quality and human health (Nastos et al., 2011). These effects will be discussed in more detail in section 1.3.4 on global warming.

1.2.1.2 Indoor Air Pollution

Although the Global Burden of Disease (GBD) study shows that indoor household air pollution has a much smaller effect on human health in the GCC countries than does outdoor PM pollution, other studies carried out in various locations in the region, some quantifying and some estimating the impact of indoor air pollution on health, reveal that it still has a notable effect on health.

A study conducted by Yassin et al. (2012) in Kuwait and measuring indoor $PM_{2.5}$ in different residential areas shows that Kuwait ranks among the worst countries for indoor residential pollution, as illustrated in Figure 1-6. The high indoor particulate concentrations found can be attributed to a number of factors, such as the indoor use of electricity generators, the cooking methods, incense burning in houses and other human activities (Yassin et al., 2012). It is worth mentioning here that burning incense is not only an important part of the GCC culture, but also an almost daily activity which has been linked with the number of hospital visits made by those with asthma. Figure 1-6 shows that indoor particulate levels in Kuwait were two to three times higher than those found in houses in the United States, the United Kingdom and Greece, although lower than those in Thailand, China and Hong Kong.

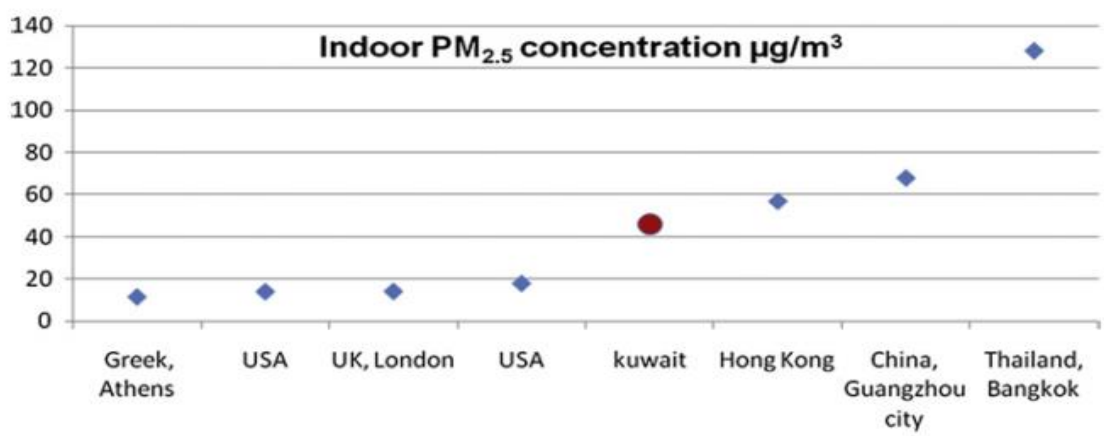

Figure 1-7: Comparison of indoor residential mean $PM_{2.5}$ concentrations in the Kuwait study sample with other selected countries/cities (Yassin et al. 2012)

Yeatts et al. (2012) conducted a population-based study of indoor air pollution and health in the United Arab Emirates (UAE), and measured a number of indoor air pollutants: sulphur dioxide (SO_2), nitrogen dioxide (NO_2), hydrogen sulphide (H_2S), formaldehyde (HCHO), carbon monoxide (CO), and particulate matter. The results showed that participants in households with quantified SO_2, NO_2, and H_2S (i.e., with measured concentrations above the limit of detection) were twice as likely to report doctor-diagnosed asthma as participants living in households with no quantified concentrations. Quantified HCHO was associated with neurological symptoms and the daily burning of incense with increased headaches, difficulty concentrating, and forgetfulness.

Cohen et al. (2013) conducted a hazard assessment of exposure to incense smoke in the United Arab Emirates. Both particulate (PM) concentrations and sizes were measured, as were the gases carbon monoxide (CO), sulphur dioxide (SO_2), oxides of nitrogen (NO_x), formaldehyde (HCHO), and carbonyls. The hazard evaluation based on this study suggests that incense burning contributes to indoor air pollution and could be harmful to human health.

In Oman and the GCC region in general, indoor air pollution and its sources have become of increasing concern due to the fact that indoor ventilation is very limited, and that people spend over 90% of their time indoors because of the hot weather (high temperature and humidity) that lasts for around nine months of the year. Burning incense is a popular practice inside residential homes in Oman and other Gulf countries. Arabian incense (bakhour) is one of the most common sources of indoor smoke and individuals are frequently exposed to it. Due to its slow and incomplete combustion, incense burning produces continuous smoke, generating pollutants such as toxic gases and chemical particles including polycyclic aromatic hydrocarbons, carbon monoxide, benzene, and isoprene; these easily accumulate indoors, especially where there is inadequate ventilation (Cohen et al. 2013, Al-Rawas et al. 2009).

Oman ranks near the top in the global ranking of symptoms taken to indicate severe asthma, according to the International Study of Asthma and Allergies in Children (ISAAC). Asthma is common in Omani children with prevalence rates of 10.5% and 20.7% in 6–7 and 13–14 year- old children respectively (Al-Rawas et al., 2009). However, Al-Rawas et al. (2009) found that while burning Arabian incense at home is a common trigger of wheezing among asthmatic children in Oman, a cross-sectional study of 2,441 school children indicated that it was not itself associated with asthma. These results suggest that other sources of air pollution may also cause asthma in Omani children.

A study focused on indoor air pollution in the GCC region finds that throughout the entire GCC, VOCs, NO_2, SO_2, PM_{10}, $PM_{2.5}$, heavy metals, and CO_2 were the most dominant indoor air pollutants found in homes, schools, cafés, and office buildings. The main sources of these pollutants were the infiltration of ambient air, the burning of Arabian incense, and smoking (Amoatey et al., 2018).

In Oman, as in other GCC countries, indoor smoking is still an accepted habit in many public locations and residential homes. Al-Lawati et al. (2015) analysed the amount of $PM_{2.5}$ emissions from second-hand indoor smoke in thirty different public places in Muscat, and found to be (about 562 µg m^{-3}). This was higher than that of the highest average concentration of $PM_{2.5}$ occurred in cafés (256 µg m^{-3}) that offered water pipes (or shisha) for smoking, offices (11 µg m^{-3}), and transport passengers' waiting rooms (43 µg m^{-3}). The health effects from exposure to these $PM_{2.5}$ emissions might well be exacerbated because of the long periods of time that people spend at cafés, especially during the evenings and at night (Amoatey et al., 2018).

Although this thesis does not focus on indoor air pollution, it should be borne in mind that, in addition to exposure to ambient PM, this may also be an important factor having an adverse health impact in the region.

1.2.1.3 Ozone

Air pollutants can be classified in two ways: they are either primary pollutants, which are emitted directly into the atmosphere, or they are secondary pollutants, which are the products of chemical reactions taking place between the primary pollutants in the atmosphere. Tropospheric ozone (O_3), for example, is a secondary pollutant formed by the reaction of the primary pollutants Non-Methane Volatile Organic Compounds (NMVOC), NO_2, CH_4 and CO in the presence of sunlight; it is produced at a higher rate in higher temperatures. Ground level O_3 is a major constituent of smog in urban areas, where motor vehicles are the main anthropogenic emission source of its precursors (Jallad and Espada-Jallad, 2010).

Ettouney et al. (2010) collected and assessed air pollution data for major pollutants beside O_3 from two monitoring stations in Kuwait over a period of four years, from 2001 to 2004. They found that the measured levels of O_3 were well below the international standards and that ozone formation actually decreased at higher ambient temperatures. This was also concluded by Abdul-Wahab et al. (1996) in their study of O_3 levels in the Shuaiba industrial area in Kuwait; they found a positive correlation between O_3 levels and temperatures below 27°C, while a negative correlation existed for temperatures above 27°C.

Jallad & Espada-Jallad (2010) monitored ambient tropospheric levels of O_3 and its precursors NO_2, and NMVOCs in the Salmiyah, a densely populated area of Kuwait, over a period of 12 months from March 2008 to February 2009. The results of this study indicated that O_3, NMVOC and NO_2 exceeded the ambient air quality standards during specific times of the year and that serious health effects were expected to result from exposure to such levels. The daily patterns for NO_2 and NMVOC showed three peaks, which were directly dependent on high traffic density. It is predicted that the pollutant levels will rise in the future along with increasing traffic density and in the absence of regulations controlling vehicle emissions.

After PM, O_3 is most likely to be the second greatest pollutant contributor to disease-causing ambient air pollution in the United Arab Emirates. Li *et al.* (2010) estimated that anthropogenic O_3 caused about 62 (95% CI: 17–127) premature deaths in the country in 2007, accounting for 0.8% of the total deaths in that year.

In Saudi Arabia, Porter et al. (2015) conducted an analysis of daily O_3, NO_x, and particulate matter (PM_{10}) concentrations for two years, 2010 and 2011, at sites in and around the coastal city of Jeddah. Within Jeddah, O_3 was found to be remarkably low overall, though there was a significantly higher weekend O_3, but reduced NO_x concentrations. In contrast, there were much higher PM_{10} concentrations than those in North American cities of similar climatology, though levels were comparable to those in other large cities within the Middle East. The strong weekend effect indicates increased health risks for pilgrims attending the annual Hajj.

In Oman itself, ground level ozone (O_3) concentrations were measured across the Sohar highway, for a four-month period from September to December 2014. The monthly average concentration of O_3 was found to vary from 19.6 to 29.4 ppb. This is considered to be under the acceptable level for human health.

Although few studies so far have investigated the link between both short-term and long-term exposure to ground-level O_3 and mortality in the GCC region, scientific evidence worldwide increasingly supports the view that ground-level O_3, even at low levels, can damage people's health, causing (among other problems) increased rates of hospital admissions, exacerbation of respiratory illnesses and premature mortality (Levy et al. 2005, Ito et al. 2005, Bell et al. 2005).

Incidentally, there are potential effects on agriculture as well as on health. It has been known for some time that elevated rates of ground-level ozone damages crops and reduces yield. Although, to the researcher’s knowledge, there has never been an estimate of the total crop losses attributable to tropospheric O_3 in the Sultanate of Oman, such estimates would be useful for projections of future food production, and also for setting regulatory standards for reducing ground-level O_3.

Since CO, CH_4, NMVOC, and NO_X are chemical compounds which, in the presence of solar radiation, react with other chemical compounds to form ozone in the troposphere, high ozone levels are to be expected in Oman because of the high temperatures and levels of sunlight, and also because the oil industry is very likely to be a source of reactive VOC emissions. While this is worth noting, this thesis will not focus on tropospheric ozone nor on its impact on human health and crop yields.

In summary, the studies reviewed in this section address linkages between air pollution and its impact on health demonstrate clearly that this is an important issue for the region. There has been a tremendous increase in air pollution-related premature deaths both in Oman and other GCC countries and this is likely to keep increasing if no action is taken. This thesis will therefore develop emission inventories for Oman, and will also use the LEAP-IBC tool to estimate the impact on health from exposure to $PM_{2.5.}$ The aim of this is to help persuade policy makers to become more engaged with the issue and to demonstrate how a SLCP-focussed strategy can contribute to a better future for the region.

1.2.2 Main sources of air pollution in the region

In 2012–13, air pollution load assessments were conducted in Bahrain, Kuwait, and Qatar as part of the Gulf Environmental Partnership and Action Program national activities phase (Eastnorth, Region and Country, 2016). Results showed that vehicles and power generation are the major sources for fine PM emissions (PM_{10} and $PM_{2.5}$), while re-suspended dust dominates for the coarse particulate matter emissions (>PM_{10}). There are mixed emission sources for SO_2, NO_x, VOC, and CO, with industry, refineries, and the power generation sector dominating (Eastnorth, Region and Country, 2016). Countries in the Arab_region are highly reliant on personal transport. For example, the number of vehicles per 1000 inhabitants is 378 in Qatar, 357 in Kuwait, 336 in Saudi Arabia, and 322 in Bahrain, t with the result that the transport sector is responsible for approximately 90% of total emissions of carbon oxides (CO_2 + CO) in these Arab countries (Tolba and Saab, 2008).

There are similar evidence from the increase of nitrogen oxides observed by Ettouney et al. (2010) from two monitoring stations in Kuwait; this was related to the increase in the number of motor vehicles and the expansion in power generation and industrial activities. Other pollutants covered by Ettouney's study, namely carbon monoxide, carbon dioxide, sulphur dioxide, ozone, and particulate matter, showed pollutant concentration trends similar to those in other locations around the world and were well below limits set by the international bodies. The only exception was particulate matter, which was at a higher level because of the stations' proximity to the desert (Ettouney *et al.*, 2010).

Omidvarborna et al. (2018) conducted a review aiming to identify the major sources of air pollutants in the hot and arid/semi-arid climate of the GCC region. They investigated the main categories contributing to specific pollutants (CO_2, CO, PM, NO_x, O_3, SO_2, VOCs, polycyclic aromatic hydro-carbons (PAHs), and persistent organic pollutants (POPs)). The findings indicated that sand, dust (natural and anthropogenic, such as cement, metal, stone cutting industries), the chemical industries (refinery, petrochemical, etc.) and transportation activities were the major contributors to overall air pollution in the GCC countries.

According to the literature, then, Oman's leading air pollution sources are the transport, energy and industrial sectors, with the energy sector, which primarily produces fossil fuels, being the biggest contributor of CO_2 and CH_4. The agriculture sector in Oman is still developing and currently only about 2% of Oman's total land area is used for agricultural purposes (Abdul-Wahab, et al. 2012), so no agriculture-related emissions were observed.

The different sources of emissions in Oman will be discussed in detail in Chapter 2, and the key sources identified that may contribute most to impacts on health and climate, to be analysed in Chapter 5.

1.3 Climate change:

Climate change is one of the most serious environmental global and transboundary problems in this century (Hoel, 2005). Emissions are linked to both air quality and climate change, with increasing levels of emissions influencing the energy balance between the atmosphere and the Earth's surface and, in turn, causing temperature changes that alter the chemical composition of the atmosphere. Climate change management and air pollution management thus have consequences for each other (Change and Trends, 2011; Peter Gilruth, 2011; IPCC, 2013; Akhmat *et al.*, 2014; Watts *et al.*, 2015)

Climate change is now well-known and well-accepted, as shown by evidences of increases in the average global temperature of air and ocean, the extensive melting of snow and ice, and the rise in the global sea level (Frich et al., 2002; Alexander et al., 2006; Barker, 2007; Dai, 2011; Alsarmi and Washington, 2014). The rise in sea-level, brought about by rising temperatures, has the potential to cause the loss of significant portions of agricultural land in the Arab region. For example, a one metre rise in sea level could reduce Qatar's land area by 2.6%. Indeed, any rise in the sea level would very probably have a negative impact not only on the agricultural sector, but also on the industrial and tourism sectors, on urban areas and on the economy in a number of Arab countries (Tolba and Saab, 2008).

From the economic perspective, an important issue for the Middle East and GCC countries would be if climate change affected the annual income from the date palm (*Phoenix dactylifera* L.). If climate change affected areas where the date palm currently occurs, and made them climatically unsuitable, the economies in those areas could suffer (Shabani et al., 2012). Indeed, there has already been a decline in date palm production in Middle Eastern countries, according to observations made between 1990 and 2000 (Zaid, 2002; Jain 2011).

Although the Arab region, including the GCC countries, contributes less than 5% to the causes of global climate change, the effects on the region will be very severe (Tolba and Saab, 2008). In fact, the region is considered highly vulnerable to the impact of climate change due to its arid climate, scarce water resources, and its long coastal stretches that are threatened by rising sea levels. Natural and physical systems in the region are already facing heavy pressure, and this will only be intensified as temperatures in the region rise and/or precipitation decreases.

1.3.1 GHG emissions inventory in Oman and the GCC region:

Exponential population growth, together with rapidly expanding industrialization, urbanization and transportation, are causing an enormous increase in energy consumption, which has resulted in increased anthropogenic greenhouse gas emissions (GHGs) such as carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). The elevated levels of these greenhouse gases in the atmosphere is linked to considerable variations in daily, seasonal, annual and decadal variabilities in our climate (IPCC, 2013).

From 1972, Oman has been importing fewer refined petroleum products than before, as the country has started producing these itself, both for local use and even for export. It was expected that the increased consumption of liquid fossil fuels and natural gas would lead to a significant increase in the country's CO_2 emissions over the years (Abdul-wahab *et al.*, 2015). That has indeed been reflected in the CO_2 inventory for Oman, an inventory which was developed to monitor the energy sector over the last 42 years, from 1972 to 2013, and was done by Abdul-wahab et al. (2015) in accordance with the IPCC reference approach. The findings indicate that there have been drastic increases in the amount of petroleum products and natural gas produced in Oman over the years. There have also been great increases in the amount of petroleum products and natural gas consumed locally and in the CO_2 emissions resulting from this consumption, with the gas sector having a much greater impact on the increase of CO_2 emissions than crude oil, as shown in Figure 1-7 (Abdul-wahab *et al.*, 2015).

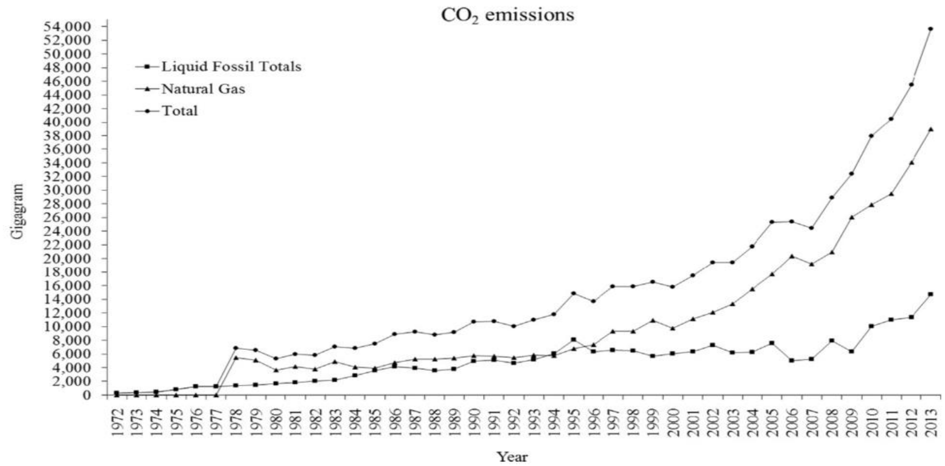

Figure 1-8: Estimated CO_2 gas emission in Oman from 1972–2013 (Abdul-wahab et al., 2015)

Another emission inventory was drawn up by Qazi et al. (2016); its aim was to estimate both the Municipal Solid Waste (MSW) generation in Oman over the period from 1971 to 2030, and also the annual CH_4 emissions from that generated waste. The estimate of total waste generation was carried out using an existing model, while the CH_4 emissions estimate was made using the default method set out by the Intergovernmental Panel on Climate Change (IPCC). It was found that the total MSW generation in Oman might reach 3,089 gigagrames (Gg) by 2030 and would account for approximately 85 Gg of methane emissions. This is an enormous increase over the figure of 142 Gg in 1971 and that of 1,464 Gg in 2010 (Qazi et al. 2016; Abushammala et al. 2016). Figure 1-8 shows that the CH_4 emissions rate increased by about 1 Gg annually between 1971 and 2011, increasing to an estimated 2.4 Gg per year between 2012 and 2030.

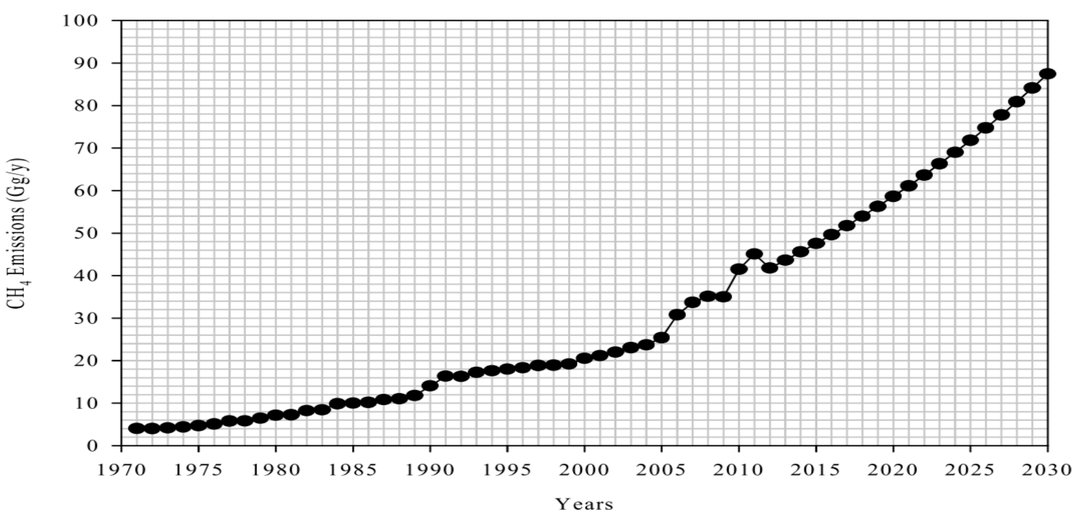

Figure 1-9: Estimated CH_4 emissions from MSW in Oman from 1971–2030 (Qazi et al. 2016)

Both inventories clearly show that two of the main GHG emission sources in Oman are increasing exponentially. Although the sources of those emissions are not the same, fast economic development and urbanisation are driving forces for the production of both waste and oil/gas. Evidence of this link is also clear in the results of studies of the nexus between environmental pollutants, energy consumption and economic growth; a number of studies prove the existence of a bi-directional causal relationship between energy consumption and economic growth in both the Middle East and North Africa (MENA) in general and the GCC region in particular (Omri, 2013; Salahuddin and Gow, 2014; Jammazi and Aloui, 2015).

Alhaddad et al (2015) conducted an emission inventory in urban areas in the vicinity of oil refineries in Kuwait over a period of one year, aiming to to predict pollutant concentrations and distributions; their study used the AERMOD software (V5.1), Industrial Source Complex Short-Term model (ISCST3). The pollutants investigated included CO, CO_2, SO_2, NO, NO_2, O_3, PM_{10}, hydrogen sulphide (H_2S), ammonia (NH_3), methane (CH_4), NMHC, and total hydrocarbons (THC). It was found that the measured concentrations of all pollutants were higher than the predicted concentrations, which was attributed to the contribution of other sources of pollution, with the strongest effect coming from the oil fields, followed by traffic and oil refineries (Alhaddad et al, 2015).

At the global level, the majority of Intended Nationally Determined Contributions (INDCs) submitted cover seven categories of gases (CO_2, CH_4, N_2O, HFCs, PFCs, SF_6, NF3). In the GCC, however, the coverage of gases varies according to country. Some GCC countries have a relatively large coverage, such as Oman, which chose to target CO_2, CH_4, N_2O, HFCs, and PFCs, and Kuwait, which accounted for CO_2, CH_4 and N_2O emissions. However, other countries in the region, such as Bahrain, cover only CO_2 and N_2O. The UAE is the only GCC country which has indicated in its INDC submission that it has launched a process to develop a full national inventory of greenhouse gas emissions (Eastnorth, Region and Country, 2016). This indicates the types of emissions data available within the GCC countries.

According to the IPCC's 4th assessment report, globally "The largest growth in GHG emissions between 1970 and 2004 has come from energy supply, transport and industry, while residential and commercial buildings, forestry (including deforestation) and agriculture sectors have been growing at a lower rate" (Barker, 2007).

The Middle East and North Africa (MENA) region, which includes the GCC countries, accounts for around 6% of the world's population, but is producing around 7% of worldwide greenhouse gases

(GHGs). More importantly, in the last two decades, MENA's emissions grew by 88% (Sileem, 2015). Three of the GCC countries, Saudi Arabia, the UAE and Qatar, have already been identified as the largest per capita CO_2 emitters in the world (Hertog and Luciani 2010).

Energy consumption in the GCC region is based on conventional, non-renewable resources originating from its 40% of the world's proven oil reserves and 23% of natural gas resources (Saddam, 2012). Fossil fuel extraction has shaped the economy of most of the GCC countries, where all except Oman and Bahrain are members of the Organization of Petroleum Exporting Countries (OPEC). Hence, fossil fuels are the main source of energy, and this has resulted in considerable climate change emissions. Oil-producing countries such as Qatar, the UAE and Kuwait rank among the world's top per capita emissions relative to per capita income (Baehr, 2009) and the GCC countries in general have uniquely high per capita emissions of carbon dioxide (CO_2), as shown in (figure 1-9). This is partly due to the fact that some of them have tiny populations, but energy intensity is also an undeniable feature (Hertog, Steffen, 2010). In 2010, for example, Iran and KSA produced 65% of the region's fossil-fuel-related carbon dioxide (CO_2) (Farzaneh, Mclellan and Ishihara, 2016).

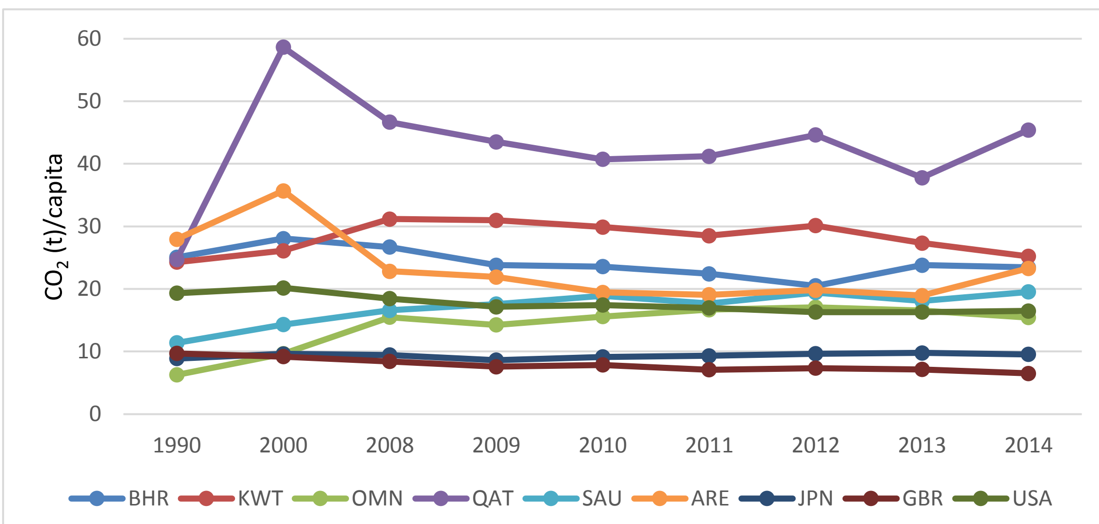

Figure 1-10: GCC CO_2 emissions (t) / capita compared with USA, UK and Japan, (based on World Bank data) (World Bank, 2018)

The GCC countries also have very high rates of per capita electricity consumption, already surpassing the level of major industrial countries. Qatar and Kuwait, for example, have higher per capita electricity consumption levels than the United States (Hertog and Luciani 2010) (Figure 1-10).

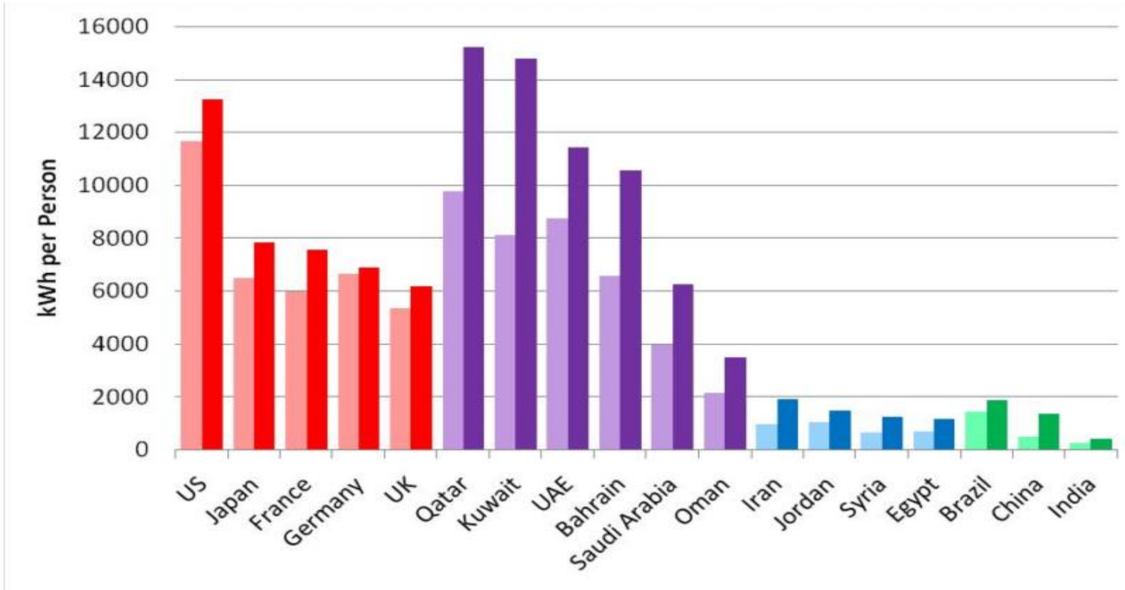

Figure 1-11: Per-capita electricity consumption of selected major developed (red), GCC (purple), regional (blue), and major developing nations (green) for 1990 and 2003. Lighter, left-hand bars, are for 1990; darker, right-hand bars, are for 2003 (Hertog and Luciani 2010)

Chaaban (2008) notes that the 2007 Annual Report of the Centre for Global Development placed KSA and Kuwait amongst the 50 countries with the highest CO_2-emitting power sectors in the world. Saudi Arabia was ranked 22nd with 75,900,000 tons and Kuwait 48th with 19,000,000 tons (Tolba and Saab, 2008).

Salahuddin & Gow (2014) examined the empirical relationship between economic growth, energy consumption and carbon dioxide emissions in the GCC countries. Their results indicate a significant association between energy consumption and CO_2 emissions and also between economic growth and energy consumption; these links exist both in the short- and the long-run. Although the GCC countries are participating in efforts to reduce their GHG emissions, these attempts have not so far been sufficient to address the increased GHG emissions in the region, because of the rapid growth in the countries' economies and in increased urbanization.

1.3.2 Weather extremes

Few studies on changes in climate extremes can be found for the Middle East, mainly due to the poor data network in Arab countries and limited access to long daily data sets. Donat et al. (2014) examined the temporal changes in climate extremes in the Arab region, with their study based on data from sixty stations in Arab countries; this data was collected during a workshop held in 2012. They found increased frequencies of warm days and warm nights and higher extreme temperature values.

According to modelling studies (Tolba and Saab, 2008), the Arab region will face an increase of 2 to 5.5°C in the surface temperature by the end of the 21st century. This temperature increase will be coupled with a projected decrease in precipitation of between 0 and 20%. Other predictions for the region include shorter winters, dryer and hotter summers, a higher rate of heat waves, increased weather variability, and a more frequent occurrence of extreme weather events (Tolba and Saab, 2008).

Figure 1-11 shows that over the Arabian Peninsula, namely in Oman, the United Arab Emirates (UAE), Qatar, Bahrain, the Kingdom of Saudi Arabia (KSA), Kuwait and Yemen, the temperature and precipitation regimes appear to be very closely coupled ($r = -0.456$, $p = 0.01$), more so than other figures for global anomalies (Alsarmi and Washington, 2011). Since 1998, sustained negative precipitation anomalies have been matched by sustained positive temperature anomalies.

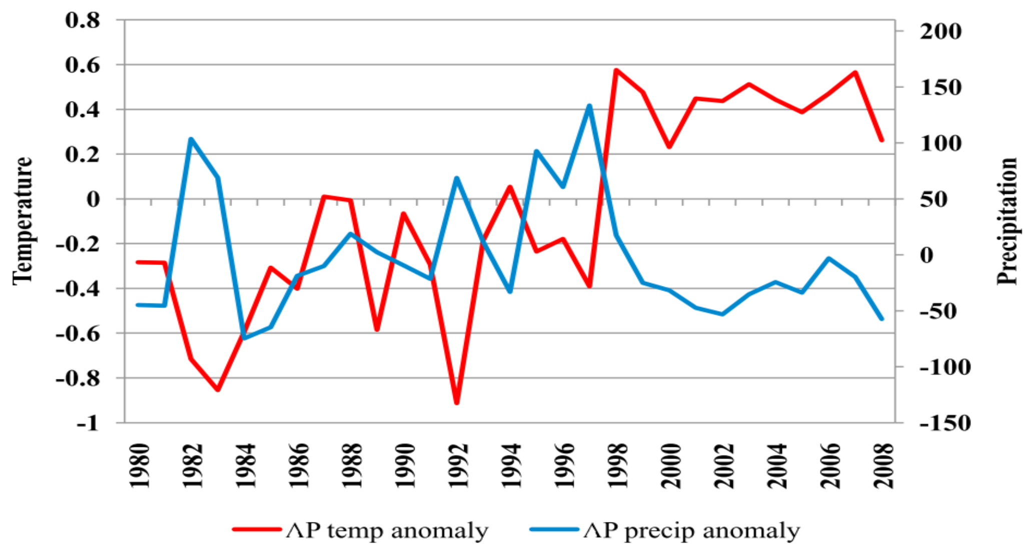

Figure 1-12: All Arabian Peninsula annual anomalies time series for both temperature and precipitation for the period 1980-2008 (Alsarmi and Washington, 2011)

Figure 1-12 shows globally averaged surface and ocean temperatures since 1850 (relative to 1961–1990 levels) and illustrates the global warming trend since the 1950s reported in Rice et al. (2014). Global temperatures rose 0.6 to 0.78 °C from 1951 to 2010. Disruption of the global climate promotes extreme weather patterns (heatwaves, droughts, thunderstorms and heavier precipitation, hurricanes, floods, desertification, and sand storms).

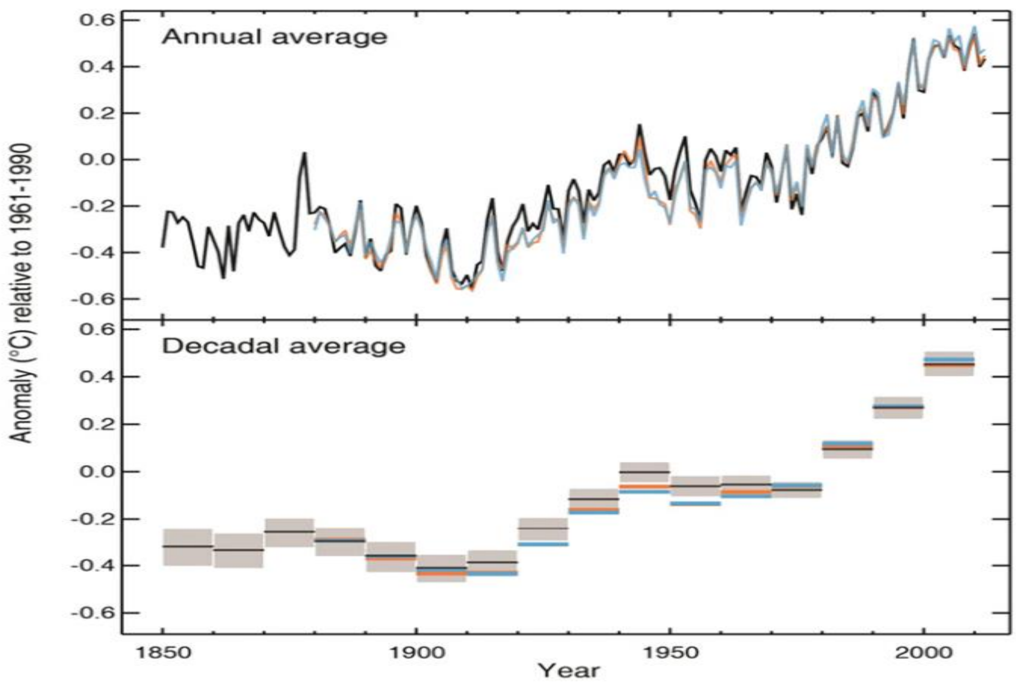

Figure 1-13: Observed globally averaged combined land and ocean surface temperature anomaly from 1850 to 2012 from three datasets used by the Intergovernmental Panel on Climate Change. Bottom panel: decadal mean values including the estimate of uncertainty for one dataset (black) (Rice et al., 2014)

A number of observation-based studies indicate significant positive trends of temperature extremes in the Eastern Mediterranean and Middle East (EMME) region (Tanarhte et al. 2015; Lelieveld et al. 2014; Kostopoulou and Jones 2005; Kuglitsch et al. 2010; Efthymiadis et al. 2011). Global and regional climate projections suggest that in addition, this region is likely to be subjected to continuous heat stress intensification throughout the twenty-first century (Sánchez *et al.*, 2004; Giorgi, 2006; Diffenbaugh *et al.*, 2007; Fischer and Schär, 2010; Lelieveld *et al.*, 2014).

The impacts of climate change have already been felt in Oman, which has recently experienced a greater frequency of heatwaves, droughts and occurrences of heavy rainfall. Along with a greater number of hot days, there has been a steady increase in the daily minimum and maximum temperatures, which has also increased the severity of tropical cyclones in the region (Abdul-Wahab, et al. 2012).

AlSarmi and Washington (2011) examined trends in temperature for the Arabian Peninsula, over a period of more than twenty years (1985-2008). They found that the general pattern of the Arabian Peninsula mean annual temperature trend is one of warming. Figure 1-13 compares mean annual temperature trends for individual stations within the Arabian Peninsula with global trends. Some site-specific stations reported significant mean temperature warming at more than 1.5–3.5 times the global rate (Alsarmi and Washington, 2011). Figure 1-14 and Table 1-2 illustrate the location of the different stations covered by the study by Alsarmi and Washington.

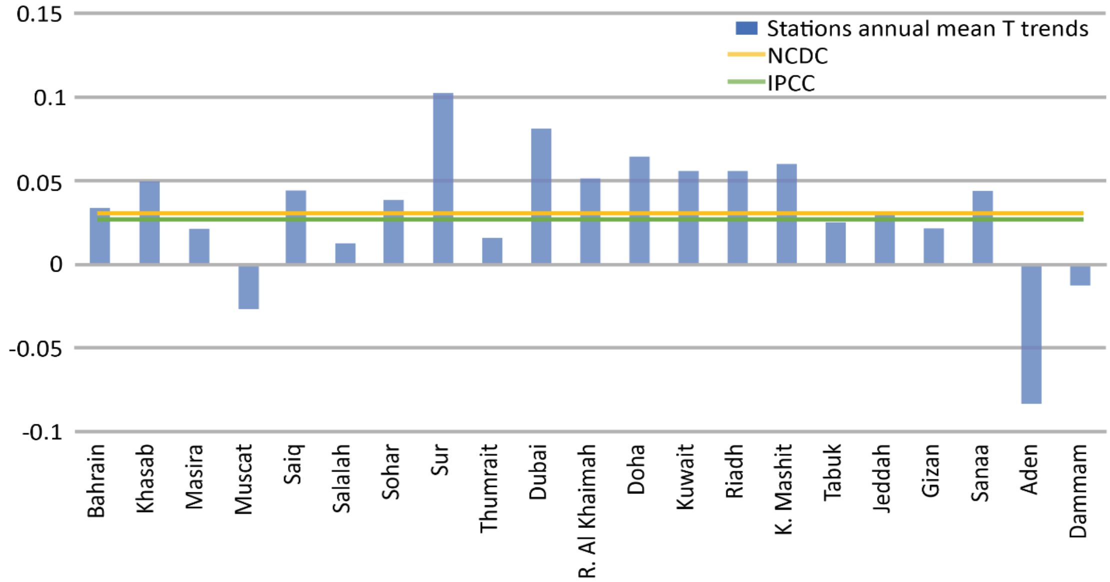

Figure 1-14: Arabian Peninsula stations mean annual temperature trends for the period 1980-2008 except Saudi Arabian stations (1985-2008) in ˚C per decade relative to global mean annual temperature according to IPCC, (NCDC) is National Climate Data Center (Alsarmi and Washington, 2011)

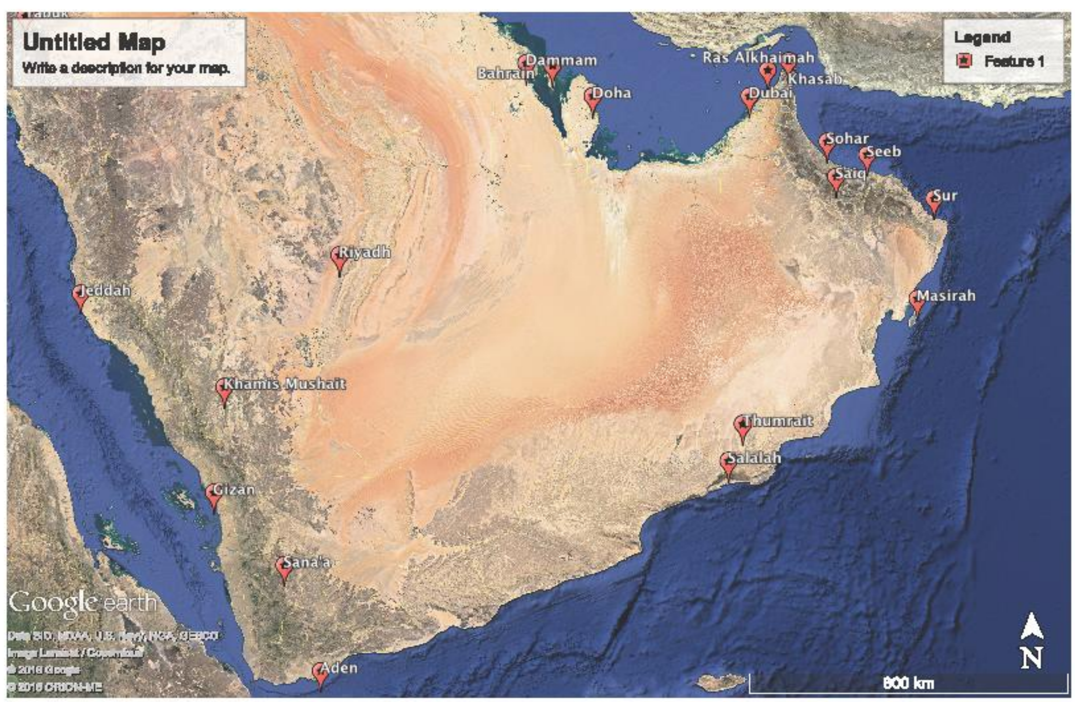

Figure 1-15: Arabian Peninsula weather monitoring stations

Table 1-2: Arabian Peninsula stations (Alsarmi and Washington, 2011)

COUNTRY	STATION
OMAN	**Salalah, Masirah, Saiq, Seeb, Sur, Thumrait, Khasab, Sohar**
UAE	**Dubai, Ras AlKhaimah**
BAHRAIN	**Bahrain**
QATAR	**Doha**
KUWAIT	**Kuwait**
SAUDI ARABIA	**Tabuk, Riyadh, Jeddah, Khamis Mushait , Gizan, Dammam**
YEMEN	**Sana’a, Aden**

Alsarmi & Washington (2014) also ran another study to observe climate extremes over the Arabian Peninsula covering GCC countries (Bahrain, Qatar, Kuwait, Oman, Saudi Arabia and the UAE) with different data periods, the longest being from 1943 to 2008. It indicates a consistent pattern of trends in daily temperature extremes over the Arabian Peninsula that is related to significant warming; there were general decreasing trends of cold temperature extremes and increasing trends of warm temperature extremes during the periods of analysis (Alsarmi and Washington, 2014). These results are generally in line with what has been observed in other parts of the world during the second half of the twentieth century (Frich et al., 2002; Alexander et al., 2006).

1.3.3 Heatwaves

The heatwaves that engulfed the Middle East in August 2015, with a combination of high temperature and humidity, came close to breaking meteorological records across the region (The Guardian 2015a) with temperatures averaging between 48 and 51 °C in Iraq (The Guardian 2015b). It was also reported that in Iran, on Friday 31 July 2015, the combination of an actual temperature of 46 °C and a dew point temperature of 32 °C produced an apparent (i.e. what it feels like) temperature of 73 ◦C (AccuWeather, 2015).

Pal and Eltahir (2015) have argued that if climate change is unchecked, the Middle East will suffer heatwaves beyond the limits of human survival. They examined how a combined measure of temperature and humidity, called wet bulb temperature (WBT), would increase if CO_2 emissions continue on current trends and the world warms by 4 °C this century, and they also investigated the impact of climate change on heat stress. Figure 1-15 shows a model ensemble average of the 30-year maximum TW_{max} temperatures for historic, RCP4.5, and RCP8.5 GHG concentration scenarios (a, b, c) and T_{max} temperatures for historic, RCP4.5, and RCP8.5 GHG concentration scenarios (d, e, f). In which T_{max} and TW_{max} are the daily maxima of dry-bulb temperature (T) and wet-bulb temperature (TW) averaged over 6 h, respectively.

RCP4.5 and RCP8.5 are two GHG concentration scenarios assumed based on the IPCC Representative Concentration Pathway (RCP) trajectories, which predict impacts of future climate change towards the end of the century (2071–2100). RCP8.5 represents a business-as-usual scenario, whereas RCP4.5 considers mitigation.

Under the historic GHG scenario, (1976–2005) the ensemble average of the largest TW_{max} event exceeds 31 °C, primarily in the Gulf and surrounding coastal regions. Under RCP8.5, the area characterized by TW_{max} exceeding 31 °C expands to include most of the Southwest Asian coastal regions adjacent to the Gulf, the Red Sea and the Arabian Sea (Figure. 1-15),with several regions in the Gulf and surrounding coasts exceeding the 35 °C threshold (Pal and Eltahir, 2015).

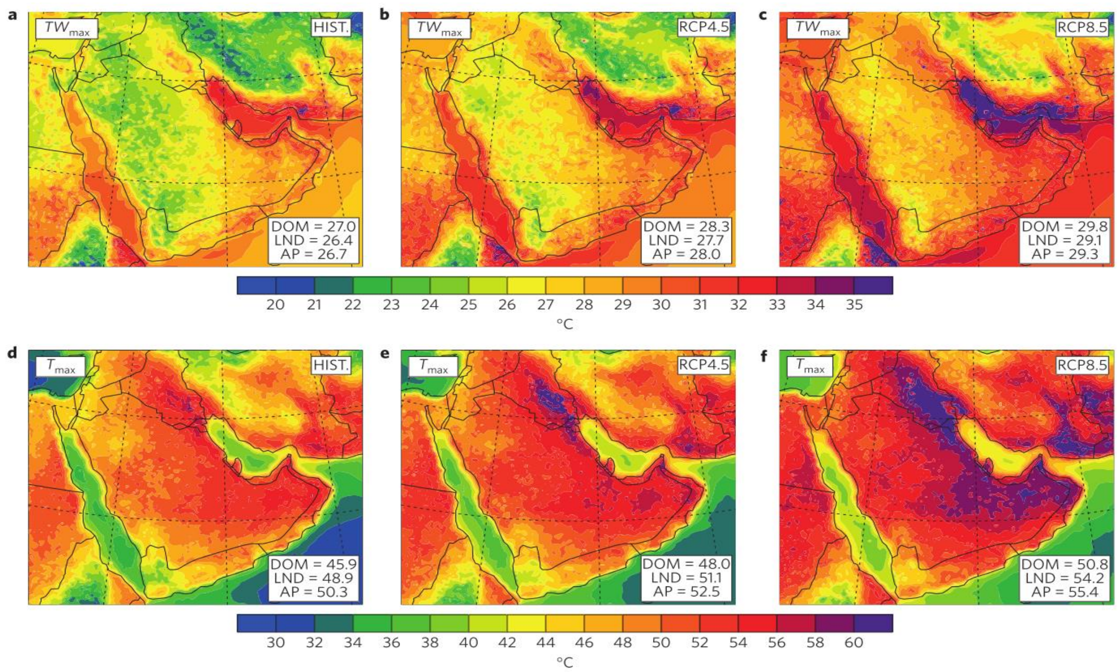

Figure 1-16: Spatial distributions of extreme wet bulb temperature and extreme temperature. a–f, Ensemble average of the 30-year maximum TW_{max} (a–c) and T_{max} (d–f) temperatures for each GHG scenario: historical (a,d), RCP4.5 (b,e) and RCP8.5 (c,f). Averages for the domain excluding the buffer zone (DOM), land excluding the buffer zone (LND) and the Arabian Peninsula (AP) are indicated in each plot. TW_{max} and T_{max} are the maximum daily values averaged over a 6-h window (Pal and Eltahir, 2015)

This means that, in the absence of significant mitigation, climate change is likely to severely impact human survivability in the region in the future. It is for this reason that this thesis places such a strong emphasis on investigating the impacts of climate change (chapter 5) and proposing a mitigation policy (chapter 4) which would have multiple benefits for both climate and air quality.

1.3.4 Global warming:

The 2013 IPCC report stated that global warming is "unequivocal" and that the observed warming since the 1950s is primarily due to human activity (Rice et al. 2014; IPCC 2013). No longer is global warming something only facing future generations. There is virtually no dispute among climate scientists that the Earth's climate system is warming. Changes to our climate are today being documented all across the planet. The world has already warmed by 1°C since the middle of the 19th century and, at the current rate of warming (IPCC, 2018), could reach 1.5°C before the middle of this century. It is also clear from the preceding section that the GCC countries in particular appear to be experiencing elevated temperatures.

Air pollutants can travel thousands of kilometres from one part of the world to another. Satellite data clearly shows that emissions can be transported half way around the world within a week. The lifetime of a CO_2 molecule in the atmosphere is more than sufficient time for the billions of tons of man-made CO_2 to uniformly cover the planet, no matter whether they are emitted from Asia, North America or Africa (Ramanathan and Feng, 2009).

As early as 1896 (Arrhenius, 1896), it was found that CO_2 in the Earth's atmosphere causes an imbalance between infrared light–transmitting and –absorbing properties and an increased back-radiation effect in the atmosphere that elevates the temperature both at the surface and in the lower atmosphere. Excess CO_2 is being emitted into the atmosphere during the burning of fossil fuels, with industrialization the key factor that has caused the dramatic increase in CO_2 levels and indeed continues to cause its frightening increase. In their 2013 report, the Intergovernmental Panel on Climate Change (IPCC) concluded that a 40 % rise in CO_2 has been recorded since preindustrial times, and have reached levels "unprecedented in at least the last 800,000 years" (Rice *et al.*, 2014)

Air pollutants and climate change have a complex interaction with each other. Some pollutants, such as black carbon and ozone, increase warming by trapping heat in the atmosphere, while others, such as sulphur dioxide, form light-reflecting particles which have a cooling effect on the climate (European Commission, 2010). For example, PM is made up of many different chemical components with different physical properties. Their impact on climate depends on their ability to absorb or reflect sunlight, so that some are warming (e.g., black carbon) while others are cooling (e.g., sulphates, organic carbon and nitrates). Black carbon, for example, a component of soot particles, contributes to global warming by absorbing sunlight, thereby heating the atmosphere (Forster et al., 2007). Do you mean facing

Ramanathan & Feng (2009) stated that "Globally, the surface cooling effect of aerosols may have masked as much 47% of the global warming by greenhouse gases, with an uncertainty range of 20–80%". They concluded that net surface cooling due to aerosols is about 1.2 °C. Based on the build-up of greenhouse gases from pre-industrial times to the present, the planet is already facing a surface warming of 2.4 °C. Of this about 0.6 °C has already been attributed to GHGs, about 0.5 °C is stored in the oceans and will manifest in the next few decades, and the balance of 1.3 °C will occur if we eliminate cooling aerosols (Ramanathan and Feng, 2009). Thus, about half of actual global warming to date is being masked by cooling aerosol particles (Solomon and Qin 2013; Ramanathan et al. 2005; Jacobson 2009). It follows that, as such particles are removed by the clean-up of air pollution, about half of the hidden global warming will be unmasked (Figure 1-16). This factor alone indicates the urgency of addressing global warming.

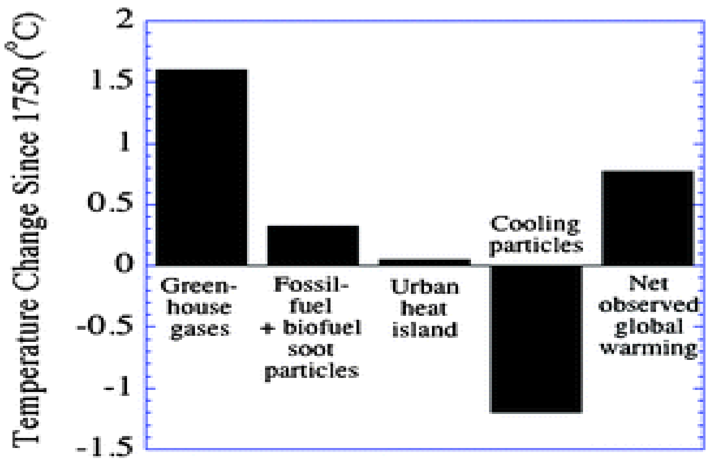

Figure 1-17: Primary contributions to observed global warming from 1750 to today from global model calculations. The fossil-fuel plus biofuel soot estimate accounts for the effects of soot on snow albedo. The remaining numbers were calculated by the author. Cooling aerosol particles include particles containing sulphate, nitrate, chloride, ammonium, potassium, certain organic carbon, and water, primarily. The sources of these particles differ, for the most part, from sources of fossil-fuel and biofuel soot (Jacobson, 2009)

Figure 1-12 given earlier demonstrates the global warming trend since the 1950s. Global temperatures rose 0.6 to 0.7 °C from 1951 to 2010, of which 0.5 to 1.3 °C can be attributed to greenhouse gases, 0.6 to 0.1 °C to other human emissions including the cooling effect of aerosols, - 0.1 to 0.1 °C to natural forcing, and - 0.1 to 0.1 °C to internal variability (Rice et al. 2014)

Air pollution and global warming are two of the greatest threats to both human health (Watts et al. 2015; Wilkinson et al. 2009; Chan 2015) and political stability, as energy insecurity and the rising prices of conventional energy sources are major threats to economic and political stability (Jacobson, 2009).

In a study on the effects of global warming on thermal comfort conditions indoors in Iran, it was found that temperatures will increase between 3.4 °C and 5.6 °C by 2100 (Roshan et al., 2010). In the central and desert zones of Iran, the neutral comfort temperature will increase and become more intense in the coming decades, though the increase in this temperature will be less in the coastal areas of the Caspian and Oman Seas in southeast Iran. The increase in temperature would be followed by a change in thermal comfort and would cause indoor-cooling-related energy consumption in air conditioning systems to rise from 8.6 % to 13.1 % (Roshan et al., 2010).

The GCC region is particularly susceptible to heat waves and weather extremes, and people are already suffering from increasing temperatures, having experienced more frequent heat waves within the last few years. It is therefore vital that this issue be addressed, and it must be communicated to policy makers as clearly and persuasively as possible in order to spur them to take effective action. If this does not happen, climate change will bring even more severe consequences and impact on health, well-being and crops.

One promising recent development has been some scientists' focus on addressing Short Lived Climate Pollutants (SLCP), and their claim that it is likely to be the only way to address the heating effects of climate change in the near term (i.e. over the next few decades). Since warming in the near term is particularly relevant to Oman and the GCC region, it is clear that the adoption of an SLCP strategy in the GCC region, and a wider promotion of such a strategy, would be of great benefit. The following sections of this chapter will therefore more closely analyse the rationale for an SLCP strategy, with the likely impact of SLCP mitigation strategies in Oman and the GCC region being explored in Chapters 4 and 5.

1.4 Short Lived Climate Pollutants:

Short-lived climate pollutants (SLCPs) are currently attracting wide attention because it has been suggested that controlling emissions of this class of pollutants would bring a number of benefits, particularly improving air quality and also reducing the near-term rate of climate warming (UNEP & WMO 2011, Shindell, et al. 2012, Trang et al. 2015, Baker *et al.*, 2015).

Short-lived climate pollutants (SLCP) are those gases and particles whose atmospheric lifetimes range from less than a day to a number of years – an average of twelve years for methane and fifteen years for HFCs (Shindell et al. 2012; Bowerman et al. 2013). SLCPs are important contributors to anthropogenic climate change, responsible for as much as one-third of the current total greenhouse forcing (Shoemaker *et al.*, 2013). The main SLCPs are black carbon (BC), methane (CH_4), tropospheric ozone (O_3) and selected hydrofluorocarbons (HFCs). Except for HFCs, they have negative effects on human health and agriculture (Shindel et al., 2012; Baker *et al.*, 2015), as shown in Figure 1-17.

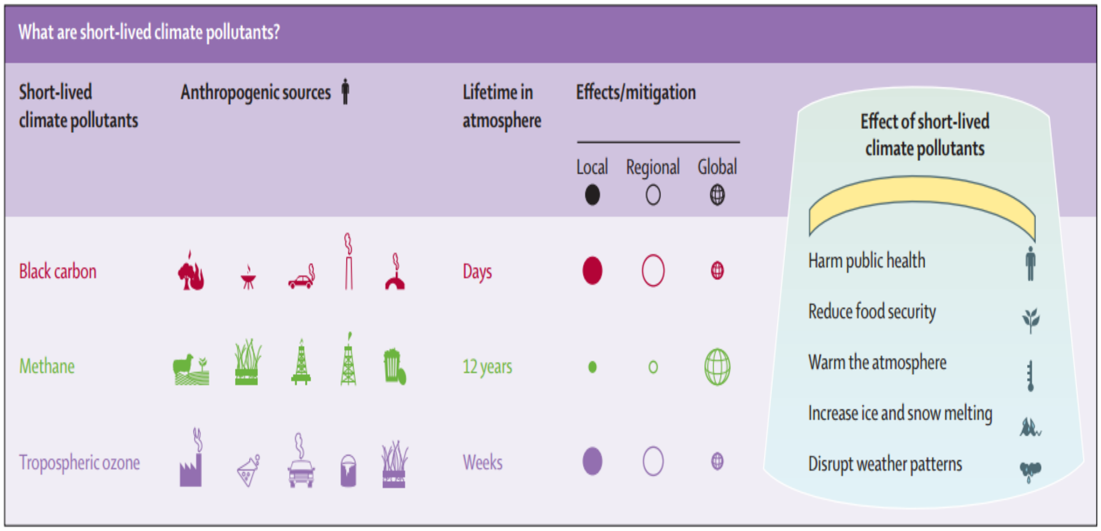

Figure 1-18: Properties of common short-lived climate pollutants. Adapted from UN Environment Programme, by permission of the Climate and Clean Air Coalition (Chan, M. 2015)

I. **Black Carbon (BC)**, sometimes referred to as 'soot', is released by the incomplete combustion of fossil fuels and biomass, remains in the atmosphere for days to weeks and harms humans who inhale it (Blackstock & Allen, 2012). It also causes warming through absorption of sunlight and by reducing surface albedo when deposited on snow (Boucher et al., 2013). Using the NASA GISS climate model (ModelE), Menon et al. (2010) estimated that about 0.9% of the decrease in the snow/ice cover over the Himalayas from 1990 to 2000 was caused by the direct effects, indirect effects, and deposition of BC aerosols (Hong, 2015).

II. **Tropospheric Ozone** is a potent greenhouse gas produced by the chemical reaction of hydrocarbons (particularly methane (CH_4) and non-methane volatile organic compounds (NMVOCs)) with specific precursor gases (carbon monoxide (CO), and nitrogen oxides (NOx)); it remains in the atmosphere for hours to days, and harms humans and crops exposed to it (Blackstock & Allen, 2012; Stohl et al., 2015). O_3 stress has caused visible injury to leaves of winter wheat, and with the prolongation of the fumigation time, the symptoms of this injury become more and more pronounced (Liu *et al.*, 2015). The increase of O_3 concentration influences the anti-oxidation activity of enzymes and the metabolite contents; this occurs to different extents during different stages of growth. It has been found (Akimoto et al., 2015) that the reduction of NO_x and NMVOC is the most efficient way for the reduction of regional O_3 at the surface, and the reduction of CH_4 is a very efficient way to reduce global Radiative Forcing (RF). Akimoto's study also demonstrated that the reducing NO_x/NMVOC and CH_4 simultaneously is more beneficial both for the regional surface O_3 concentration and global RF at the tropopause than the reduction of each separately.

III. **Methane** generates tropospheric ozone and is also a potent greenhouse gas that remains in the atmosphere for roughly 12 years before being oxidised to CO_2. (Blackstock & Allen, 2012). In a study focusing on the potential impact of SLCP mitigation on global sea-level rise (SLR), researchers found that methane mitigation has the largest effect in mitigating Sea Level Rise, with the next most effective method being the mitigation of black carbon and HFCs (Hu *et al.*, 2013).

IV. **Hydrofluorocarbons (HFCs)** are a set of very potent climate-warming greenhouse gases that are industrially produced, mainly for use in refrigeration, air conditioning units and insulating foam. Different HFC molecules have lifetimes ranging from roughly a year to several hundred years, with a current use-weighted average of roughly 15 years (Blackstock and Allen, 2012).

Since CO_2 emissions contribute 60–70% to global warming, making it the largest contributor and meaning that the reduction of CO_2 emission is essential. However, such reduction would not help with the near-term mitigation until the period 2030-2050, since the atmospheric "lifetime" of CO_2 is around 100 years. As a result, any measures taken to reduce anthropogenic emissions of CO_2, will take effect only in a few decades time, regardless of how successful such measures might be. This has led researchers to propose that it would be better to focus on the reduction of the emissions of other gases and aerosols, ones that have significant effects on warming but considerably shorter atmospheric lifetimes (weeks, months, or years – namely, the SLCPs). If this is done, the climate system can respond more rapidly (Shindell et al. 2012; Molina et al. 2009; IPCC 2007; Karol' et al. 2013; 2012).

As well as benefiting the climate (Anenberg et al. 2012), reducing SLCPs also provides important co-benefits like energy security (McCollum *et al.*, 2013), and benefits to local health and agriculture (Shindell et al. 2012; Anenberg et al. 2012; Rao et al. 2012; West et al. 2014). According to Anenberg et al. (2012), the deaths avoided from technically possible reductions in black carbon and methane would represent "1-8% of cardiopulmonary and lung cancer deaths among those age 30 years and older, and 1-7% of all deaths for all ages". Improvements in crop production due to reduced impact of tropospheric ozone are estimated to be up to 4% of the total annual global production of the four major staple grains: maize, rice, soybeans, and wheat (UNEP & WMO 2011).

The early part of this century has seen growing international interest in mitigating climate change by reducing emissions of SLCPs, in addition to reducing emissions of CO_2. The Climate and Clean Air Coalition (CCAC), hosted by the United Nations Environment Programme, is a voluntary partnership of governments, intergovernmental organizations, and civil society who support actions to reduce emissions of short-lived climate pollutants, and complement the global effort to reduce emissions of long-lived CO_2 and other greenhouse gases covered by the United Nations Framework Convention on Climate Change (UNFCCC). Recent studies have estimated that by using available technologies to mitigate emissions of CH_4, BC, and O_3,we could avoid about 0.5 to 0.6 ◦C warming by the mid-21st century (Xu *et al.*, 2013). This would clearly bring huge benefits for Oman and the GCC, which are already suffering the impacts of higher temperatures.

Shindell et al (2012) studied fourteen identified SLCP reduction measures (Table 1-3) targeting methane and BC emissions, and estimated that they would reduce projected global mean warming by ~0.5°C by 2050. The study also found that this strategy would save 0.7 to 4.7 million people annually from premature death related to outdoor air pollution, and would also increase crop yields by 30 to 135 million metric tons a year as a result of ozone reductions in 2030 and beyond. The benefits of methane emission reductions are valued at $700 to $5000 per metric ton, which is well above typical marginal abatement_costs which are less than $250. The controls selected target different sources and would influence climate in less time than would carbon dioxide–reduction measures, while implementing both types of control would substantially reduce the risks of crossing the 2°C threshold (Shindell et al. 2012).

Table 1-3: The top 14 measures to reduce SLCP, Seven measures target CH4 and the other seven target BC, Tech refers to technical measures and Reg is primarily regulatory measures (Shindell et al. 2012)

CH_4 measures	**BC measures**
coal mining	diesel vehicles (Tech)
oil and gas production	clean-burning biomass stoves (Tech)
long-distance gas transmission	clean-burning brick kilns (Tech)
municipal waste and landfills	clean-burning coke ovens (Tech)
wastewater	banning agricultural waste burning (Reg)
livestock manure	eliminating high- emitting vehicles (Reg)
Rice paddies	providing modern cooking and heating (Reg)

Mitigation focused on SLCPs is a potentially attractive option for reducing the magnitude of anthropogenic climate change, given that it would have a faster influence on climate than would carbon dioxide mitigation (UNEP & WMO 2011; Ramanathan & Xu 2010; Shindell et al. 2012; Smith and Mizrahi 2013).

The UNEP/WMO integrated assessment calculates that a combination of fourteen mitigation measures (already given in Table 1-3) – seven targeting emissions of methane and seven targeting emissions of black carbon – are capable of reducing global methane emissions by approximately 38% and emissions of black carbon by approximately 77% (UNEP & WMO, 2011).

Figure 1-18 shows that by reducing tropospheric ozone, CH_4, and BC, the measures would substantially reduce the increase in the global mean temperature over the next few decades. The short atmospheric lifetime of these species means that a rapid response to emissions reductions is possible. CO_2, in contrast, has a very long atmospheric life- time and growing CO_2 emissions will affect climate for centuries, so that the CO_2 emission reduction measures analysed here will have minimal effect on temperatures before 2040. However, the combination of CH_4 and BC measures, along with substantial CO_2 emissions reductions [a 450 parts per million (ppm) scenario], has a high probability of limiting global mean warming to <2°C during the next 60 years, something that neither set of emissions reductions achieves on its own (Shindell et al. 2012).

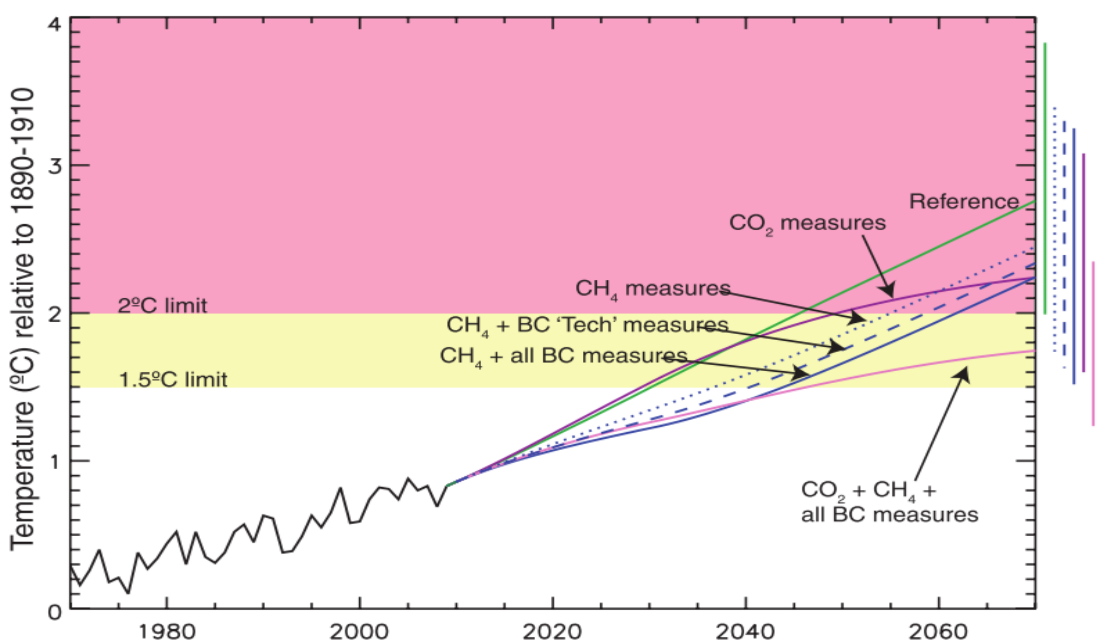

Figure 1-19: Observed temperatures through 2009 and projected temperatures thereafter under various scenarios, all relative to the 1890–1910 mean. Results for future scenarios are the central values from analytic equations estimating the response to forcings calculated from composition-climate modeling and literature assessments. The rightmost bars give 2070 ranges, including uncertainty in radiative forcing and climate sensitivity. A portion of the uncertainty is systematic, so that overlapping ranges do not mean there is no significant difference (for example, if climate sensitivity is large, it is large regardless of the scenario, so all temperatures would be toward the high end of their ranges; see www. giss.nasa.gov/staff/dshindell/Sci2012) (Shindell, Kuylenstierna, Vignati, Dingenen, et al., 2012)

Many of the measures above are applicable to the situation in Oman and other GCC countries, whereas others relate to activities which are not taking place in the region. Assessing which would be the best measures and which would have the greatest benefits for health and climate will be discussed in Chapter Five.

1.5 Integration of air quality and climate policy:

Recent scientific findings have increasingly linked air quality with climate change, highlighting the possibility of implementing win-win policies to efficiently tackle both problems. The findings suggest the importance of strategies that couple air quality and climate change. As climate change mitigation has become the top issue on the global environmental agenda, there is a risk that related fields such as air quality might be downgraded. However, scientific evidence suggests that it would be mistaken to continue to decouple air quality and climate change strategies. Until now, the division between the two issues has split resources. However, fostering a win-win strategy for air quality and climate change would not only avoid health costs but would also be more effective overall.

Although in Oman, the Ministry of Environment and Climate Affairs (MECA) is responsible for both air quality and climate change policies, they fall under different policy frameworks, so that thus far emissions of GHGs and air pollutants have been regulated separately. This separation of goals and competences has produced different action plans and policy agendas. As a consequence, the relationships between these two policy areas have often been ignored or underestimated, despite some in the global scientific community arguing that climate change and air quality are actually two faces of the same problem (Vittorio et al., 2016).

There is one major challenge to a better understanding of air quality and climate co-benefits, which would facilitate the integration of these arenas in the political domain, and, for example, the creation of regulations which simultaneously address air quality and climate. This challenge is the small amount of overlap that currently exists between the networks of institutions and individuals who contribute to knowledge on air quality and those who specialise in climate change. A recent paper by Williams, (2014) points out the disadvantages of having a variety of mitigation measures that target the issues separately, and outlines some air quality and climate co-benefits, with a focus on the economics of air quality and climate change synergies. There are a number of options that provide co-benefits, such as energy efficiency, carbon capture and storage (CCS), and renewable energies including wind and solar. Other options do require trade-offs, such as biofuels, the use of diesel particulate filters, and flue gas desulfurization (von Schneidemesser and Monks, 2013).

Some concerns have been raised, however, about the repercussions of an integrated air quality and climate policy; this view was outlined by Thambiran and Diab, (2011). They looked specifically at developing countries and questioned whether, if they were to focus on GHG emission reductions as part of air quality policies, this might prevent them from actively engaging in GHG emission reduction strategies at an international level, and might thus prevent substantial global progress on GHG reduction (von Schneidemesser and Monks, 2013).

However, the key question remains how we can achieve the additional benefits, that will arise from a closer integration of air quality and climate change policies, particularly in the area of improving public health. In the much shorter term we face challenges in meeting our current air quality targets, especially in relation to nitrogen dioxide and also particulate matter (Defra, 2010).

Chapter 6 of this thesis will look at the opportunities for integrated AQ and climate planning via the suggested mitigation scenarios / strategies for both GHG and air pollution. It will discuss the main issues concerning air pollution and will outline the ways in which most of the interconnections between measures addressing air pollution and climate change can be made.

1.6 Research gap:

Air pollution, then, has an adverse effect on human health (Dang & Unger 2015; Alaa et al. 2018; Heal et al. 2012) and also contributes to climate change (Waked & Afif 2012; Dang & Unger 2015). In spite of the fact that many countries have legislated air pollution policies, recent studies estimate that 80% of the world's population continues to be exposed to ambient pollution that far exceeds the WHO-recommended Air Quality Guideline (AQG) of 10 µg m^{-3} for long-term $PM_{2.5}$ concentration levels (particulate matter with aerodynamic diameter smaller than 2.5 µm) (Rao *et al.*, 2013).

Most of the studies in the GCC region have focused on identifying quantities and sources of air pollution, and have placed limited emphasis on how the issue should be addressed. Generally, studies have focused on a particular city and aimed to characterise the nature of its air pollutants and their adverse impacts.

Saddam (2012) investigated the question of foreign investment over the period from 1998 to 2008, and whether or not it had affected the environment in the GCC. He concluded that the GCC countries had adopted lax environmental policies towards foreign investors. As a result, these countries have achieved high levels of economic growth but also continuously increasing carbon dioxide emissions.

This has taken place in spite of the passing of a number of environmental laws, which have not yet been effective in reducing air pollution in GCC countries.

Oman and its GCC neighbours are developing countries whose economies mostly rely on oil and gas. Although they have developed mainly within the last thirty or forty years, they have been classified by the World Bank as 'High Income' countries. Their accelerated economic growth has not been matched by a high level of attention to the environment and its quality. In spite of the GCC's desire to be part of the international environmental community and to play its part in implementing mutually beneficial strategies, their interest started somewhat late.

Few studies on air pollution have been conducted in Oman and other GCC countries; there are fewer still on climate change. Comparing this situation with that in a neighbouring country like Iran shows there is a huge gap in the coverage of these important issues. Iran has published more than 1180 articles on air pollution, which is more than the publications of all the GCC countries, plus Yemen, combined. Of all the GCC countries, Kuwait has the highest number of publications on the issue, often related to the Gulf War and the resultant air pollution, as well as some investigating the frequent sand storm events which pay a major role in Kuwait's air pollution. Significantly, no article on SLCPs has as yet been published by any of the GCC countries. The majority of air pollution studies in Oman examine the effects of air pollution on health in industrial areas and in communities close to them. However, there seem to be no comprehensive studies that focus on air pollution, greenhouse gases, and SLCPs on human health and climate change, and investigate the implications for the Sultanate of Oman as a whole. The situation is the same for other GCC countries. There is also a lack of data on how much Oman currently contributes to global emissions, and little progress has been made on CO_2 mitigation.

Despite the significant impact of air pollution on health in the region, policy makers have paid it little attention. The GCC countries have experienced continued and increasing emissions for many years, and while several environmental policies have been initiated in the region, they produced no reduction in air pollution over the period from 1998 to 2008 (Saddam, 2012). Some studies have highlighted the gaps in policy, but none have proposed any detailed strategies to address them. Oman NDC is based on an emission inventory conducted from 1994 onwards, but it contains no consideration of air quality management or of the advantages of integrating climate change (CC) and air quality (AQ) planning.

Given the gap between the current situation of AQ and CC in Oman and the policies governing them, this study will attempt to bridge that gap and add Oman to the global picture.

1.7 Motivation:

Short-lived climate pollutants (SLCPs) are potent climate warmers and reducing their atmospheric concentrations can effectively reduce warming in the near term. Globally, a coordinated SLCP mitigation strategy also has the potential to prevent millions of premature deaths from air pollution annually and substantially improve crop yields. We have the opportunity to achieve multiple benefits and reduce premature deaths, boost crop yields by millions of tonnes and avoid climate-related impacts – but this will only happen if we implement near-term strategies along with long-term goals.

This research is the first investigation of SLCPs in Oman. The focus on this group of pollutants will be on investigating the implications of a SLCP strategy that can reduce SLCP pollution and its impacts on both health and the climate. In addition, this is an opportunity to consider the option of developing strategies that will integrate air quality and climate mitigation.

There are a number of measures that can be implemented to deliver significant benefits for the climate, air quality, and health. These measures involve technologies and practices that already exist and in most cases are cost-effective. A global implementation of these measures by 2030 is likely to prevent 2.4 million premature deaths a year from outdoor air pollution and would also slow down the warming expected by 2050 by about 0.5°C (UNEP & WMO 2011). The research presented here will assess the feasibility and likely impacts of implementing similar measures in Oman.

The research idea will test the following hypothesis: that tackling SLCP-related emissions and taking an integrated AQ and CC strategy approach, if measured and controlled by an adequate environment management system, will generate multiple benefits and quantify the impacts on the economy, the environment and health. The research will design an Energy Management System and show how it can be mainstreamed within existing national and sectoral policies, strategies, plans and activities, so that its long-term sustainability can be ensured. The relevant research questions are:

1. What is the current situation in terms of emissions trends and policies relating to Air Pollution (AP), Climate Change (CC) and SLCPs and GHGs in Oman? (Chapter 2)
2. How will the situation develop if nothing is done to address the problem (baseline scenario)? (Chapter 4)

3. What are the possible mitigation measures, and their likely benefits (mitigation scenarios)? (Chapter 4)
4. What are the current and future impacts (effects) of AP/CC in Oman? (Chapter 5)
5. What are the policies that could help address the problem? (Chapter 3)

Answering these questions within this thesis will help determine the truth or otherwise of the null hypothesis: "It is possible to implement measures in Oman that will significantly reduce impacts of both local Air Pollution (AP) and global Climate Change (CC) in both the near and the long term".

1.8 Approach:

To accomplish these research goals, and test the research hypothesis, the following approach has been used:

Collection of data for emissions inventories of all sectors related to activities causing SLCP/GHG/air emissions. Collection of data regarding the relevant policies of Oman and of other GCC countries, identifying synergies between them, assessing their level of coherence, and comparing them with the most advanced national and international policies available.

Using the LEAP-IBC tool for conducting an emission inventory, for estimating impacts on health and climate, and for developing different scenarios for Oman, including historical, current and mitigation scenarios.

The thesis is organized into six chapters; the first of which. the current chapter, outlines the research hypothesis from which the arguments of the thesis are developed, and refers to relevant peer-reviewed literature. The chapter also introduces the issues of air pollution and climate change and what is currently known about them. It outlines the global impacts of air pollution on climate change and human health, and focuses on these impacts in Oman and the wider GCC region. The issue of SLCPs is also highlighted, along with an introduction to the opportunity to reduce near-term warming and the other benefits and co-benefits that could arise from their reduction.

Chapter 2 "Estimating current and historic emissions in Oman" deals with emissions in Oman, and outlines the main sectors contributing to the pollution. It presents the main sources of data on emission sources, along with a description of the methods used to estimate the emissions with details on the types of data and how they were collected and analysed. This chapter presents the emission inventory for Oman, along with a description and review of the emission inventory methodology and an interpretation of the results of the historical emission inventory. The chapter will conclude with the a discussion of the results; it will also highlight the uncertainty and gaps revealed and how they can be addressed or avoided. It also compares this inventory with other national and international emission inventories, and presents an overall conclusion.

Chapter 3 “Policies addressing air pollution and climate change in Oman and GCC countries” gives an overview of the policies, regulations, legislations and guidelines that govern aspects related to environmental impact, with special attention to those relevant to climate, emissions, and air pollution in Oman. The chapter will also analyse policymaking processes in Oman, and will describe the development of its environment policies. It will investigate the implementation of those policies, along with the drawbacks resulting from the fact that they are implemented from different points of view, and will assess the effectiveness of the policies.

Chapter 4 “Estimating baseline emission scenario and developing mitigation policy scenarios for Oman” considers the estimated baseline emission scenarios for key sectors in Oman, and discusses the development of different mitigation policy scenarios, with different measures that could reduce emissions in the country. The chapter then reviews the policies from chapter 3 and assesses which could be used to implement these mitigation measures. It also presents the methods used to estimate the emission and policy scenarios and reviews the literature on emission and policy scenarios in other countries. The chapter will conclude with a discussion of the results, including the uncertainties in the various scenarios.

Chapter 5, “Estimating Impacts of current and historic atmospheric emissions from Oman”, looks first at both the impacts of atmospheric emissions in Oman and at where they occur. It then reviews the literature concerning the different methods used to estimate impacts, along with their findings. The chapter then describes the methods and data sets used to estimate the impacts; it concludes by illustrating the results of the impact assessment and compares them with estimates made previously.

Chapter 6 “Opportunities for Oman to mitigate atmospheric emissions” suggests opportunities for Oman and other GCC countries to mitigate atmospheric emissions, presenting the available and convenient options for the region and discussing the significant impacts these would have on air quality, health, and climate. It concludes by offering the planning authorities a number of recommendations that could be implemented in and for the future.

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2 Estimating current and historic emissions in Oman

2.1 Introduction

The aim of Chapter 2 is to estimate emissions from different sources in Oman for 2010 (the model base year) and other historic years where data before or after the base year have been used (e.g. transport sector, flaring data, and others). LEAP-IBC is the tool which has been selected for this study to complete a national emission inventory for major air pollutants and Green House Gases (GHGs). This part of the thesis will give an overview of air pollution and Short-Lived Climate Pollutant (SLCP) and GHG emissions in Oman and will rank sources of pollution in relation to their contribution to different problems. That information will guide the degree of analysis devoted to different source sectors in the chapters that follow. Also, in this chapter, the level of emission of each pollutant will be compared with that in other national and international emission inventories in order to validate the work presented here.

The chapter will describe the method used for developing the emission inventory for Oman and will interpret the results. The end of the chapter will discuss the resulting emission estimates and will highlight any gaps and uncertainties.

2.2 Emission Inventory

There are multiple sources of atmospheric emissions. For example, emissions can be caused by human activities (anthropogenic sources); these sources can derive from power plants, refineries, incinerators, industrial plants and processes, domestic households, offices and public buildings, cars and other vehicles, fossil fuel extraction and production sites, animals and humans. There are also natural sources such as Non-Methane Volatile Organic Compounds (NMVOCs) from trees and other vegetation, methane (CH_4) from biological decay, particulate matter (PM) from deserts, and sulphate (SO_4) from marine sources.

To be able to assess the air pollution problems, and to work effectively towards their management and reduction, one of the first and main prerequisites is to have quantitative information about the sources and the amount and types of emitted compounds. Estimating these emissions requires an emission inventory (EI).

An emission inventory is a calculation using data that quantifies emissions, expressed by source, for a chosen scale, from global to national and down to individual plant level, for a particular time period (e.g. annual emission for a given year). Establishing emission inventories helps in prioritizing action on different sources of air pollutants. It helps to focus regulation and management, land use planning and urban planning; it also assists in developing appropriate controls to achieve the best possible reduction of pollution from the sources outlined (Alanezi, 2012).

Since direct measurements of air emissions are infrequent, emissions are usually estimated with the help of emission factors applied to statistics on human activities using the formula:

Emissions = Emission factor x Activity rate

where emission factors (EFs) are the estimated average emission rate of a given pollutant for a given source, relative to units of activity.

In practice, the calculations tend to be more complicated, but the principles remain the same. For example, to estimate annual emissions of sulphur dioxide in tonnes per year from a power plant, annual fuel consumption (in tonnes fuel/year) is multiplied by an emission factor (in tonnes of SO_2 emitted/tonne fuel consumed) derived from the sulphur content of the fuel. Another example is the estimation of NO_x emissions from vehicles in a city. The basic emission factor here is the NO_x amount emitted per km driven, which is then multiplied by average driving distance per year for the category of vehicle concerned, and then multiplied by the number of registered/counted vehicles. The reliability of emission estimates depends on the precision of the emission factors in relation to the specific emission source and the accuracy of the data describing the level of activity. The default emission factors used in this study are mainly taken from the EMEP/EEA 2016 Air Pollutant Emission Inventory Guidebook (EMEP/EEA, 2016) and, for CO_2 and CH_4 , from the Intergovernmental Panel on Climate Change (IPCC) Guidelines (IPCC, 2006). For BC and OC in several sectors, emission factors are taken from (Bond *et al.*, 2004), and for fugitive CH_4, NMVOC and CO_2 from the oil and gas industry, emission factors are taken from IPCC 2019 refinement. For a detailed description of default emission factors which have been used by different sectors in this study, see LEAP[6], and/or Vallack et al (in press).

2.3 Methodology for estimating emissions in Oman:

2.3.1 Estimating emissions using LEAP-IBC:

LEAP, the Long-range Energy Alternative Planning system, is a software tool for energy policy analysis and climate change mitigation assessment (Heaps, 2012), that uses integrated modelling to track energy consumption, production, and resource extraction in all sectors of an economy. Emission inventories are compiled for a base year which needs to be defined. The base year is the

[6]http://www.energycommunity.org/?action=47

most recent year for which relatively complete and reliable energy data are available and, in this analysis, 2010 will be the base year, as this base year is required for the Integrated Benefits Calculator (IBC) to work – see Chapter 5 – and data are generally available in Oman for that year.

LEAP has been adopted by thousands of organizations in more than 190 countries worldwide. Its users include government agencies, academics, non-governmental organizations, consulting companies, and energy utilities. It has been used at many different levels ranging from cities and states to national, regional and global applications (LEAP, 2017). LEAP has been used for over 70 peer-reviewed journal papers including an investigation into CCS in Korea (Lee et.al, 2008), analysis of the potential reductions in energy demand and GHG emissions within road transport in China (Yan and Crookes, 2009), identifying the feasible penetration of sustainable energy on the Greek island of Crete (Karapidakis et. al 2015), and also an investigation into the benefits of improved building energy-efficiencies in China (Li, 2008).

In this study, a variant of the LEAP tool called LEAP-IBC will be used. This includes a sectoral breakdown structure that is suitable for air pollution emission inventories, as well as GHG emission inventories, and is optimised for an SLCP analysis. It includes emission factors for important air pollutants needed to estimate the impacts of pollution. The IBC stands for Integrated Benefits Calculator; this tool can estimate air pollution concentrations and impacts on health, crop yields and temperature change, in addition to pollutant emissions.

Current and historic emission estimation is developed by populating the LEAP-IBC with different data relating to activities related to the SLCP, air pollutant and GHG emissions; it covers all key sectors and also contains default emission factors for all key pollutants. Running the emission analysis based on the activity data and default emission factors data calculates emissions for current and historical years, a process which will be explained in the following sections.

2.3.2 LEAP-IBC Structure:

LEAP-IBC is provided with a default template tree structure with category branches that include '*Key Assumptions'* that are required by the IBC module as well as emission source category branches for '*Demand'* (energy combustion sources), '*Transformation'* (energy transformation) and '*Non-energy sources'*. The final category branch is called *'Indicators'* and this is where the results of the IBC calculations appear. These category branches are described in more detail in the following sections and Appendix A2 shows the branch structure within the LEAP-IBC template.

2.3.2.1 Analysis and Results Modes:

There are two modes of LEAP-IBC: 'analysis mode' is where data which have been gathered are entered for the analysis either as a current account (emission inventory) or scenario (baseline and mitigation). In order to examine the resulting emission inventory you go to the 'result mode' based on the selection of current accounts. The first step is to enter data for the start year (currently 2010) in current accounts.

2.3.2.2 Key Assumptions:

The Key Assumptions are the macroeconomic, demographic, disease rates, crop production and transport variables that are used in various calculations in LEAP-IBC, such as the development of scenarios. It contains data specific to a country – some of these are default values within the LEAP-IBC version of the country template, while some of this data has been replaced in this study by better national data found by the study. The data are for GDP, GDP growth, population, population fraction, disease rates, crop production and dry day per year for transport calculation.

2.3.2.3 Demand

Demand here refers to the total amount of energy used, including the type of fuel and the characteristics of the end-use technology. This section contains sub-branches for the source sectors which are used to calculate the country emissions related to energy use. In general, one or more activity variables are required (e.g. number of vehicles, amount of fuel consumed by the sector), as well as an emission factor which quantifies the emissions of each pollutant for each unit of activity. The sub-folders within 'Demand' are for source sectors associated with the combustion of different fuels. The source sectors are grouped within seven categories. For example, in 'Energy Industry own use' there is 'Petroleum Refining' and 'other own use'. In each category the fuel types used are listed. Default emission factors are provided within LEAP-IBC for each pollutant for each fuel type. These emission factors were kept without being changed, since more specific emission factors are not available for Oman.

2.3.2.4 Transformation

Energy transformation is the process whereby one type of energy is converted into another type. In this folder the industries involved with extraction, transformation and distribution of energy are categorized into sub-folders: transmission and distribution (of electricity), electricity generation, gasoline service stations, gasoline transport and depots, oil refining, transport and production, gas distribution, processing and production.

It is worth mentioning that there is a linkage between the transformation and the demand sectors in LEAP, as the electricity demand is met by electricity generation in the transformation sector where the emissions calculations actually take place.

2.3.2.5 Non Energy

The 'Non-Energy' folder mainly contains source sectors that are not associated with fossil fuel combustion. These include:

(1) fugitive emissions of methane and non-methane volatile organic compounds (NMVOCs) from fossil fuel exploration, drilling, and production.

(2) agricultural sources (e.g. enteric fermentation, manure management, and fertilizer application).

(3) industrial process emission (e.g. minerals, and chemicals.

(4) waste (e.g. Municipal Solid Waste (MSW) in landfills, Human excreta, and domestic water).

As with the 'Demand' source sectors, activity data and emission factors are required to calculate emissions. However, the non-energy source sectors are diverse, and the type of information required often differs markedly.

2.3.2.6 Indicators

The indicators option is designed to view the results from IBC, including results for pollutant concentrations, premature deaths, and global temperature change. The IBC calculations are basically developed from two sets of data; those which are pre-defined and distributed with LEAP-IBC so cannot be changed by the user, and those that are specified by the user as key assumption variables, such as population, its fractions based on age group and gender, mortality rate, life expectancy, annual crop production and others.

2.3.3 Emission Inventory Framework and design:

In LEAP-IBC, the energy demand sectors are those source sectors that consume energy. The demand for energy across all sectors is then met by processes in the transformation sector. For example, the electricity required from the demand sectors is then produced under the transformation sector. There are various ways in which the emissions associated with energy consumption in the Demand sectors can be estimated. In the default LEAP-IBC template, for most Demand sectors the total energy consumption in each sector is specified. Other commonly used methods to calculate total energy consumption involve specifying i) an activity variable related to energy consumption (e.g.

number of households as an activity variable for the residential sector), ii) an energy intensity associated with using different types of fuel (e.g. energy consumption for one household cooking using LPG, or other fuels/technologies), and iii) emission factors that quantify the emissions of different pollutants per unit of energy consumed. Other non-energy source sectors also contribute to national emissions, and are specified by a range of different types of activity data, and associated emission factors.

Figure 2-1 presents an overview of the emission source categories used in this inventory in order to calculate the total emissions in Oman, as covered in section 2.3.2

Energy demand sectors include fuel combustion activities within seven sectors, namely: (1) the manufacturing industry, (2) the energy industry's own use, (3) transport, as well as other sectors such as (4) residential (5) commercial, (6) agriculture and fishing and (7) non-specified other.

The non-energy sector includes (1) industrial processes that generate by-product emissions or fugitive emissions, (2) agriculture, (3) waste, and (4) fugitive emissions from non-combustion activities related to the extraction, processing, storage, distribution and use of fuels.

Below is a definition of other key concepts used in this study:

Accuracy: In which emission estimates are made accurate in the sense that they are systematically neither over- nor under-estimated so far as can be judged, and that uncertainties are reduced as far as practicable. The study attempted to remove all bias from the inventory estimates.

Comparability: This emission inventory is reported in a way to be comparable with other inventories of different countries. This will be reflected in the appropriate use of tables and in the use of a common classification system and common definitions of sources of emissions.

Completeness: The inventory covers all sources, pollutants, and geographic areas within the scope of this inventory. If any data is absent, that absence is clearly documented and its association with any published data is highlighted.

Consistency: This is ensured by using the same methodologies for all of the years of the inventory and by estimating the emission using consistent data sets in order to reflect the real differences in emissions.

Transparency: The data sources, assumptions and methodologies used for this inventory will be clearly explained, in order to facilitate the replication and assessment of the inventory.

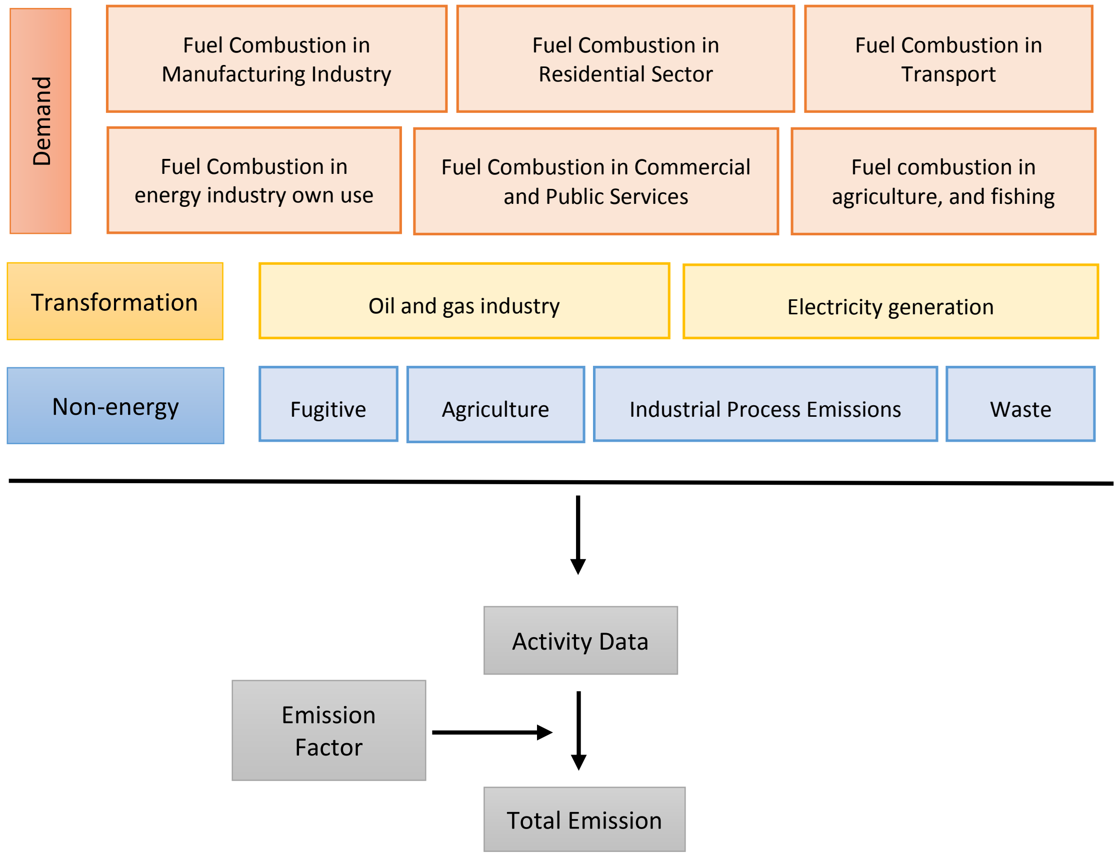

Figure 2-1: The framework used in data compilation for the Oman emission inventory

2.3.4 Data collection strategy:

The strategy for data collection in this study is based on the following:

- Focus on the collection of data needed to improve estimates of the largest key categories, as improvement of these would have the greatest potential to improve air quality in Oman;
- Collect data/information at a level of detail appropriate to the needs;
- Review data collection activities and methodology on a regular basis, to guide continuing and efficient inventory improvement;
- Introduce agreements with data providers to support consistent and continuing information flows;
- Since national data sources are typically more up-to-date than international sources and provide better links to the originators of the data, to the use of national data as opposed to data from international data sources;

- In cases in which data from reputable international bodies are more accessible and more applicable to the inventory, then international data have been used;
- Cross-checking national data sets with any available international data in order to assess completeness and identify possible problems with either data set.
- A comparison will be conducted between national and international data for Oman.

Appendix B2 summarizes the activity data which were collected from Oman and have been categorized into high priority data (that includes: Oil production, Road transport, Manufacturing and construction, Electricity power stations, Municipal Solid Waste (MSW) in landfill, Domestic wastewater treatment and discharge) and lower priority data (which includes: industries such as chemicals, cement, metals, and solvent production). Most of those data was gathered from ministries or the National Centre for Statistics and Information (NCSI), is described in Appendix B2, and C2.

Open-burning of crop residues and municipal, industrial and commercial waste is not allowed according to Article 5 of ministerial decision 118/2004, which states that "Dark smoke shall not be emitted from a chimney of any building, any industrial / commercial premises, or any other site. Open burning of organic or agricultural wastes is prohibited." Although these activities may still be happening in some places, from personal experience, waste burning is not something commonly seen in Oman. Therefore, for the purposes of this study, it is assumed that emissions from these sources are negligible.

Implementation of the detailed methods usually requires collection of additional data, in particular on technologies and abatement. To set up a stable inventory system it is important to establish cooperation arrangements with data providers. In compiling this inventory, some assumptions were made in some cases where data was not available, and these cases will be discussed throughout this section.

The choice of LEAP-IBC as a tool provided the information needed for what data must be collected to compile the Oman Emissions Inventory, and a number of contacts were set up to facilitate this data collection. In January 2016, an initial survey was conducted to investigate the existing information in the National Centre of Statistics and Information (NCSI) and in databases of several other organizations in Oman. Based on this information, the data collection structure outlined in Appendix B2 and C2, was developed to help identify the sources of data needed for the inventory and the different organizations where it could be found. More than thirty governments, institutional and private sector organisations were then contacted as potential data providers for this study.

Default emission factors were used for all sources as locally derived factors are not available. Other sources of data and information used within this study are statistics from international organisations such as the UN, the FAO, the WB, Eurostat, the International Energy Agency (IEA), the OECD and the IMF, as well as scientific and technical articles, journals and reports, IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2016), and National Inventory Reports from Parties to the UNFCCC.

2.4 Oman data description (by sector):

This section provides a description of the different sets of data that were gathered or provided as a default with LEAP (emission factors) and were used for this study so as to develop a comprehensive emission inventory for Oman. The data will be illustrated based on the LEAP structure sequences of branches, sectors and sub-sectors, starting from the demand branch then moving to the transformation and non-energy branches. The main emission source categories for each branch will be discussed.

2.4.1 Demand

The sectors related to fuel combustion in demand includes (1) residential, (2) commercial and public services, (3) agriculture and fishing, (4) transport, (5) the manufacturing industry, and (6) the energy industry's own use. Fuel combustion leads to emissions of CO_2, CH_4, SO_2, NO_x, CO, NMVOC, NH_3, PM_{10}, and $PM_{2.5}$ emissions which include BC, OC and other $PM_{2.5}$. It is worth mentioning that BC and OC are also calculated separately.

2.4.1.1 Fuel Combustion in the Residential Sector, and in Commercial and Public Services:

This sector includes emissions from fuel combustion in residential households and 'Commercial and Institutional' buildings. In Oman, people do very occasionally use solid fuel for cooking. Table 2-1 shows some activity data from Oman's energy usage for residential households and commercial and public services.

Table 2-1: Activity data for Energy Combustion in Residential Sector, Commercial and Public Services, (2010).

	Data	Source	Unit
Liquefied petroleum gases (LPG) used in residential	180	IEA (International)	ktoe
Electricity used in residential	722		
Electricity used in Commercial and public services	492		

Sources: (IEA, 2017)

In Table 2-2, the absolute values by sector are given as provided nationally and internationally, and it is clear that they are effectively the same. The number of electricity customers has increased from 727,483 in 2011 to 790,277 in 2012, an increase of 8.6%. Electricity consumers are mainly residential, namely 71% (Authority for Electricity Generation, Annual Report 2012). Oman's total final consumption (TFC) has steadily increased in recent years. In 2000 the energy consumption accounted for 588 ktoe (6,833 GWh), but increased to 1,591 ktoe (18,510 GWh) by 2011, more than doubling in a period of eleven years. Comparing various sectors with each other, the residential sector consumes the most energy, namely 49%, followed by commercial and public services (34%) and the manufacturing industry sector (14%).

Table 2-2: Electricity consumption data for 2011 as provided from Authority for Electricity Generation (AEG) in Oman, and for 2010 as provided from IEA in ktoe.

Sector	AEG data*	%	IEA data	%
Industry	222	14	132	10
Residential	779	49	722	52
Commercial and Public Services	549	34	492	35
Other non-specified	40	2.6	40	2.9
TFC	1,590		1,386	

*Authority for Electricity Generation, Annual Report 2012

Since more than 50% of energy consumed in the residential sector is for space cooling, it has been decided for the benefit of this study to add air conditioning to the residential and commercial and public services demand sectors in LEAP-IBC, Oman version, as another specific branch.

Air conditioning:

Global energy demand from air conditioners is expected to triple by 2050. The global stock of air conditioners in buildings will grow to 5.6 billion by 2050, up from 1.6 billion today – which amounts to 10 new ACs sold every second for the next 30 years, according to the “Future of Cooling” report (IEA, 2018).

Using air conditioners and electric fans to stay cool already accounts for about a fifth of the total electricity used in buildings around the world – or 10% of all global electricity consumption today. But as incomes and living standards improve in many developing countries, the growth in AC demand in hotter regions is set to increase substantially. AC use is expected to be the second-largest source of global electricity demand growth after the industry sector, and the strongest driver for buildings by 2050.

Supplying power to these ACs comes with large costs and environmental implications. One crucial factor is that the efficiency of these new ACs can vary widely. For example, ACs sold in Japan and the European Union are typically 25% more efficient than those sold in the United States and China. Efficiency improvements could cut the energy growth from AC demand in half through mandatory energy performance standards (IEA, 2018).

There is no published data specifying the consumption of energy for air conditioning in Oman, but in this study, this consumption has been estimated by multiplying the IEA data for electricity used in the residential sector (722,000 toe) as shown in Table 2-2 by 52%, where 52% is the cooling breakdown percentage of the domestic energy consumption in Muscat, as illustrated in Figure 2-2 (Sweetnam *et al.*, 2014). This figure was therefore used as the percentage for the whole of Oman.

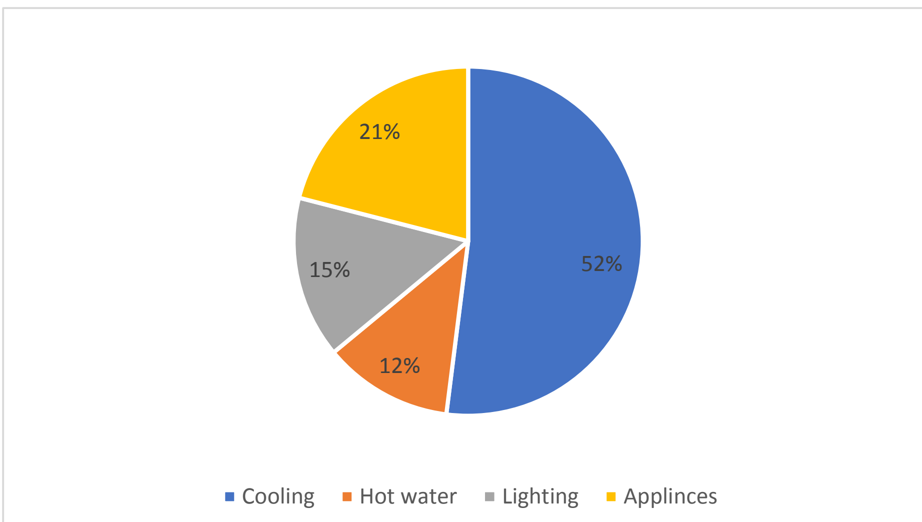

Figure 2-2: Estimated breakdown of domestic energy consumption in the residential of Muscat (Sweetnam et al., 2014)

Based on the estimated data above, consumption of energy for air conditioning was developed and populated in LEAP with other data, as shown in Table 2-3.

Table 2-3: Total energy consumption in residential sector (2010)

	Data	Source	Unit
Cooking	180,000	IEA (International)	toe
Lighting	108,300		
Air-conditioning*	375,440		
Other	238,260		

*estimated as described in section 2.4.1.1

2.4.1.2 Fuel Combustion in Agriculture and fishing:

This sector describes emissions from fuel combustion in "Agriculture and Fishing". The sector includes mobile emissions from off-road activities in agriculture and from water-borne vessels engaged in domestic inland, coastal or deep-sea fishing. Fuel combustion in fishing activities is that associated with building and maintaining fishing vessels and providing fishing gear, in most fisheries, or that required to propel fishing vessels and deploy fishing gears. Agriculture relies on fossil fuels for powering machinery used for farm production and irrigation systems. Table 2-4 shows the fuel combustion in the agriculture and fishing sector as a total.

Table 2-4: Activity data for Energy Combustion in agriculture and fishing (2010).

	Data	Source	Unit
Agriculture	2.527*	FAOSTAT (International)	ktoe
Fishing	Unavailable		

Source: http://www.fao.org/faostat/en/#data

*this data includes only irrigation in the agriculture sector and excludes the fishing sector

2.4.1.3 Fuel Combustion in Transport:

Transport sector emissions include emissions from the combustion of fuel during transport activities (road transport, aviation, shipping, and pipelines), evaporative losses from vehicles and road dust emissions. In this inventory, the transport sector includes road transport and aviation, while domestic shipping and pipelines (i.e. compressors used to transport materials (oil or gas) by pipeline) emissions are excluded. The data for the energy consumed for the transportation of oil and gas in pipelines is unavailable and emission from pipelines is expected to be very small due to the short distances of the pipelines that carry oil and gas in Oman. For domestic shipping, more detail is provided at the end of this section. The data used to develop the emission inventory from this sector in is illustrated in Tables 2-5 – 2-10.

Road transport:

There are primarily four types of road transport vehicles available in Oman: private passenger cars, public buses, public taxis, and public coaches. The transport sector in Oman is mainly based on private vehicles, there being only one government-owned company, founded in 1972, which offers public transport services. In November 2015, the company launched its new brand identity 'MWASALAT, and has been making great strides in the development of public transport in the Sultanate, starting with the expansion of Muscat's internal and external bus routes. During the period from January 1 to December 31, 2016, MWASALAT transported a total of more than 3.7 million passengers on its local routes in Muscat Governorate and on its intercity lines to the various governorates of the Sultanate. That amounted to an average of more than ten thousand passengers a day, and more than sixteen thousand passengers each week, with the peak of passenger travel being reached on Fridays, the day preceding the weekend. Of these passengers, more than 30 % were Omani. Oman does not have a rail network at present nor, indeed, any major railway line. A railway project had been proposed which would involve the construction of 2135 kilometres of national railway and plans to connect the sultanate's three major ports, Salalah, Sohar, and Duqm, with other ports in the GCC region (Oman Rail 2017). However, the project was suspended ahead of the announcement of construction tenders for the first phase in 2016; this was due to lower oil prices which resulted in the Omani government introducing cuts in government spending and revisiting some of its planned projects. Appendix D2 represents Oman's Commercial and Industrial Ports.

At present Oman is exploring options for a light rail system in Muscat itself, as well as a national passenger network but these plans remain in the early stages.

It is worth mentioning that Muscat city was ranked first in the Arab world in the Arcadis 'Sustainable Mobility Index' for 2017. The index monitors the development of transport networks and focuses on environmental standards. The city of Muscat was ranked 83rd in the world while Hong Kong topped the index, followed by Zurich, Paris, Seoul, Prague, Vienna and Singapore[7].

Emissions from the road transport sector were estimated by two different methods for different pollutants. For greenhouse gases (CO_2, CH_4 and N_2O) and SO_2, emissions were estimated by

[7]https://www.omanobserver.om/muscat-city-tops-sustainable-mobility-index-2017/

multiplying the total fuel consumed by an emission factor based on this fuel consumption. The total fuel consumption was estimated based on the total number of vehicles in the fleet (disaggregated by fuel type, fuel used, and vehicle emission standard), the average distance travelled by vehicles of each type, and the fuel economy (litres of fuel per km travelled). For air pollutants (NO_x and $PM_{2.5}$), emissions were calculated based on the total number of vehicle-km travelled by vehicles of different types, multiplied by an emission factor based on the emission of pollutants per km travelled. In this case the total number of vehicle-kms travelled was based on the total number of vehicles of different types in Oman, and the average distance travelled by one of these vehicles per year. Table 2-5 shows the activity data for fuel combustion in road transport in 2010.

Table 2-5: Activity data for Fuel Combustion in Road Transport (2010).

	Data	Source	Unit
Motor Gasoline used in road transport	1999	IEA (International)	ktoe
Gas/diesel oil used in road transport	175		

Source: (IEA, 2017)

For historical years, i.e. 2010, the number of vehicles is based on an estimate from two sets of data; Oman NCSI data and data from the GCC statistical centre. The annual vehicle kilometres travelled are estimated from data provided by Oman United Insurance, as shown in Table (2-6).

Table 2-6: Activity data for Fuel Combustion in Transport (2010).

	Fuel type	Vehicles number	Distance travelled	Source	Unit
Passenger cars (Private)	100% gasoline	538,510	24,000	National: NCSI, GCC statistical centre and Oman United Insurance.	km/yr
Light Commercial Vehicles (Taxi)	100% gasoline	4,342	80,000		
Heavy Duty Vehicles (Trucks)	100%diesel	48,840	60,000		
Motor Cycles: 4 stroke 80% 2 stroke 20%	100% gasoline	4,781	6,000		
Urban Buses	100% diesel	5,824	90,000		

Source: NCSI, GCC statistical centre & Oman United Insurance

Vehicle stock turnover model:

To project emissions from the Omani vehicle fleet into the future, the number of vehicles of each type, and of different vintages (and thus conforming to different vehicle emission standards) were projected for future years 2011-2040 using a stock turnover modelling approach. The stock turnover model of vehicles is an approach to track how fast technological developments and other changes in the attributes of new vehicles penetrate into the vehicle fleet. It was developed here by relying on administrative records available from government and corporate agencies, and some estimates such as penetration of EURO technology. Since the progression of numbers of buses is not available, the progression of light commercial vehicles was adopted for buses in this study. It is used to calculate the total number of vehicles in a particular future year, and to track the number of vehicles made in a particular year that remain in the fleet *x* years later. Doing this requires different input data for current and future years: the total number of vehicles sold (new registrations), the total number of vehicles on the road, the number of vehicles retired (scrapping), the average life-times of vehicles, and the distances travelled. A comprehensive and coherent vehicle stock turnover model for the car fleet in Oman has been developed, and can be regarded as the first vehicle stock turnover model of the car fleet for Oman.

The stock-turnover method is described by the following equations (1) and (2):

$$Stock_{t,y,v} = sales_{t,v} x\ survival_{t,y-v}, \qquad (1)$$

$$Stock_{t,y} = \Sigma Stock_{t,y,v} (i=0,....,v) \qquad (2)$$

Where

t denotes the type of technology (i.e. the technology branch)

v is the vintage (the year the technology was added)

i is the calendar year

Sales is the number of vehicles added in a particular year

Stock is the number of existing vehicles in a particular year

Survival is the fraction of vehicles surviving after a number of years and

v is the maximum number of vintage years. Sales of vehicles in Oman in future years were based on survival of vehicles (i.e. the percentage of vehicles manufactured in year *x* that remain in the fleet in year *x+t).* This was calculated based on the vehicle survival patterns model developed by Han *et al.*, (2011) and used here to estimate the decrease in vehicle numbers with the growth of vehicle age for Oman, figures which are important for the projection of Oman’s vehicle scrappage and ownership.

The vehicle scrappage rate is defined as the absolute value of the derivative of vehicle survival ratio with respect to vehicle age. The function of vehicle survival ratio is described by Han *et al.*, 2011 as:

$$SR_{i,m}(t) = \exp[-(t/T_{i,m})^{k_{i,m}}], \qquad (3)$$

Where $SR_{i,m}(t)$ is the survival ratio of vehicles (type m, registered in year i) at the vehicle age of t; $T_{i,m}$ and $k_{i,m}$ are the characteristic parameters representing the average life span of a vehicle and scrappage intensities respectively. Table (2-7) illustrates the parameters which were used to estimate the survival ratio for different type of vehicles.

Table 2-7: Characteristic parameters of the vehicle survival patterns

Vehicle classification	T_m	k_m	Reference
Private passenger vehicles	14.46	4.79	(Han *et al.*, 2011)
Government and business buses	13.11	5.33	
Heavy duty trucks	12.8	5.58	

Source:(Han *et al.*, 2011)

A substitution of parameters from Table (2-7) in equation (3) was used to develop the vehicle survival ratio or retirement rate of vehicles for each category during specified years. Combining the sales and survival rate patterns in Equation 3 yielded the total number of vehicles in a future year that were manufactured in the preceding years. These were then converted into the total number of vehicles meeting different Euro standards based on the years for which the Euro standards were introduced, as shown in Table 2-8.

Table 2-8: History and levels of Euro standards for vehicles

EURO category	Applied to new passenger car approvals from:	Applied to most new registrations from:
Euro 1	1 July 1992	31 December 1992
Euro 2	1 January 1996	1 January 1997
Euro 3	1 January 2000	1 January 2001
Euro 4	1 January 2005	1 January 2006
Euro 5	1 September 2009	1 January 2011
Euro 6	1 September 2014	1 September 2015

Dust emissions from vehicles travelling on unpaved roads are an important source of PM_{10} and $PM_{2.5}$ emissions in many developing countries (Philip *et al.*, 2017). Dust emissions from this source tend to occur on dry days and therefore, the dry weather PM emission factors given in this study are derived from Gillies et al. (2005), and the fraction (as %) of dry days (taken to be when rainfall is less than 0.25 mm) was estimated for calculating emissions, together with an estimate of the fraction of total distance travelled on unpaved roads (Table 2-9) and also on the following information:

Based on Oman's climate and health profile, as developed by the World Health Organization (WHO) and the United Nations Framework Convention on Climate Change (UNFCCC), the longest dry spell per year is an average of about 230 days (WHO, 2015). This means that Oman typically has 63%. of dry days. In Table 2.9, the paved and unpaved road lengths are given for the year 2010 and it has been assumed that all types of vehicles: passenger cars, light commercial vehicles, heavy duty vehicles, motorbikes and buses are traveling 10% of their distances on unpaved roads.

Table 2-9: Oman road lengths end of 2010

Road Lengths of		Unit	Reference
paved road (asphalted)	28,903	Km	Statistical year book, 2011 (NCSI)
unpaved road (graded)	30,460		

Aviation:

Data for the aviation sector in this study are summarised in Table 2-10, the sources being the National Centre for Information and Statistics (NCIS) and the Public Authority for Civil Aviation (PACA). The estimate was calculated based on information about Oman's production of kerosene jet fuel. Jet fuel is produced in refineries in both Muscat and Sohar, in the following amount: 3290.8 x 10^3 barrel in 2012 which is converted to 460.7 kt of Kerosene jet fuel. Oman does not import any jet fuel, and the jet fuel it produces is used for both domestic and international flights. However, there is no data on fuel consumption for domestic flights only, and since Oman is a small country and most of the domestic flights cover short distances, it has been assumed that the emissions from planes cruising in Omani airspace are very small in comparison with those from LTO (landing and taking off). This analysis, therefore, only covers LTO emissions for domestic and international flights. Based on an interview with PACA, Oman no longer permits the landing of any older aircraft, a restriction aimed at controling air pollution. It can therefore be assumed that all planes in this study are in the average fleet category.

Table 2-10: Aviation data for 2010

	Data	Source	Unit
Domestic LTO	6269	National: NCIS and PACA	Number of flight
International LTO	52816		
% share of average and older fleet	100 (average fleet)		%

Source: NCIS and PACA

Domestic Shipping:

Emissions from domestic shipping come from fuel burnt by all vessels not engaged in international shipping (excluded are fishing vessels, which are covered under the Agriculture/Forestry/Fishing branch). Although emissions from shipping are considered one of the major sources of NO_x (Abdul-Wahab *et al.*, 2008), the data for total energy consumption for this domestic shipping is not available for Oman. There are emissions from international ships in Omani waters, but this is not part of this inventory because it falls outside the boundary of a national emissions inventory. International shipping emissions are included in the rest of the world contribution to $PM_{2.5}$ emission as a background emission in LEAP-IBC, where the source of international shipping emission data is the GAINS/ECLIPSE[8].

2.4.1.4 Fuel Combustion in Manufacturing Industry:

This sector includes combustion of all fuels within the manufacturing industry. The industries covered in this study are all types of industry, presented as a single unit (Table 2-11).

Table 2-11: Activity data for Fuel Combustion in Manufacturing Industry.

	Data	Source	Unit
Natural gas used in Industry	357	IEA (International)	ktoe
Fuel oil used in Industry	1735		
Electricity used in Industry	132		

Source: (MOCI 2017; IEA 2017)

2.4.1.5 Fuel combustion in the Energy Industry Own Use:

This sector covers emissions from the so-called 'Own use' of fuels in the energy industries, in which fuel combustion occurs to provide energy for internal (own) use in fuel extraction and processing. This sector is subdivided into 'Petroleum Refining' and 'Other Own Use' and only includes fuels combusted during the extraction or conversion process (i.e. own use), not the feedstock fuel. That is, only the crude oil burnt during oil refining is included, not the crude oil actually refined. Emissions from electricity generation, and gas flaring from the oil and gas industry are excluded, since they are dealt with under Transformation.

[8] http://www.iiasa.ac.at/web/home/research/researchPrograms/air/ECLIPSEv5a.html
https://www.giss.nasa.gov/tools/panoply/download/

i. Oil Refineries:

In Oman, there are two oil refineries operated by the Oman Oil Refineries and Petroleum Industries Company (ORPIC), one in Muscat (Mina Al Fahl), the other in Sohar (Mina Sohar); together thy have a production capacity of 222,000 barrels of crude oil per day. The crude oil is refined into naphtha, Liquefied Petroleum Gas (LPG), gas oil (diesel), gasoline, heavy fuel oil and kerosene jet fuel. In addition, the Aromatics Plant has a production capacity of 818,000 t per annum of paraxylene and 198,000 t of benzene. Finally, the Polypropylene Plant can produce up to 350,000 t of polypropylene pellets. Appendix E2 illustrates the plant production of fuels and petrochemicals, for end use or for further downstream processing (ORPIC, 2017). The Oman Oil Company (OOC) is in the process of building a new refinery in Duqm for producing light/middle distillates at a high efficiency rate. It focuses on naphtha, jet fuel, diesel and LPG as its primary products. The refinery contains hydrocracking, hydro-treating and delayed coking units, along with sulphur recovery, hydrogen generation and merox treating units. Expected to be operational by 2022, the Duqm Refinery project will operate with a refining capacity of 230,000 barrels per day when it is completed (DR, 2017).

This sub-sector deals with all emissions from the combustion of fuel used to support the refining of petroleum products. The international sources of data include IEA (IEA, 2017), and the national source of information is the Ministry of Oil and Gas (MOG). The international data used in LEAP-IBC are shown in Table 2-12.

Table 2-12: Activity data for own use of fuel in petroleum refineries in Oman (2010)

	Data	Source	Unit
Refinery Gas	319	International Energy Agency (IEA, 2017)	ktoe
Fuel oil	325		

Source:(IEA, 2017), ktoe = kilotonnes oil equivalent

ii. Other Own Use of energy in the energy industry

This includes all emissions from the combustion of fuels used during the manufacture of secondary or tertiary products from fuels and includes the combustion emissions from own (on-site) energy use in oil and gas extraction. The data used in LEAP-IBC are shown in Table 2-13.

Table 2-13: Activity data for the sub-Sector (Own Use Industry) of Energy combustion in Energy Industry (2010)

	Data	Source	Unit
Natural gas used in Other own use in energy industry	2541	International Energy Agency (IEA, 2017)	ktoe
Electricity used in Other own use in energy industry	76		

Source: (IEA, 2017), ktoe = kilotonnes oil equivalent

2.4.1.6 Fuel combustion in Non-specified other:

Sometimes, fuel consumption data for the Residential, Commercial and Public Services and the Agriculture, Forestry and Fishing sectors are not reported separately (e.g. in the International Energy Agency (IEA) databases) and these are then classified as 'Non Specified Other'. Table 2-14 represents the declared data by IEA for this sub-sector, classified according to the source of fuel. The total fuel combustion is 535 ktoe for 2010.

Table 2-14: Activity data for 'non-specified other' in Oman (2010)

	Data	Source	Unit
Natural gas annual consumption in non-specified other	164	IEA (International)	ktoe
Gas/diesel oil annual consumption in non-specified other	331		
Electricity annual consumption in non-specified other	40		

Sources: (IEA 2017)

2.4.2 Transformation:

The Transformation branch includes combustion emissions from electricity generation and fugitive emissions from crude oil exploration, production and transport, oil refining, the distribution and handling of gasoline (including emissions from service stations) and the production and distribution of natural gas (including venting). Also included here are emissions from 'flaring' during crude oil and gas extraction/production which are classified as 'fugitive emissions' as no useful energy is extracted from this combustion of waste gas.

It is worth mentioning that there is not much activity data to enter here. This is because, as LEAP is an energy modelling tool, it assumes that this sector will generate both the electricity and petroleum products required to meet the demand in the Demand branches above - after taking into account any import or export of electricity or petroleum products. Therefore, most of the 'activity' data entered in this sector is a percentage share of different processes or fuel, as described in the following sub-sections.

2.4.2.1 Electricity generation:

This includes all emissions from the combustion of fuel for the generation of electricity for sale to the public. The power stations or utilities may be publicly or privately owned. Emissions from own on-site use of fuel are also included.

In Oman, natural gas is the predominant fuel used in the electricity generation sector. It accounted for 82% of the fuel used in 2010; by 2016 the figure had risen to 97%, with diesel accounting for the remaining 3 percent. There were eight power generation plants in 2010: Al Kamil, Al-Ghubrah, Barka I, Barka II, Manah, Rusail, Sohar I and Wadi Jizzi.

The data used for compiling the emission inventory in LEAP-IBC is shown in Table 2-15. This data is based on what was provided by the Public Authority for Electricity and Water (PAEW) for the annual consumption of natural gas used to produce electricity; in 2010 it was 207,268 TJ which is equivalent to 4951 ktoe. The data for this given by IEA is quite similar at 5182 ktoe. Although there is little difference between the two, it was decided to adopt the IEA data to be consistent with the other IEA oil and gas figures which have been used throughout this study (Table 2-15). No SO_2 or NO_x emission control systems are fitted to any of the power stations (PAEW, 2017).

Table 2-15: Percentage of electricity output met by natural gas and diesel in 2010

	Data	Source	Unit
Natural gas % share in electricity power generation	81.5	Based on IEA (International)	%
Gas/diesel oil% share in electricity power generation sector	18.5		

2.4.2.2 Oil and Gas industry:

This sub-sector covers all fugitive emissions related to the extraction, processing, storage, distribution and use of fossil fuels. During all of the stages from the extraction of fossil fuels through to their final use, the escape or release of gaseous fuels or volatile components of liquid fuels may occur. This includes fugitive emissions of NMVOC from crude oil exploration, production and transport, oil refining, the distribution and handling of gasoline (including emissions from service stations) and the production and distribution of natural gas (including venting).

During oil well drilling, fugitive emissions of methane (CH_4) and non-methane volatile organic compounds (NMVOCs) are likely to occur when the drilling breaks through small oil/gas reservoirs. In oil/gas production platforms, fugitive emissions of NMVOCs, CH_4 and CO_2 arise from several sources, in particular gas leakage through compressor seals, valves and flanges.

For the onshore exploration or production fields, fugitive emissions of VOC (CH_4 plus NMVOC) are expected from pneumatic devices used at oil and gas wells. When drilling for crude oil, natural gas often comes to the surface along with the oil. This associated gas is often vented or flared to maintain safe pressure in the well. Flaring and venting are processes whereby gas is burned or released into the atmosphere. These processes have a negative effect on the environment by contributing to the emission of greenhouse gases, sulphur dioxide, and methane into the air. There are typically two main reasons for flaring and venting at petroleum refineries, chemical plants, and natural gas processing plants. Firstly, it may sometimes be commercially uneconomical to recover or transport the gas that is an auxiliary release during oil production. Gas may also be vented or flared in a controlled manner for safety reasons when oil extraction results in over-pressurisation. Venting is simply the release of the gas (mainly CH_4, NMVOC and CO_2) directly into the atmosphere, while flaring is the burning of the vented gas. Emissions from flaring from the gas well completion phase are BC, CO, NO_X, and VOC, and emissions from flaring from the oil well completion phase are BC, CO, NO_X, VOC, and SO_2.

Oil and gas well heads are a source of VOC emissions from various fugitive outlets. The wellhead is the part of an oil or gas well that terminates at the surface, whether onshore or offshore, and is the place from where oil or gas products can be withdrawn. Oil and condensate stored in storage tanks is transferred to trucks for shipment for further processing. Fugitive VOC emissions are released from these loading processes. At producing well sites, there are numerous pumps and piping configurations used to move oil and gas products and get them into the processing and distribution systems. These pieces of equipment contain numerous components, such as flanges, valves, and seals, that are potential sources of fugitive VOC emissions.

Table 2-16 shows activity data from Oman's oil industry which are estimated based on information given in Table 2-17. The percentage split between conventional drilling and fracking for oil drilling can also be calculated from the following information: in 2010, three oil fields were using fracking technology out of more than 45 other conventional fields. The gas fields, however, were different; all the 11 gas fields were using fracking technology. One of the main chemicals released in the fracking process is methane. It must be noted here that the emission factors for the oil and gas industry used in this study come from the more advanced IPCC update (IPCC Guidelines 2019 refinement).

Table 2-16: Percentage process share for calculating fugitive emissions for Oman's oil industry (2010)

	Data	Source	Unit
Oil Transport in Marine Tankers	99.68	Based on MOG	%
Oil Transport in Pipelines	0.32		
Oil Production (Offshore)	10.0		
Oil Production (Onshore)	90.0		

Table 2-17: Data used to calculate process share for fugitive emissions from Oman's oil industry (2010)

	Data	Source	Unit
crude oil loaded onto marine vessels	$1.56\ x10^7$	MOG	kt
crude oil transported in pipelines	$5.02\ x10^4$		
oil production onshore	$4.97\ x10^4$		
oil production offshore	$5.22\ x10^2$		

Source: Ministry of Oil and Gas (MOG, 2017)

2.4.3 Non energy

The 'Non-Energy' category branch includes all sectors responsible for non-energy related emissions (Industrial Processes, Solvent use, Agriculture, and Waste) as well as fugitive emissions from oil well drilling and gas flaring during oil production. Vegetation fires do not occur in Oman, and therefore are excluded from this study.

2.4.3.1 Fugitive emissions from oil production:

This sector captures emissions from drilling new oil wells during oil exploration, and fugitive emissions from the flaring of natural gas during oil production. Table 2-18 represents these data based on data provided by Ministry of Oil and Gas (MOG).

Table 2-18: Activity data for fugitive emissions from Oman's oil industry (2010)

	Data	Source	Unit
wells drilled/year	995	MOG (National)	Number
Volume of gas flared	$1.29x10^9$		10^3m^3

Source: Ministry of Oil and Gas (MOG, 2017)

2.4.3.2 Industrial Process (non-combustion) emissions:

A number of air pollutants not associated with fuel combustion are emitted during a variety of industrial processes. The industrial process emission categories covered in this sub-sector are: mineral products (cement and lime), and the production of chemicals (urea and sulphuric acid).

The major activities contributing to Oman's emissions from the non-combustion industrial process are cement companies, and production of petrochemicals. Oman has two major cement companies; Oman Cement Company (OCC) and Raysut Cement Company (RCC), both of which use an electrostatic precipitator (ESP) as a PM dust controller. In addition, three production lines in RCC use bag-house filters. Table 2-19 shows the data for non-combustion industrial process.

Although the Oman Mining Company (OMC) is producing copper cathodes, no smelting for copper is involved. Nor is there any production of zinc or lead, but as a part of the operation zinc and lead are collected from the refinery mixed with gold, silver and other elements (Ali Al Waili, Personal communication). Some activities are not included in the emissions inventory because of lack of data. These include the fugitive emissions of particulate matter (PM) from quarrying, and major construction activities, which would be listed as hectare-months per year. Another omissions include asphalt roofing, asphalt road paving and food production, but emissions from these are expected to be very small.

Table 2-19: Activity data used for non-combustion industrial process

	Data	Source	Unit
Cement production	5,020	OCC & RCC (National)	kt/yr
Lime production	4,390		
Urea	2,077		
Sulphuric acid	14.6		

Source: (OCC 2016; RCC 2016)

2.4.3.3 Agriculture:

Only 5.9% of the total land area of the Sultanate of Oman is considered suitable for agricultural production activities (FAOSTAT, 2017). Its geographical location in the arid and semi-arid belt of the globe means it is classified as an arid country. As a result, one of the biggest challenges facing development in the agriculture sector is access to water resources. Another major challenge is that most farms in Oman are managed by unskilled labour, so that fertilizers and pesticides are not used properly or efficiently.

Several types of agricultural activity can emit air pollutants. These include the treatment of livestock manure (a source of ammonia (NH_3) emissions), the application of fertilizers (a source of both NO_x and NH_3), enteric fermentation in livestock which emits CH_4, and the burning of agricultural residues, which emits a range of pollutants (NO_x, SO_x, NH_3, CO, NMVOC and particulate matter). Agricultural emissions are generally calculated by multiplying an activity rate by an emission factor. Activity data such as the numbers of livestock present, the amount of fertilizer applied and annual crop production (for crop residue burning) are available on the internet from the FAOSTAT database. Table 2-20 and 2-21 show agriculture data for Oman, where the data provided by Ministry of Agriculture and Fisheries (MOAF) have exactly the same default FAO data for number of animals.

Table 2-20: Activity data for livestock enteric fermentation and manure management and animal housing for Oman in 2010

	Data	Source	Unit
Sheep	388590	MOAF (National)	Animals
Goats	1719120		
Camels	129560		
Mules and Asses	25000		
Poultry	4390000		
Other Cattle	332780		

Source: (MOAF, 2017)

Table 2-21: Fertilizer consumption in Oman for 2010

Fertilizer	Data	Source	Unit
Ammonium nitrate (AN)	1000	FAOSTAT (International)	Tonnes
Ammonium sulphate	689		
Calcium ammonium nitrate (CAN) and other mixtures with calcium carbonate	816		
Diammonium phosphate (DAP)	977		
Monoammonium phosphate (MAP)	255		
NPK fertilizers	3910		
Other NP compounds	463		
PK compounds	371		
Potassium chloride (muriate of potash) (MOP)	2000		
Potassium nitrate	619		
Superphosphates above 35%	847		
Urea and ammonium nitrate solutions (UAN)	87		

Source: (FAOSTAT database), http://www.fao.org/faostat/en/#data

2.4.3.4 Waste:

Waste here covers the treatment and disposal of waste, including the disposal of waste in landfills, and the aerobic and/or anaerobic treatment of municipal sewage. MSW in landfills and wastewater treatment are often important sources of methane. Waste incineration by ‘open burning’ has been prohibited by law in Oman since 2004, as mentioned in section (2.3.4), so this study has assumed that no municipal solid waste is disposed of by open-burning. Nor does Oman have any incineration plants for its municipal, industrial or commercial waste.

Municipal Solid Wastes (MSW) in landfill:

The Oman Environmental Services Holding Company Be'ah was established in July 2007, and in 2011 started taking over the responsibility for collecting waste from municipalities in all the governorates which used to collect waste from the residents of Oman.

Based on Be'ah's estimates for 2008, there were more than 300 dumpsites all over Oman and four landfill sites. Currently no methane is recovered from landfills, but Be'ah is working on installing a flaring system at the Al Multaqa landfill, the biggest engineered landfill in the country.

Currently 95% of the MSW generated is sent to landfills or dumpsites spread across the Sultanate. The 5% exception is as a result of the SMEs collecting valuable waste from MSW, such as plastics and metals for recycling.

Oman's per capita waste generation rate varies across various governorates for a number of reasons. However, Be'ah uses a national average of 1.2 kg/person/day; this is equal to 0.438 tonnes/capita/year. Information on the population whose waste was collected, the per capita rate, the MSW generation rate, the fraction of MSW sent to solid waste disposal sites, and other details are listed in Table 2-22.

Table 2-22: Activity data for MSW and waste water

	Data	Source	Unit
(MSW) in landfill (methane emissions)			
Amount of methane recovered from landfill	0	Be'ah (National)	kt/yr
population whose waste was collected	2773000		People
per capita MSW generation rate	0.438		tonnes/capita/year
fraction of MSW sent to solid waste disposal sites	50*	IPCC (2006)	%
Domestic wastewater treatment and discharge (methane emissions)			
the population income group split between Rural, and Urban	75% urban 25% rural	Be'ah (National)	%

Source: (Be'ah, 2017), IPCC (2006)

*the data provided by Be'ah for the fraction of MSW disposed is 95%, however In this study the default assumption of 50% was used since the information given by Be'ah was for 2014.

Domestic wastewater treatment and discharge:

Haya Water, a registered trademark of Oman Wastewater Services Company S.A.O.C, is the organization responsible converting wastewater into environmentally-friendly products, and thus serving society. Table 2-23 shows the share represented by each treatment system (i.e. Latrine, Septic tank, Anaerobic reactor or deep lagoon, Aerobic treatment plant, Untreated (Sea, or lake discharge) for the urban and rural populations.

Table 2-23: Activity data for waste water

Share represented by each treatment system:	Data		Source	Unit
	Income group			
	Rural	Urban		
Latrine	0	0	Haya (National)	%
Septic tank	75	40		
Anaerobic reactor	0	0		
Aerobic treatment plant	0	0		
Untreated discharge	0*	0*		
Sewage network	25	60		

Source: (Haya, 2018)

*There is no untreated discharge; Haya turns sewage into treated water used for irrigation, plantations, fencing, fountains, decorations, and playgrounds. Human waste is converted into fertilizer. A gravity and vacuum system is used in the sewage network.

2.5 Results and discussion:

This section, will reveal the results of Oman emission inventory for 2010 based on the data discussed in the sections above. This will be presented in different ways, either as the absolute value of emissions or as a percentage share of fuel responsible of emissions, or as a source of emissions. This emission inventory is the first of its kind to be developed for Oman, apart from the GHG inventory which was jointly produced in 1994 by the Ministry of Environment & Climate Affairs (MECA) and Sultan Qaboos University (SQU), and was submitted as the Sultanate of Oman's Initial National Communication.

2.5.1 Oman Total Emission Estimate:

Estimates of the emissions of carbon dioxide (CO_2), carbon monoxide (CO), methane (CH_4), non-methane volatile organic compounds (NMVOC), nitrogen oxides (NO_X), sulphur dioxide (SO_2), particulate matter ($PM_{2.5}$), black carbon (BC), organic carbon (OC) and ammonia (NH_3) in Oman from this study, as derived for the year 2010, are summarized in Figures 2-3 and 2-4.

The largest emissions apart from CO_2 were of CH_4 at 565 kt, followed by SO_2 (160), NMVOCs (142), NO_x (137) , $PM_{2.5}$ (61), CO (51), NH_3 (18), BC (4), and OC (0.9) kt. (Figure 2-3)

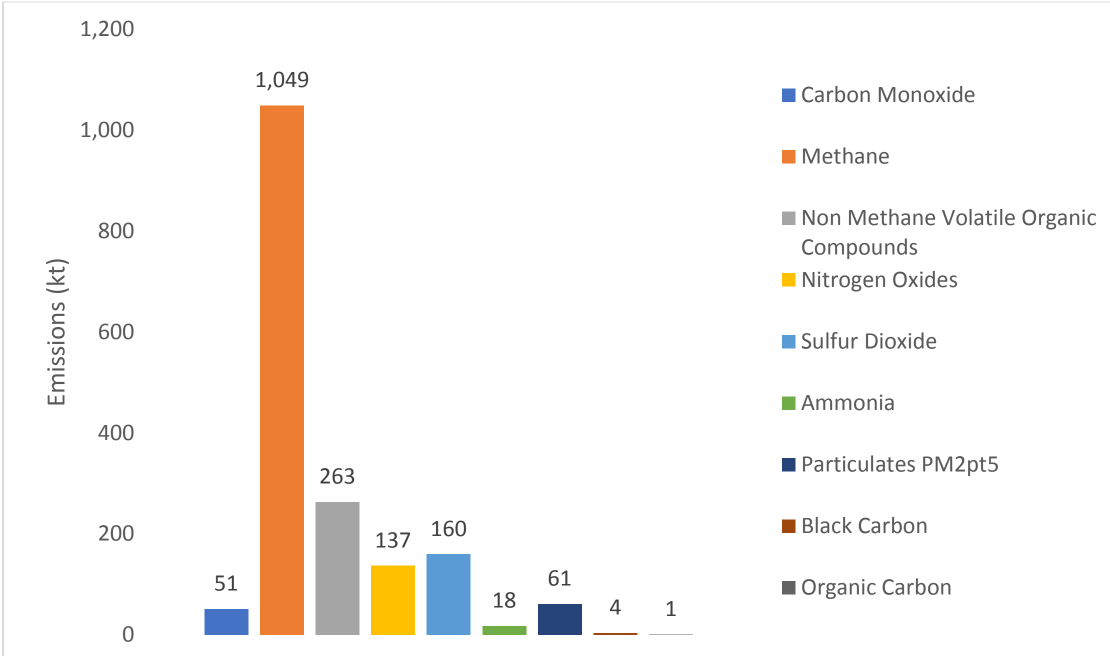

Figure 2-3: Total emissions of pollutants which are covered in this study (CO, CH_4, NMVOCs, NO_x, SO_2, NH_3, $PM_{2.5}$, BC, and OC) in Oman for 2010 apart from CO_2

2.5.1.1 CO_2 emission:

The estimated emission of CO_2 in Oman for 2010 is 50 Mt, in which electricity generation (31%) and transport (24%) are the sectors responsible for the highest percentage share of CO_2 emissions (Figure 2-4). The other main sources include: the energy industry's own use, industry, and industrial process emissions.

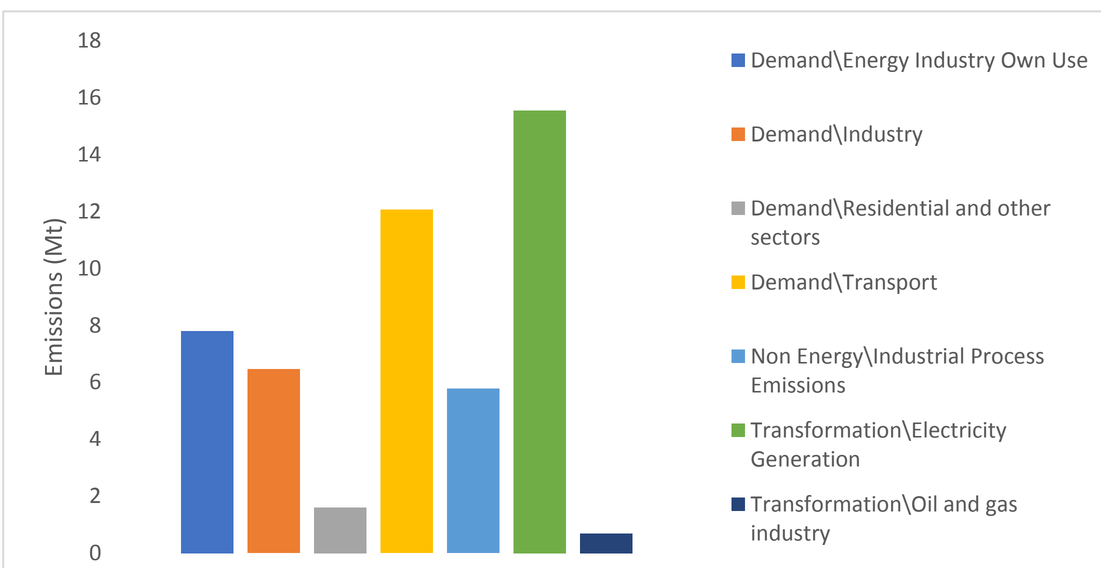

Figure 2-4: Sources of CO_2 emission in Oman for 2010

As shown in Figure 2-5, natural gas had the highest percentage share of CO_2 emissions than the combustion of any other fuels; these emissions came mainly from the burning of gas in the two major sectors for CO_2 emission, electricity generation and the energy industry's own use. The second largest share of CO_2 emissions was from the diesel consumed in road transport as well as in electricity generation. Heavy fuel oil, which is consumed in industry and the energy industry's own use (in petroleum refining) was the third biggest source, with crude oil, burnt in the process of oil and gas production, coming fourth. Motor gasoline consumed in the road transport was next in line. The non-energy share in CO_2 emissions can be attributed almost totally to industrial process emissions from the lime and cement industry (99.8%), with fugitive emissions in the exploration and production of oil and gas responsible for only 0.2%.

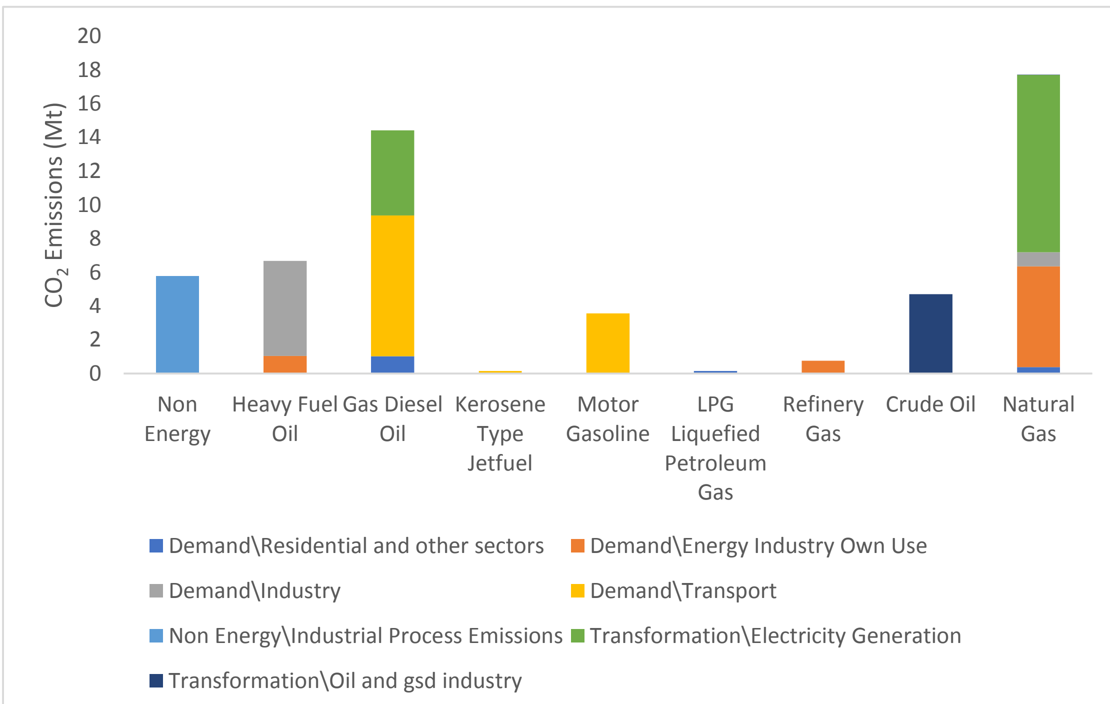

Figure 2-5: Percentage share of CO_2 emission from the combustion of fuel in different sectors contributing to CO_2 emission.

2.5.1.2 CH_4 emission:

Total emission of methane in Oman for the year 2010 was 565 kt, of which most (92%) came from fugitive emissions from the oil and gas industry (Transformation processes). Much lower amounts of CH_4 emission came from waste, both Municipal Solid Waste (MSW) and domestic waste-water (4.5% for all waste), and livestock enteric fermentation and manure management in agriculture (2.6%), as shown in Figure 2-6.

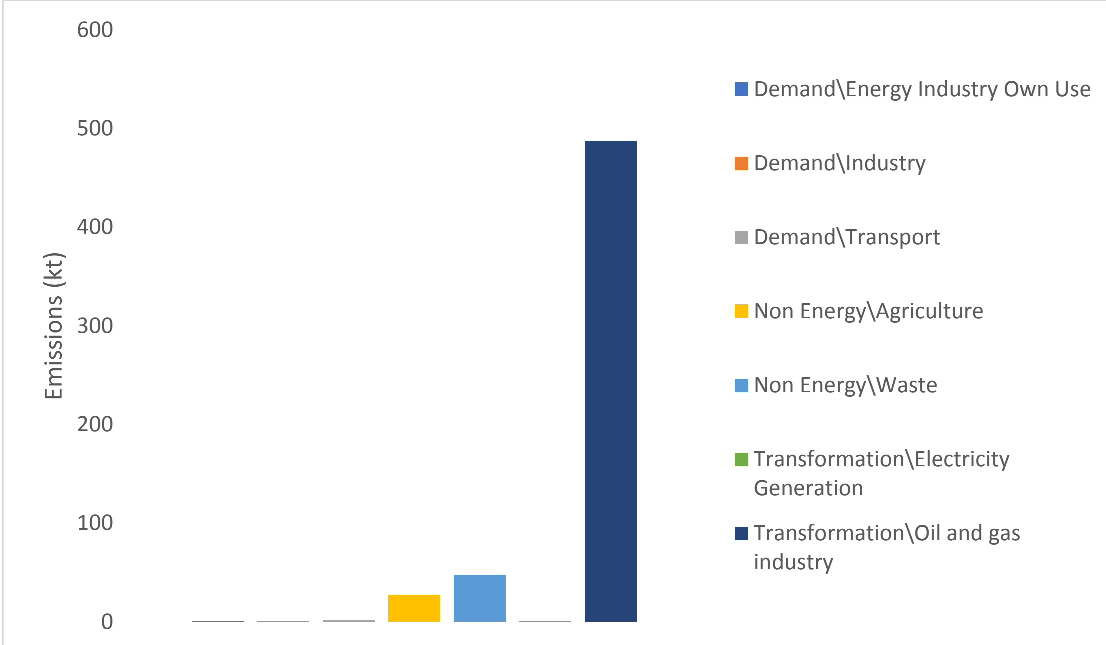

Figure 2-6: Source of CH_4 emission in Oman for 2010

2.5.1.3 SO_2 emission:

The total emission of SO_2 in 2010 was 160 kt. As illustrated in Figure 2-7 this came mainly from fuel combustion in the industry sector, with the next largest sources being the energy industry's own use and the oil and gas industry respectively. In Oman, heavy fuel oil (HFO) is designated by international standards (ISO 8217) as a high-sulphur fuel oil (HSFO) with a maximum sulphur content of 3.5% (Hammed Al-Manthary, personal communication) and so this percentage was assumed for this study.

As also shown in the graph below, the highest source of SO_2 emission in 2010 was from fuel combustion in the industry sector, with SO_2 emission of 126 kt. This figure is based on the assumption of heavy fuel oil having a 3.5% sulphur content , since it is this oil which is burnt in the cement- and lime – producing industry..

As shown, the fuel mostly responsible for SO_2 emissions is the HFO burnt in the industry sector. It is worth mentioning that although diesel can be burnt in the electricity sector, 82% of electricity generation in Oman in 2010 was based on natural gas, so the share of diesel (in the electricity sector) in SO_2 emissions is very low.

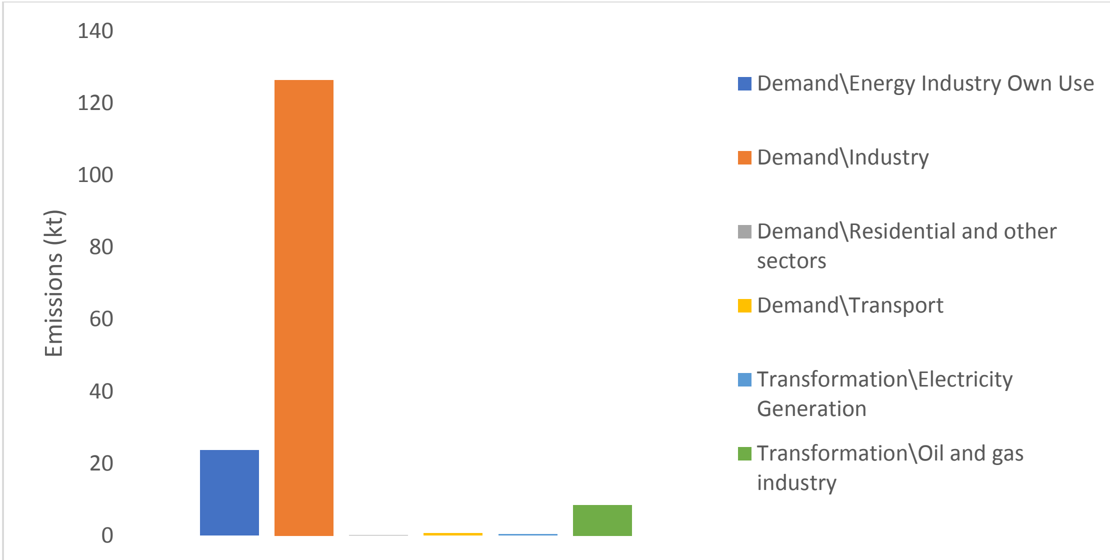

Figure 2-7: Source of SO_2 emission in Oman for 2010

2.5.1.4 NMVOCs emission:

There was 142 kt of NMVOC emission in 2010 and although there were many sources contributing to this, as illustrated in Figure 2-8, it was highly dominated by the oil and gas industry.

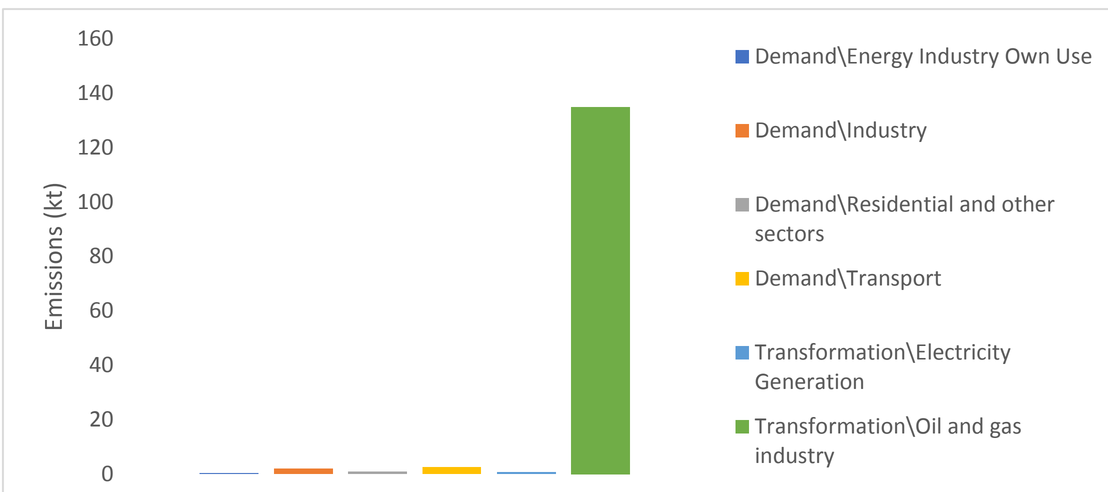

Figure 2-8: Source of NMVOCs emission in Oman for 2010

2.5.1.5 NO_x emission:

NO_x emission in 2010 was 137 kt and came mainly from five sectors: transport (37%), industry (28%), electricity generation (15%), residential and other sectors (10%), and energy industry's own use (9%), as illustrated in Figure 2-9.

The emissions of NO_x from the transport sector were due mainly to the use of diesel in road transport (urban buses and heavy-duty vehicles). In the industry sector, the emissions were related to the combustion of HFO, while in the electricity generation and energy industry own use sectors, they are related to natural gas combustion. For residential and other sectors, the main contributor is diesel combustion.

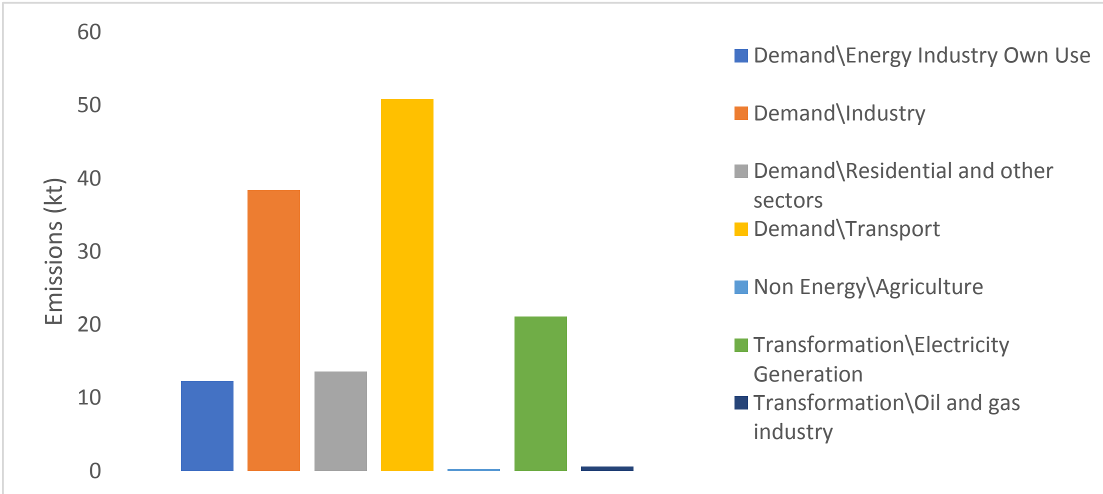

Figure 2-9: Source of NOX emission in Oman for 2010

2.5.1.6 CO emission:

The 51 kt of CO emissions in 2010 (Figure 2-10) came mainly from fuel combustion in transport, as well as from electricity generation, industry, energy industry own use, and residential and other sectors, with a small share from the oil and gas industry. In terms of fuel share it is mostly motor gasoline in the road transport sector, natural gas in electricity generation and energy industry own use, and heavy fuel oil from the industry sector.

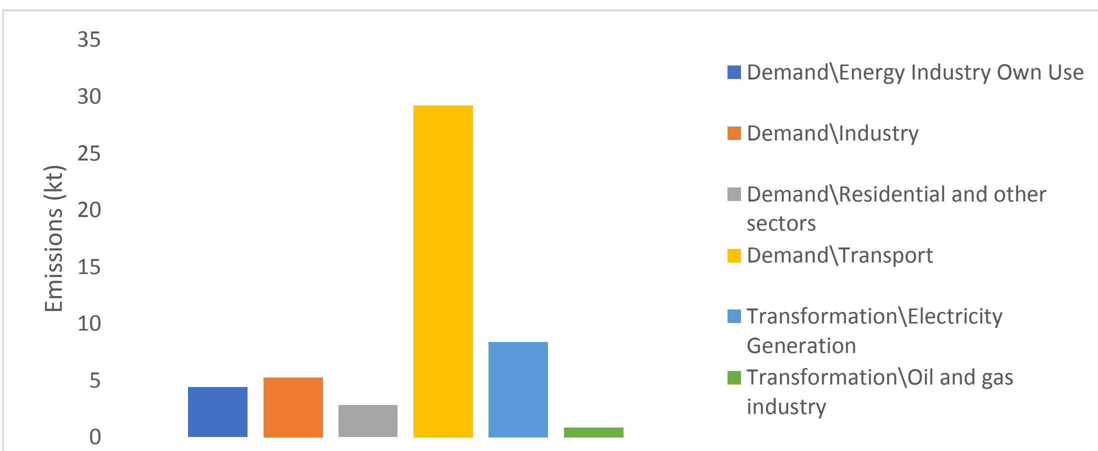

Figure 2-10: Source of CO emission in Oman for 2010

2.5.1.7 $PM_{2.5}$ emissions:

The $PM_{2.5}$ emissions were 61 kt in 2010, with most of it (Figure 2-11) coming from the road transport sector (81%), mostly as dust from unpaved roads. Smaller amounts came from industrial process emission (9%), and fugitive emissions from the oil and gas industry (4%). As stated in section 2.3.4, open-burning of crop residues is illegal in Oman and is therefore assumed to be zero. It was noted before that $PM_{2.5}$ here includes black carbon (BC), organic carbon (OC) and other $PM_{2.5}$ such as ash and crustal minerals.

Industrial process emissions, which made up the second highest share of $PM_{2.5}$ emission in 2010, basically comes from the minerals used in the production of lime and cement and chemicals. Flaring during oil production is also a source of fugitive emission of $PM_{2.5}$ (mainly as BC).

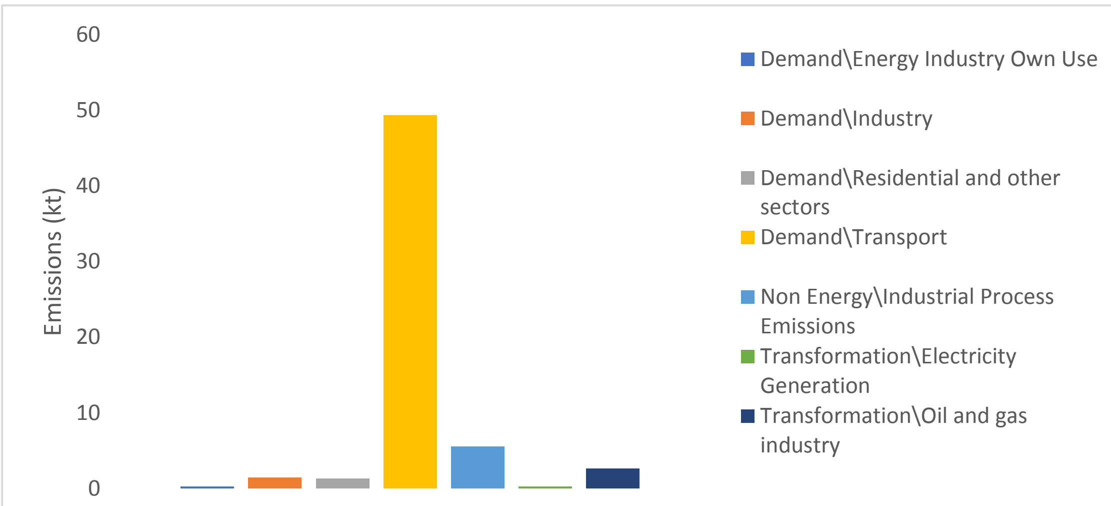

Figure 2-11: Source of $PM_{2.5}$ emission in Oman for 2010

as shown, the highest contributor to $PM_{2.5}$ emission is from the transport sector; in terms of fuel share, the fuels contributing are motor diesel and gasoline (66:34), whereas there is very little heavy fuel oil burnt in the industry sector, and thus a very small share of $PM_{2.5}$ emissions. Returning to the transport sector, it is of note that the exhaust emission of $PM_{2.5}$ is negligible compared with the dust emission from vehicles travelling on unpaved roads. This is illustrated clearly in Figure 2-12 for both $PM_{2.5}$ and PM_{10}. Dust emissions from vehicles travelling on unpaved roads are an important source of PM emissions in many developing countries; this study has discussed it in detail in section 2.4.1.3, where estimating the PM emission was seen to require an estimate of the percentage of days during the year with precipitation less than 0.25 mm.

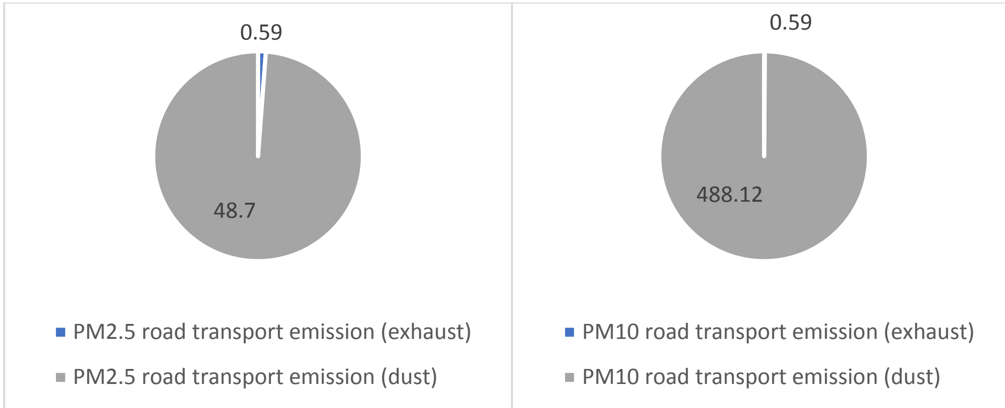

Figure 2-12: $PM_{2.5}$ and PM_{10} emission from road transport sector divided into (exhaust emissions and unpaved road dust emissions) in Oman for 2010

Asphalt road paving and asphalt roofing are other potential sources of $PM_{2.5}$ emission in a country such as Oman, which has a rapidly expanding road network (approximately 10 km of paved roads in 1970, rising to 9,673 km in 2001). A 2004 survey of the road network in Oman found that about 80% of the 7,452 km surveyed roads were paved. Of the unpaved roads, 10% were under construction, 6% were gravel, and 4% were earth. (MTC, 2003).The unpaved roads are another source of PM_{10} and $PM_{2.5}$.

2.5.1.8 NH_3 emission:

In 2010, there were 18 kt of NH_3 emissions. These came mainly from agriculture (57%), industrial processes (29%), and waste (6%), with a very small share from electricity generation, transport, and industry (7%). Figure 2-13 shows the absolute value of the NH_3 emissions from different sources. The sources of NH_3 emissions from the agriculture sector were livestock enteric fermentation, manure management and fertilizer application, while industrial process emission came only from chemical production For the waste sector, the main source of NH_3 emission was ammonia from human excreta.

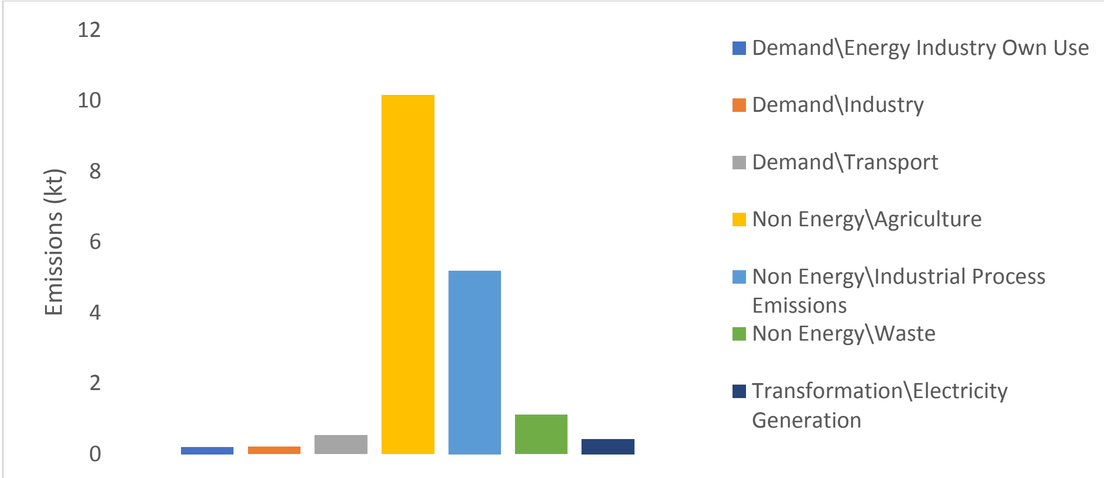

Figure 2-13: Source of NH_3 emission in Oman for 2010

2.5.1.9 BC emission:

There were four main sources of BC emissions in Oman for 2010. As shown in Figure 2-14, the major source was the industry sector, where the BC emission comes mainly from the burning of heavy fuel oil. In second place was the fugitive emissions caused by flaring within the process of oil exploration and production, and smaller sources were the residential and other sector and transport, where BC emission comes mainly from the burning of diesel.

Although the Ministry of Environment and Climate Affairs should be controlling the level of air pollutants released from stationary sources, and using controls based on standards for emissions relating to flaring in refineries and petroleum field, the BC emission level is still high. The policy which governs this, Ministerial Decision No. 118/2004, will be analysed in Chapter 3 of this thesis.

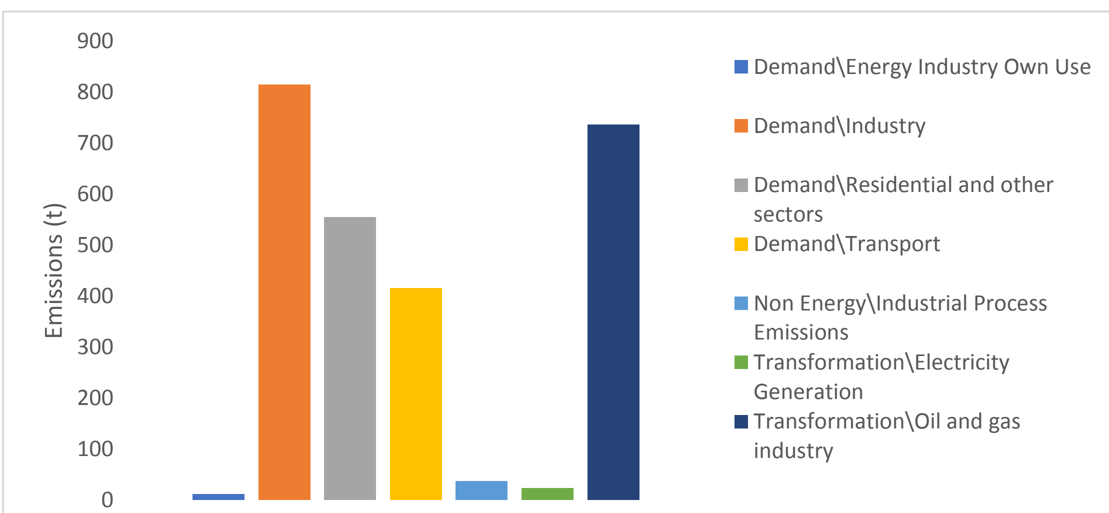

Figure 2-14: Source of BC emission in Oman for 2010

2.5.1.10 *OC emissions:*

OC emissions in Oman in 2010 came from two main sources: ‘Residential and other sectors’ (46%) and Combustion in the manufacturing industry (36%). Transport, electricity generation, and the energy industry’s own use made up the remaining share of OC emissions, as shown in Figure 2-15.

The diesel used in the ‘Residential and other sectors’ (which includes residential, commercial and public services as well as agriculture and fishing) is the main fuel responsible for the OC emission, while heavy fuel oil burnt in combustion in the manufacturing industry sector is the second largest contributor in terms of type of fuel.

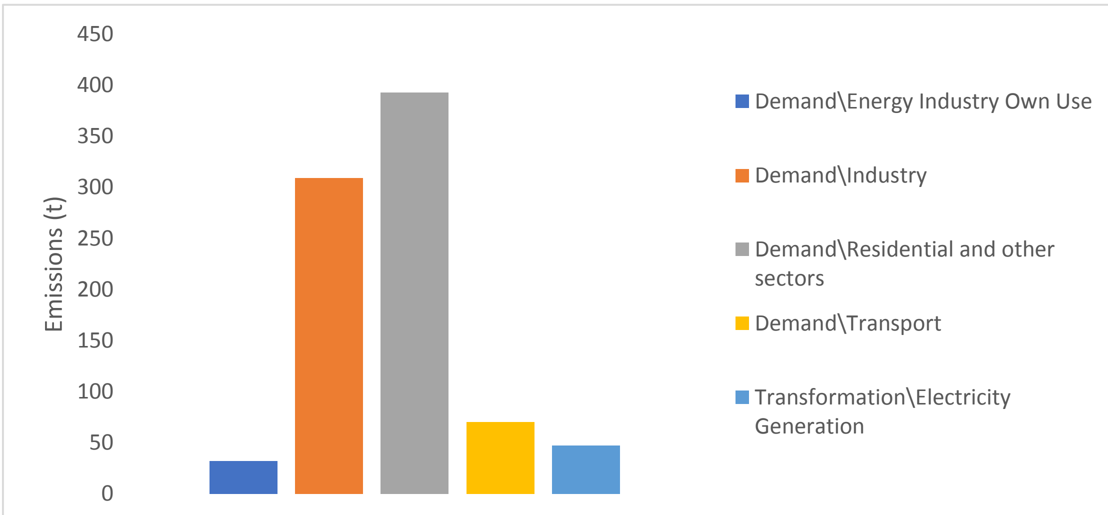

Figure 2-15: Source of OC emission in Oman for 2010

2.5.2 Comparing results from this study with other national and international inventories:

In order to assess the model performance for different emissions and their sources, the results from this study are compared with those in GAINS, EDGAR, and the Sultanate of Oman's Initial National Communication. It is also helpful to compare the emissions estimates from these inventories with other estimates of Oman, and to analyse similarities and differences. Before analysing the estimate for each inventory, it is important to note how each inventory classifies the sources of emissions. Table 2-24 shows the different sectors and sub-sectors used to categorise and estimate emissions in the EDGAR and GAINS inventories for Oman, and compares them with the LEAP classification system.

The EDGAR database (Emissions Database for Global Atmospheric Research) is a bottom-up global database covering all countries from 1970 to the present day. It provides historic emission time series and grid maps for all countries for both air pollutants and greenhouse gases and is calculated in a consistent and transparent way, so that comparisons between countries can be clearly made (Aardenne *et al.*, 2018).

GAINS (Greenhouse gas and Air Pollution Interactions and Synergies) is an integrated assessment model developed by the International Institute for Applied Systems Analysis (IIASA). It describes the pathways of atmospheric pollution from anthropogenic driving forces to the most relevant environmental impacts and identifies portfolios of measures that would improve air quality and reduce greenhouse gas emissions at the least cost (Borken-kleefeld*et al.*, 2011).

Table 2-24: LEAP sectors and sub sectors compared with EDGAR, and GAINS/ECLIPSE sectors

	LEAP category (This study)	EDGAR	GAINS
Demand			
1	Residential and other sectors*	Residential and other sectors.	Domestic
2	Transport	Road transport.	Transport
3	Industry	Manufacturing industries and construction.	Industry
4	Energy industry own use	Other energy industry.	Energy
Transformation			
5	Oil & gas Industry**	Fugitive emission from oil and gas.	Energy
6	Electricity generation	Public electricity and heat production.	
Non energy			
7	Industrial process emission (minerals, chemicals, metals, pulp & paper, food production and building construction)	Cement, lime, minerals, chemicals, metals, pulp and paper production.	Industry
8	Agriculture (livestock enteric fermentation, manure management, animal housing, fertilizer application, agriculture residue burning)	Agriculture waste burning, manure management, direct soil emission, manure in pasture, other direct soil emission.	Agriculture and Crop residue burning
9	Waste (MSW in landfills, waste incineration, human excreta, domestic water)	Wastewater handling, waste incineration, solid waste disposal on land.	Waste
10	Solvent	Solvent (paint & other)	Solvent

* Residential and other sectors includes fuel combustion in 'Residential', 'Commercial and public services', 'Agriculture and fishing', and 'Non-specified other' combined.

** Oil & gas industry (LEAP) includes gasoline service stations, gasoline transport, oil refining, transporting and production, gas distribution, processing and production and flaring combined.

GAINS's classification system has eight categories for sources of emissions:

1. Agriculture	2. Crop Residue Burning	3. Domestic	4. Energy
5. Industry	6. Solvents	7. Transport	8. Waste

The energy database in GAINS includes three major components of the energy system:

• Electricity and district heat generation in the power and district heating sector.

• Energy use for primary fuel production, conversion of primary to secondary energy other than conversion to electricity, and heat in the power and district heating plants, and for delivery of energy to final consumers.

• Final energy use in: industry, domestic sector, transport, and non-energy use of fuels.

Industry: includes industrial combustion, and non-energy use. Other industrial combustion is divided into: iron and steel, chemical, non-ferrous metals, non-metallic minerals, paper pulp, and printing and other manufacturing industries

Domestic: includes residential, commercial and public services.

Agriculture: includes agriculture, forestry, fishing, and non-specified sub-sectors.

Transport: includes transport, other mobile source sectors, and sources from the so-called national sea traffic which includes seagoing ships and fishing boats operating between ports in the same country ('GAINS Online : Tutorial for advanced users', 2009).

Table 2-25 below presents a comparison of these inventories of emissions in Oman. It reviews the estimates presented in EDGAR and GAINS and summarizes them in comparison with this study's emission inventory using LEAP-IBC. The table yields some interesting information which will be discussed below. Table 2-25 bellow shows that many of the estimates obtained from this study compare fairly well with those in other inventories. For example, the figures for all three estimates of NH_3 emissions are similar. EDGAR and this study give similar estimates for BC and CO_2, while GAINS and this study give similar estimates for NO_x emission. However, there are large differences in some of the estimates, notably for CH_4, NMVOCs, and CO; these will be analysed along with the discussion of Table 2-26.

Table 2-25: Total emissions in the Sultanate of Oman, 2010 (kt)

Unit: kt = Gg	This study	EDGAR	GAINS	IEA
CO_2	49,948	65,700	-	42,400
CH_4	564.8	861.8	1927.2	
SO_2	159.6	85.7	58.99	
NO_x	136.9	166.2	123.4	
NMVOCs	142.1	300.6	588.0	
CO	50.8	208.0	275.1	
$PM_{2.5}$	60.8			
$PM_{2.5}$ (without unpaved road dust)	12.1	6.92	14.95	
PM_{10}	510.6			
PM_{10} (without unpaved road dust)	23.1	9.01	15.98	
NH_3	17.8	11.5	10.6	
BC	3.9	1.46	9.11	
OC	0.9	1.45	4.91	

For some emissions, the differences can be relatively easily explained. For $PM_{2.5}$ and $PM_{10,}$ for example, the difference can be explained by the fact that this study uses a more detailed method for calculating $PM_{2.5}$ emissions from the transport sector, and also includes dust from unpaved roads, a factor which was not taken into account in either EDGAR or GAINS.

The GHG inventory jointly conducted by the Ministry of Environment & Climate Affairs (MECA) and Sultan Qaboos University (SQU) and submitted in 1994 as the Sultanate of Oman's Initial National Communication, is the first and only version of a national communication by Oman. The estimates of CO_2 and CH_4 emissions in 1994 are 11,184 and 124.2 kt respectively, with several emission sources not being included; these are flaring, cement production and waste, as well as indirect emissions from loading crude oil, solvent use and venting offshore (MECA, 2013). This might go some way to explaining the large difference in the figures for emissions of CO_2 between the MECA and the emissions calculated in this study. The fact that MECA's inventory was conducted as far back as 1994 also makes it more difficult to make comparisons.

As pointed out, it is difficult to make direct comparisons between the values in Table 2-25, but it would still be useful to compare the results in more detail. Table 2-26 therefore presents more detail of the sources of emission based on the classification system of each tool, and summarizes the results developed from each model.

Table 2-26: comparison between results obtained from this study (LEAP-IBC), EDGARs and GAINS eclipse by sector and pollutant for 2010, unit in (Mt) for CO_2, in (kt) for CH_4, NMVOCs, SO_2, NO_x, $PM_{2.5}$, PM_{10}, CO and NH_3, and in (t) for BC and OC

	Source of pollutants	This study	EDGAR	GAINS	Comment
	CO_2 (Mt) by sector				
1	Residential and other sectors	1.6	0.86	NA	
2	Transport	12.1	8.4		
3	Industry	6.5	23.4		
4	Energy Industry Own Use	7.8	7.8		
5	Oil & gas industry	0.7	3.3		
6	Electricity Generation	15.5	15.1		
7	Industrial Process Emissions	5.8	6.8		
8	Agriculture	0	0		
10	Solvent	0	0		
	Total CO_2	49.9	65.7	-	
	CH_4 (kt) by sector				
1	Residential and other sectors	0	0.1	8.8	
2	Transport	2.1	0.7	6.9	
3	Industry	0.2	0.5	6.3	
4	Energy Industry Own Use	0.2	0.4	1797.6	
5	Oil & gas industry	487.1	763.5		
6	Electricity Generation	0.4	1.0		
7	Industrial Process Emissions	0	4.2	-	
8	Agriculture	27.3	29.9	24.1	
9	Waste	47.5	61.5	83.4	
10	Solvent	NA			
	Total CH_4	564.8	861.8	1927.2	
	NMVOCs (kt) by sector				
1	Residential and other sectors	1.9	0.1	3.1	
2	Transport	2.5	70.0	68.3	
3	Industry	2.0	10.8	2.9	
4	Energy Industry Own Use	0.3	0.9	491.2	
5	Oil & gas industry	134.9	200.4		
6	Electricity Generation	0.5	1.0		
7	Industrial process emission	0	1.6	-	
8	Agriculture	0	0	0	
9	Waste	0	1.2	0.4	
10	Solvent	0	14.6	22.2	
	Total NMVOCs	142.1	300.6	588.0	
	SO_2 (kt) by sector				

1	Residential and other sectors	0.1	1.3	1.6	
2	Transport	0.6	2.3	0.5	
3	Industry	126.4	32.3	35.1	
4	Energy Industry Own Use	23.7	16.4	21.8	
5	Oil & gas industry	8.5	0		
6	Electricity Generation	0.3	30.7		
7	Industrial process emission	0	2.7	-	
8	Agriculture	0	0	0	
9	Waste	0	0	0	
10	Solvent	NA			
	Total SO_2	159.6	85.7	59.0	
	CO (kt) by sector				
1	Residential and other sectors	2.8	0.6	6.5	
2	Transport	29.2	94.4	196.2	
3	Industry	5.2	11.4	28.5	
4	Energy Industry Own Use	4.4	14.6	41.9	
5	Oil & gas industry	0.8	10.1		
6	Electricity Generation	8.4	21.3		
7	Industrial Process Emissions	0	55.1	-	
8	Agriculture	0	0.5	0	
9	Waste	NA			
10	Solvent	NA			
	Total CO	50.8	208.0	275.1	
	NO_x (kt) by sector				
1	Residential and other sectors	13.6	0.9	4.1	
2	Transport	50.8	23.7	55.8	
3	Industry	38.4	71.3	29.4	
4	Energy Industry Own Use	12.2	8.2	34.1	
5	Oil & gas industry	0.6	1.8		
6	Electricity Generation	21.1	57.8		
7	Industrial Process Emissions	0	1.7	-	
8	Agriculture	0.2	0.8	-	
9	Waste	0	0	0.1	
10	Solvent	NA			
	Total NO_x	136.9	166.2	123.4	
	NH_3 (kt) by sector				
1	Residential and other sectors	0	0	0	
2	Transport	0.5		0.6	
3	Industry	0.2	0.3	0.7	
4	Energy Industry Own Use	0.2	0.1		

6	Electricity Generation	0.4	0.2	0.1	
7	Industrial Process Emissions	5.2	3.2		
8	Agriculture	10.2	7.1	8.5	
9	Waste	1.1	0	0.7	
10	Solvent		NA		
Total NH_3		17.8	10.9	10.6	
	$PM_{2.5}$ (kt) by sector				
1	Residential and other sectors	1.3	0	1.1	
2	Transport	49.3	0.5	2.9	
3	Industry	1.5	2.3	0.9	
4	Energy Industry Own Use	0.2	0.1		
5	Oil & gas industry	2.6	0	9.5	
6	Electricity Generation	0.2	0.5		
7	Industrial Process Emissions	5.6	3.4	-	
8	Agriculture	0	0.1	0.1	
9	Waste	0	0	0.4	
10	Solvent		NA		
Total $PM_{2.5}$		60.8	6.9	15.0	
	PM_{10} (kt) by sector				
1	Residential and other sectors	1.3	0.5	1.2	
2	Transport	488.1	0.2	3.3	
3	Industry	1.5	2.3	1.3	
4	Energy Industry Own Use	0.3	0.2		
5	Oil & gas industry	0	0	9.6	
6	Electricity Generation	0.4	0.9		
7	Industrial Process Emissions	19.0	4.3	-	
8	Agriculture	0	0.3	0.3	
9	Waste	0	0	0.4	
10	Solvent		NA		
Total PM_{10}		510.6	9.0	16.0	
	BC (t) by sector				
1	Residential and other sectors	555.1	4.9	122.0	
2	Transport	415.4	220.4	1,410	
3	Industry	814.0	978.1	132.4	
4	Energy Industry Own Use	11.4	28.5		
5	Oil & gas industry	2,067	61.8	7,414	
6	Electricity Generation	22.4	121.7		
7	Industrial Process Emissions	37.4	39.5	-	
8	Agriculture	0	1.3	0	
9	Waste	0	0	30.8	
10	Solvent		NA		

Total BC		3,923	1,457	9,110	
	OC (t) by sector				
1	Residential and other sectors	393.0	10.6	441.4	
2	Transport	70.3	186.1	2,503	
3	Industry	309.0	1,179	102.9	
4	Energy Industry Own Use	32.2	25.1	1,616	
5	Oil & gas industry	0	1.4		
6	Electricity Generation	47.2	30.4		
8	Agriculture	0	19.0	0	
9	Waste	0	0	248.5	
10	Solvent	NA			
Total OC		851.7	1,451	4,911	

1 Gg = 1000 tonnes = thousand tonnes = kilo tonnes = 10^{-3} Million tonnes. NA: Not Applicable.

CO_2 estimate:

A comparison of the inventories developed by this study (using LEAP) and by EDGAR have both similarities and differences in their estimates of CO_2 emissions. The CO_2 emission figures are similar for the following sectors: energy industry own use, electricity generation, Industrial Process Emissions, and the oil and gas industry. However, estimates for the industry sector differ hugely (6.5 Mt and EDGAR at 23.4 Mt); it is possible that EDGAR over-estimated the emissions from this sector. There is also a large difference between the estimates for the transport sector (with this study at 12.1 Mt, and EDGAR: at 8.4 Mt). This might be explained by the fact that the detailed method of estimating emissions (the vehicle stock turnover model) was developed for this study for the first time for Oman; it is likely to be more reliable than other estimates because it takes emission control technologies by vehicle type into account.

CH_4 estimate:

In 2008, Oman was considered by the World Bank to have the 4th highest energy-related methane emissions in the world, after Qatar, Brunei and the United Arab Emirates. The energy sector was estimated to contribute 93% of CH_4 emissions in 2008, a figure compatible with this study's estimate of 86% in 2010.

Although this study, EDGAR and GAINS all found the oil and gas industry to be the main contributor to CH_4 emissions, there are sizeable differences in their estimates of CH_4 emissions both within the sector and for the total emissions. However, there are a number of similarities in the estimates for other sources, such as the agriculture, waste, energy industry own use, industry and transport sectors.

There are a number of possible reasons for the discrepancy between this study and both EDGAR or GAINS in the estimates of the absolute values for CH_4 emissions from the oil and gas sector.

GAINS did not undertake an inventory for Oman as a separate country, but estimated emissions by taking regional-scale Middle East estimates of total emissions and distributing them spatially down to a national scale. The assumed spatial distribution pattern for the region makes the figures potentially unreliable, and it is possible that the Omani emissions were over-estimated. In addition, the IPCC (2006) guidelines for oil and gas sector offer a huge range of default CH_4 emission factors (EFs). For example, for onshore oil production, the IPCC (2006) default range for fugitive CH_4 covers more than four orders of magnitude, ranging from 1.7 to 68,650 kg/kt. It is not clear which EFs were used by GAINS and EDGAR, but they may have chosen relatively high EFs towards the upper end of the IPCC (2006) range for developing countries. This study, however, took figures for fugitive emissions from the oil and gas industry from the recent 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories[9]. This reflects the advances in scientific knowledge gained since 2006, which makes it likely that the results presented in this study are more reliable than those based on the earlier default IPCC CH_4 EF ranges.

NMVOCs estimate:

Again, there are both similarities and differences between this study's estimates of NMVOCs and those in EDGAR and GAINS. There are only minor differences between this study's and EDGAR's estimates of NMVOCs from electricity generation and the energy industry's own use. Also, this study and GAINS present only small differences in their estimates of emissions from industry and from residential and other sectors. However, there are major differences in the estimates for the oil and gas industry, transport, and solvents, and these are responsible for the difference in the total emissions. However, the sectors are not categorised in identical ways. For example, what is called the energy sector in GAINS is categorised as three separate sectors in LEAP: the energy industry's own use, the oil and gas industry and electricity generation. So the 491 kt of NMVOCs emission from the energy sector in GAINS should be compared with the sum of 0.5, 0.3, and 134.9 kt emitted in the three LEAP categories in this study. As for CH_4, the default NMVOC emission factors for fugitive emissions from the oil and gas sector used in this study were taken from the 2019 IPCC refinement,

[9]https://www.ipcc-nggip.iges.or.jp/public/2019rf/index.html

while the higher estimates in the EDGAR and especially GAINS studies are probably due to their use of the higher EFs taken from the wide ranges offered in the original IPCC (2006) guidelines.

SO_2 estimate:

Although all three studies see the highest contribution of SO_2 emission as coming from the industry sector, the value obtained in this study is much higher than that in the other two studies. According to the analysis in this study, the industries which contribute most to SO_2 emissions are lime and cement. The relatively high value (126 kt) obtained in this study might be explained by the fact that the emission factors were based on an assumed high sulphur (S) content (3.5%) for heavy fuel oil, the main source of energy for the industry sector. The EFs used for the EDGAR and GAINS studies are not known, but may have been based on lower assumed sulphur (S) contents.

CO estimate:

There are considerable differences between the CO emissions estimate in all three studies, possibly because of differences in the components included in the transport sector. The estimate in this study is far lower than those in both EDGAR and GAINS, possibly because GAINS includes sea traffic, which this study does not. The estimates in EDGAR and GAINS are also different.

$PM_{2.5}$ estimate:

For the $PM_{2.5}$, the main contributing sector in this study is transport. The relatively high estimate in this study is due to the inclusion of dust emissions from unpaved roads, a source that is not included in either the EDGAR or the GAINS studies. If the emission from unpaved road dust is deducted, the total emission estimates are fairly similar. There are also similarities between this study and EDGAR in values for energy industry own use, electricity generation and industrial process emissions. All three studies also present relatively consistent estimates for residential and other sectors, which refers to residential, agriculture and fishing, and commercial and public services.

PM_{10} estimate:

The situation for PM_{10} emissions is similar to that for $PM_{2.5}$, with the big difference in the estimates from transport having already been explained. In other areas of PM_{10} emissions, the three studies offer relatively similar estimates, though the majority of GAINS's estimates for the electricity generation sector are higher than those in EDGAR and in this study.

BC estimate:

The results obtained by this study and by EDGAR for BC emissions are fairly consistent, especially the estimate for industry and industrial process emission. This study has a higher estimate than the two other studies for the “residential and other” sectors; this can be attributed to classification differences. In this study, “residential and other” refers to the Residential, Commercial and Public Services and the Agriculture, Forestry and Fishing sectors and their fuel consumption (mainly demand for gas diesel oil). These sectors and services are not reported separately elsewhere (e.g. in the International Energy Agency (IEA) databases) and are then classified as ‘Non Specified Other’, rather than with residential.

Another difference of note is that between GAINS’s total estimate of BC, and that made by EDGAR and this study. This stems from GAINS’s energy sector estimate, and the fact that the assumptions used by GAINS for emission factors in the oil and gas sector have a high range of uncertainty.

OC estimate:

The estimates for OC emissions in this study are more in agreement with EDGAR than with GAINS, with similar results like those presented for electricity generation, and energy industry own use., as well as for the total emission estimate.

NO_x estimate:

In terms of the total estimate of NO_x, both GAINS and EDGAR are consistent with the estimates in this study. Despite classification differences, where the energy sector in GAINS (34.1kt) is equivalent to electricity generation, energy industry own use and oil refining in this study (33.9kt), the estimated figures are almost the same.

NH_3 estimate:

Interestingly, EDGAR and GAINS present the same estimate for total NH_3, but comparing estimates for the sectors reveals many differences. The total estimate in this study is slightly higher than that in the other two studies, but there are a number of correlations between the three estimates. All three studies have similar results for NH_3 emission from agriculture; this study and EDGAR have similar results for industry and the energy industry’s own use, and GAINS and this study have similar results for transport.

2.6 Uncertainty in emission estimates:

All emission inventories involve uncertainties. These are mainly due to input parameters (activity data, and emission factors) and to the completeness and quality of information across sectors and pollutants. Other contributing factors include differing interpretations of source/sink categories, and an incomplete scientific understanding of the basic emission and removal processes.

A formal uncertainty analysis was not undertaken in this study; this was because the focus was on the policy implications, and also because such an analysis could not have been undertaken using LEAP, but would have required the use of a separate spreadsheet. Comparison with the other inventories was undertaken both to save time and also to see whether they were sufficiently valid for the purposes of this thesis. However, it would be useful to carry out a formal uncertainty analysis in further work. The following section will provide only a qualitative discussion of the three basic sources of uncertainty, namely: the input data, the assumptions used in selecting the emission factors, and missing sources of emissions.

2.6.1 Limitation of activity data:

The activity data is a source of uncertainty in this inventory mainly because some is missing some and/or of poor quality. While for some sectors there are well-documented and regularly updated national and international sources of activity data, other sectors have poor quality or missing activity data. This source of uncertainty in this emission inventory has been classified in the following ways:

•Unavailable/missing activity data: These uncertainties appear when the input data needed is unavailable, and in some cases the study uses extrapolated and/or averaged values for a particular set of data. In this current emission inventory, several emission sources have not been included; these are for shipping, fishing, the food industry, solvents, and building construction.

•Conflict of data: This occurs when there are two or more sets of data which are inconsistent. In this case the input data generally used is either the set more consistent with the rest of the data (such as the data for the transport sector in this inventory) or in some cases the data from the most trusted and reputable source.

•Misleading data: Some data was found to have been misused or misrepresented; it then results in an incorrect conclusion being reached. This can sometimes be addressed through the comparison of national and international data.

•Confidential data: Data classified as confidential is very high in uncertainty and must be judged on the quality of the estimates that can be developed using the available information. This data category in this study is usually related to the industry sector, such as data about food products and solvents.

• Gaps in a time series: Sometimes the activity data is available for a range of years, but not for 2010, the base year in this study. In this case, the missing year's data is usually estimated from the data set that is available.

• Lack of references. Sometimes there is no information on the calculation or estimation method used in data, so its representativeness at local or national level is unknown.

2.6.2 Limitation of Emission Factor:

Uncertainties involved in the selection of emission factors come from the fact that the default values provided in the EMEP/EEA Guidebook (EMEP/EEA, 2016) and the IPCC Guidelines (IPCC, 2006) were established for a certain group of activities that include a number of processes. The nature of a group of activities in one particular country may differ from the nature of the activities in a generalized context, so the derivation/establishment of the default emission factors may be uncertain. In such cases, the default emission factors may not accurately represent and characterize the actual conditions of source/sink activities, and using these factors to calculate the emissions would result in high uncertainties. High levels of uncertainty in the emission factors may also be due to a lack of relevant measurements, which can lead to subsequent generalisations, uncertainties in measurements, or an insufficient understanding of the emission generating process (also leading to wrong model assumptions). Emissions may be very dependent on climate (temperature, humidity, wet and dry days) and specific practices, and if these are not taken into account, the default emission factor should be considered uncertain. This issue is exacerbated because globally there is very little information about local emission factors, but considering local data and knowledge about emission sources and their emission factors can significantly reduce uncertainties (Zhang et al., 2009). In the case of Oman, national emission factors are not available and this inventory uses average emission factors instead, with the majority of emission factor being taken from IPCC (2006) for GHGs and EMEP/EEA (2016) for other pollutants. For fugitive emissions from the oil and gas industry, the study used the 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2019).

2.6.3 Missing sources of emissions:

Uncertainty also results from incompleteness of information; this is due to missing emission sources and is caused by incomplete scientific understanding of the emission processes. For example, emissions from ships were not mentioned in many inventory studies, because of the assumption that such emissions were small. However, in more recent years, it has become clear that sulphur dioxide emissions from ships contribute substantially to general sulphur dioxide emissions (Abdul-Wahab *et al.*, 2008). The shipping sector was not covered in this study because of a shortage of data about the amount of energy it consumes.

Another example relates to the use of heavy fuel oil (HFO) for supplying energy in the production processes of cement and lime. This study noted that SO_2 emissions from cement and lime plants are very high; depending on the process used, and the source and concentration of sulphur, SO_2 absorption in preheater/precalciner kiln systems has been estimated to range from around 70 to more than 95%. There is thus a high uncertainty in results for the total emission of sulphur from cement and lime industry, and it is probably overestimated, but there is no firm information regarding the consequences of SO_2 emission and its absorption by cement.

Another uncertainty concerns municipal solid waste and waste-water treatment plants; these might not be as high a source of CH_4 emission in Oman as in other parts of the world, since the high temperatures in the region might speed up the evaporation of water and give no chance for anaerobic decomposition of organic material within solid waste disposal sites (SWDS). An example of the dryness of a landfill in Oman is given in a photo in Appendix F2.

2.7 Conclusion:

This chapter, has outlined the compilation of an emission inventory for Oman for the year 2010. It was compiled from different sources using the LEAP-IBC tool to determine the overall emission of CO_2, CH_4, NMVOCs, CO, $PM_{2.5}$, SO_2, NO_x, BC, OC, and NH_3 as well as their major sources. This emission inventory will inform the process of deciding what action should be taken regarding the controls necessary to meet ambient air quality standards and climate commitments; the results obtained will also help in more efficiently planning strategies to reduce pollution.

The findings showed that the total amount of CO_2 emission in 2010 was 50 Mt, and that this was mainly due to the burning of natural gas for electricity generation and the use of diesel in the transport sector and in electricity generation. Other sectors which contributed to CO_2 emissions are the industry sector and the energy industry's own use.

The level of Oman's CO_2 emissions is expected to change in the near future as a result of the start-up operations of the Duqm Refinery and Petrochemical Project in the Duqm Special Economic Zone, planned for 2019. In the first phase crude oil will be distilled to produce naphtha, kerosene, LPG, diesel oil and ethylene, with production of propylene and other petrochemical products being added in the second phase. In addition, according to Oman's 2040 Vision, the Duqm clean coal independent power project (IPP) will start to operate in 2024. This will be a new source of energy for Oman, as no coal is being combusted at present. However, if this goes ahead, it will work against efforts to reduce climate change. These future changes will be analysed within the baseline scenario in Chapter 4.

The emissions estimated for Oman in 2010, apart from $CO_{2,}$ were of CH_4 at 564 kt followed by SO_2 (160), NMVOCs (142), NO_x (137), $PM_{2.5}$ (61), CO (51), NH_3 (18), BC (4), and OC (0.9) kt.

Fugitive emissions from the oil and gas sector contributed most to CH_4 and NMVOCs emissions while the manufacturing industry sector was the main contributor to SO_2 emissions. The transport sector was the main contributor to NO_x, CO and $PM_{2.5}$ emissions, with the agriculture sector dominating emissions of NH_3.

The national emission inventory generated from this study using LEAP and other inventories was compared with inventories from EDGAR and GAINS/ECLIPS, revealing both similarities and differences between them. The key differences between this inventory and others are listed below, along with the probable cause of each discrepancy.

- Oil and gas sector: emission factors (using the most updated version of IPCC, 2019),
- Transport sector: the detailed method (stock turnover model) used in the road transport sector and the inclusion of dust emissions from unpaved roads
- Manufacturing industry sector: the high sulphur (S) content for heavy fuel oil which is the main fuel used in industry sector.

The resultant emission inventory presented in this chapter provides an overview of the air pollutant emissions for Oman in 2010. Based on the presented here, Chapter 4 will focus on the sectors which are major sources of emissions and will highlight in detail their contribution to emission, along with predictions for future emission. These predictions will be analysed in order to develop the most efficient regulatory options needed to achieve reductions in air pollution and GHG emissions; these options will be discussed in Chapter 3.

The rapid economic development, improved living standards, and increased urban population density in Oman have led to increased air pollution. As revealed from the emission inventory conducted in this study, the major sources of air pollution are from power generation, oil and gas industry, manufacturing industry and transportation. This is particularly evident in coastal areas where the combination of high population, industrial concentration and unfavourable natural conditions for pollution dispersal aggravate air pollution problems[10]. Intense industrial activity in seaport areas in Oman make them of the most polluted locations. Other prominent areas with air pollution concerns include the capital Muscat where dense vehicular traffic contributes to high ambient air pollution.

The Sultanate of Oman has the advantage over leading the Gulf region to bring about changes in regulations and laws related to air pollution and climate change for several reasons, the most important of which are:

1. The Sultanate of Oman geographical location and its direct impact on climate changes such as frequent cyclones, heat waves, extreme weather, and the inconsistency of rainfall rates.
2. The other reason is the Sultanate 2040 vision of diversification of economy by focusing on manufacturing industries, petrochemicals, logistics, tourism, and agriculture and fisheries. Oman will be the most affected country within the region by climate change especially the seaports and will not be able to implement its plans in the event that climate changes continue in this way. The Sultanate has not presented any initiatives or solutions in the regional level by setting policies that protect the region from the aggravation of the issue of air pollution and climate change.
3. The last reason is that the Sultanate of Oman is exposed to transboundary pollutants ($PM_{2.5}$ and its components) as demonstrated in chapter five (Figure 5-24) through pollution transportation from neighbouring countries that the Sultanate cannot avoid unless it has a voice at the regional level to make rigid policies on the air quality and within the Gulf region at least.

The availability of data on national activity and emission factors, especially for the oil and gas sector, is a key requirement for future updates and is essential if we are to minimise will be the uncertainty in the estimating of emissions. It is therefore strongly recommended that a systematic database for all sectors be developed urgently, and also be maintained. Such a database should include

[10] Climate and health country profile, 2015 OMAN - WHO (http://www.who.int/globalchange/en/

disaggregated activity levels and more appropriate local emission factors, as well as indicators of technological performance and other relevant information.

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3 Policies addressing air pollution and climate change in Oman and the GCC countries:

3.1 Introduction and Objectives:

The aim of Chapter 3 is to understand the current legislation and institutional arrangements in Oman in order to assess the strengths and weaknesses of the current environmental policy in the country, the impact of the implementation of this policy on emissions, as well as to suggest any policy changes that could help to achieve lower emissions and improved outcomes. This includes an assessment of the adequacy of the current institutions, regulations, legislation and specific laws, and to relate this to international best practice. The research question raised in this chapter is: "Are the current policies which regulate activities related to air pollution and GHG emissions effective for the current situation and future development?"

To help to answer the research question, a survey of people's attitudes, understanding and opinions was undertaken; this survey was conducted through interviews. The method used in these interviews is described in detail in section 3.5.2 of this chapter, outlining the approach, why people were interviewed, why those particular people were chosen, and what questions they were asked.

This chapter analyses and describes policy-making processes in Oman and especially the development of the country's environmental policies. The analysis is based on an assessment of the literature, informed by the interviews conducted with different people involved in the policy-making process, as well as by a consideration of people who are not currently involved, but should be. It covers an assessment of how long it takes for a policy to be developed and implemented, and how often it is revised. It also asks whether these policies are evaluated and if so, how and by whom, and assesses whether there has been any improvement in this process compared to ten years ago.

The current regulations, legislation and guidelines that govern areas related to the environmental impacts relevant to climate, emissions, and air pollution in the GCC in general, and in Oman in particular, are discussed and analysed. This analysis also considers their positive and negative impact on people's quality of life (health, air quality) in order to assess whether the policies have any gaps and drawbacks, and also asks whether these have been investigated. The study reveals possible reasons for any negative impacts and develops ideas for resolving the issues involved. Those suggestions will be further explored in the development of mitigation scenarios in Chapter 4, which will cover activities related to Oman's largest emission sources as identified in Chapter 2, namely, energy, industry, and transport.

This chapter also investigates how policies are implemented and examines barriers to such implementation, along with the different points of view involved: this enables a better assessment of the effectiveness of the policies. The main questions being investigated here are these:

- Are the current policies adequate to keep air quality within acceptable safety limits?
- What other legislation could be implemented to improve the situation?
- Are these policies implemented effectively, and if not, why not?
- Is the enforcement of the policies effective?

The study evaluates current policy through a literature review that complements the interviews. The literature review has suggested a number of useful investigative tools. These include comparing air quality 10 years ago and now, looking at whether there have been any media stories covering climate change or air pollution, and at how many cases related to environmental issues have been raised in the courts. The chapter also gives an overview of the "Oman 2040" initiative, produced by stakeholders representing all segments of Omani society and aiming to implement the vision and Royal Decrees of His Majesty Sultan Qaboos bin Said; this study focuses on whether the vision has included and discussed the environment as an issue of strategic importance. The vision is based around three general themes: "People and Society", "Economy and Development", and "Governance and Institutional Performance", as well as a number of key issues assigned to committees in the National Priorities Alignment of Strategies. This study also seeks to ascertain if there are any environmentally relevant laws in the pipeline, and to outline the vision of "Oman 2040" for the most emitting sectors in the country, namely energy, industry and transport, given that the effects of the vision will affect the country for at least twenty to thirty years into the future.

This chapter also introduces points made in the judiciary and media interviews about the need to raise awareness. It also summarises feedback from other interviews about possible challenges and obstacles, the overall picture and the planned steps for the future. The end of the chapter suggests different policies; these will later be used in producing the scenarios (and modelling them using LEAP) in the mitigation scenario chapter, Chapter 4.

3.2 The history of the development of a structure of environmental institutions in Oman:

The Sultanate of Oman is a country that takes a special interest in caring for the environment. This care emanates from Sultan Qaboos's interest in environmental preservation. The Sultan's speech on the occasion of the 15th National Day in November 1985 revealed his deep concern for the environment and the need to find ways to preserve it. He said: "As a result of our great concern for the protection of the natural environment, and our achievements in this respect, Oman has gained a respectable position among nations concerned with environmental protection; yet we still have to exert more effort and consider the special conditions relevant to this issue, when we come to plan and implement development projects. We must proceed to develop contacts with regional and international organizations concerned. It is a duty which must be undertaken by each citizen, to guarantee the protection of our natural resources and public health against any harmful effects, and protect the beautiful and distinguished nature which God Almighty granted to our beloved Oman."

In 1982, the Sultanate of Oman became the first country in the Gulf region to pass a comprehensive law on the environment. Environmental law in Oman is now a mix of primary legislation (which takes the form of Royal Decrees from the Sultan), secondary legislation (ministerial decisions), and the signing of international treaties, conventions and protocols. Most areas of environmental law that one would expect to see covered in highly-regulated countries, such as those in Western Europe, are covered in Oman, albeit briefly, but the law has not yet benefited from the high level of development and interpretation that has been achieved in countries where environmental regulation has a longer history.

Oman, however, is one of the few jurisdictions in the Gulf region which has an integrated national environmental policy with high-level, cross-cutting bodies under the direct control of the government, though this is not reflected in the extent of the implementation of this policy within the country. In 1984, Oman became the first country in the region to establish a specific Ministry for the Environment. On June 1, 1989, on a visit to UNESCO's headquarters, Sultan Qaboos announced The Sultan Qaboos Prize for Environmental Preservation. It is awarded every two years and is open to individuals, institutes and organizations around the world that work to preserve the environment. It was first awarded to an environmental institute in the state of Filakroze in Mexico in 1991. It is the first Arabic prize to be presented by UNESCO in this field at an international level (UNESCO, 2017).

3.2.1 Environmental Institutional structure

Many efforts have been made to strengthen not only the Sultanate's attention regarding environmental issues but also its keenness to take necessary steps to contribute to the international effort to confront and combat climate change and mitigate its effects. The Sultanate signed the United Nations Framework Convention on Climate Change (UNFCCC) at the first Earth Summit in Brazil Conference in 1992, and then ratified it by Royal Decree No. 119/94, December 7, 1994. Oman also ratified the Kyoto Protocol to the Framework Convention on Climate Change in Royal Decree No. 107/2004, October 10, 2004, and lately ratified the Paris Agreement of May 22, 2019 which had been signed on 22 April 2016. Before this, responsibility for environmental matters had gone through several organizational and structural stages. The first step was the establishment of the Office of the Advisor for Conservation of the Environment in 1974; its most important function was the establishment and development of the project to reintroduce the Arabian Oryx into their natural habitat.

Since then, there have been many other actions and institutional developments in Oman to protect the environment and conserve its natural resources, as well as to address all forms and sources of pollution. Some of the more prominent developments regarding air pollution and climate policy are briefly described below (Table 3-1).

There have also been several non-governmental activities which have supported the government's efforts to protect the environment, including the establishment of civil society organizations such as the Environment Society of Oman (ESO) and the Oman Green Awards. The ESO is a non-governmental organization (NGO) which aims to help conserve Oman's natural heritage and raise awareness about environmental issues. It was founded in 2004 by Omanis from different regions and a variety of professional backgrounds. However, this environmental NGO focuses only on marine, terrestrial and protected areas, protecting and conserving Oman's natural heritage. It has not paid much attention to air quality or climate change, except for awareness-raising activities such as participating in the 'Earth Hour' by turning off lights for one hour at 8:30pm on the last Saturday in March in order to raise awareness of Climate Change.

Table 3-1: Chronological development of actions and institutions related to environment in Oman

Chronology:	Actions and institutional developments
1974	Establishment of the "Office of the Advisor of Environmental Protection at the Diwan* of Royal Court".
1979	Establishment of the "Board of Environmental Protection and Pollution Control" under Royal Decree No. 68/79.
1985	Modification of the Ministry of Environment to become "The Ministry of Environment and Water Resources" under Royal Decree No. 104/85.
1985	Modification of the Council of Environmental Protection and Pollution Control to the "Council for the Protection of the Environment and Water Resources" under Royal Decree No. 105/85.
1986	Development of the terms of reference of the Ministry of Environment and Water Resources and Environmental Protection and Water Resources Council under Royal Decrees No. 91 and 92/86.
1989	Establishment of the Ministry of Water Resources and determination of its terms of reference under Royal Decree No. 100/89.
1990	Modification of the organizational structure and terms of reference of the Ministry of Environment after the establishment of a "Public Authority of Water Resources" under Royal Decree No. 11/90.
1991	Integration of the Ministry of Environment and the Environmental Protection Council and the Ministry of Regional Municipalities to become "The Ministry of Regional Municipalities and Environment" under Royal Decree No. 117/91.
1999	Development of the terms of references of the Ministry of Regional Municipalities and Environment under Royal Decree No. 18/99).
2001	Integration of the Ministry of Regional Municipalities, Environment and Ministry of Water Resources into one ministry called "The Ministry of Regional Municipalities, Environment and Water Resources" under Royal Decree No. 47/2001.
2007	Establishment of the Ministry of Environment & Climate Affairs by Royal Decree No. 91/2007.
2008	Issuing of Royal Decree No. 18/2008 specifying the mandate of the Ministry of Environment & Climate Affairs (MECA) and approving its organizational chart, including setting up a new Directorate General of Climate Affairs.

* This is one of the most important government entities in the Cabinet of Oman

3.2.2 Environmental Policy (GHG, air pollution, and climate change)

The legal system in Oman usually operates in three tiers. The fundamental regulations are published as “Royal Decrees”; principle legislations are published as Ministerial Decisions/Directives/Decrees, and all detailed requirements (technical and administrative) which are subject to regular change (due to amendments to the international instruments) are issued as guidelines, If they are only recommendations, or instructions if they are actual rules by the related Directorate General. At the national level, Oman’s environmental regime is primarily regulated by the ‘Law on the Conservation of the Environment and Combating of Pollution' (Royal Decree No. 114/2001). There are a number of other laws and ministerial decisions which cover air quality (Table 3-2), and other more general regulations related to air quality which are listed in Table 3-3. Other environmental protection laws and regulations are listed in Appendix A3.

Table 3-2: Laws which regulate air quality in the Sultanate of Oman

No.	Title	Description	Responsible authority
1	SD: (114/2001)	Law on the Conservation of the Environment and Prevention of Pollution	MECA
2	SD: (8/2011)	Oil and Gas Law	MOG
3	SD: (28/1993)	Traffic Law	ROP
4	SD: (35/1981)	Maritime Law	MOTC
5	MD: (41/2017)	Ambient Air Quality	MECA
6	MD: (118/2004)	Air pollution from stationary sources (Stack Emissions)	MECA
7	MD: (107/2018)	Enforcement of Standard (GSO 2530/2016) on energy efficiency requirements.	MOCI

Table 3-3: Ministerial decisions that covers aspects of air quality, pollution and environment

No.	Ministerial decision No.	Title of the Ministerial decision
1	MD: (18/1993)	Management of Hazardous Waste
2	MD 200/2000	Crushers, Quarries & Transport of Sand
3	MD 187/2001	Issuance of Environmental approvals and final Environmental Permit
4	MD 39/2004	Marine Environmental Management Bylaws
5	MD 243/2005	Regulation for the control & management of ozone depleting substances
6	MD 18/1993	Management of hazardous waste
7	MD 421/1998	Regulation for septic tanks, soakaway pits and holding tanks
8	MD 145/1993	Regulation for waste water re-uses and discharge

Regionally, the Gulf Cooperation Council (GCC) aims to create inter-connectivity through unified regulations in fields such as the environment, industry, and economy. Several reference laws have been developed under the umbrella of the GCC that recognise that economic and industrial growth can increase environmental pollution, and aim at protecting the environment and health from the adverse effects of pollution. These laws are additional to "The General Regulations of Environment in the GCC States" which provides a framework for establishing wide-reaching rules and regulations on environmentally-related topics. Table 3-4 lists the GCC laws which are the most relevant to and significant for air quality. All the laws given in the table are taken as general principles which establish minimum legislation for the member states in how they protect the environment from threats such as hazardous chemicals, waste, ozone depletion, and different types of pollution. These laws provide a regional umbrella for national policies and are in line with GCC laws.

Table 3-4: Laws which regulate environmental quality within the GCC countries

NO.	TITLE	DESCRIPTION	APROVAL
1	The General Environment Protection Law	A comprehensive framework incorporating the basic rules for environment conservation and protection	Muscat, 1995
2	The Common Law for the Environmental Assessment of Projects	The law aims at observing the environmental impact of various projects to prevent any adverse effects on the environment, natural resources and development.	Muscat, 1995
3	The environmental criteria and standards for the quality of air and water and the controls thereof	The objective of these criteria and standards is to identify pollution levels of the internal and external environment in the GCC States	Manama, 2004
4	The Common Reference Law for Controlling Ozone-Depleting Materials	Objective of the law is to eliminate the use of ozone-depleting materials and substitute them with safe alternatives according to the Montreal Protocol and amendments thereof	Abu Dhabi, 2005
5	The Common Law for Waste Management	The law aims at protecting human health and the environment from the hazards of solid and toxic waste through sound management	Kuwait, 1997
6	The Common Law for the Management of Hazardous Chemicals	The law aims at controlling the practices of the management of hazardous chemicals in the GCC States.	Muscat, 2001
7	Coordination of procedures among Member States for trans-border handling of hazardous waste for the purpose of processing, recycling or disposal	These procedures aim at enabling member states to utilize the existing facilities of any other member state for the processing or recycling of hazardous waste.	Kuwait 1997

Source[11]

[11] https://www.gcc-sg.org/enus/CooperationAndAchievements/Achievements/CooperationinthefieldofHumanandEnvironmentAffairs/Pages/EnvironmentalCooperation.aspx

To support international efforts to preserve the environment, the Sultanate has approved a number of conventions and protocols in different fields; these are set out in Table 3-5. In addition, a Ministerial decision was given (MD 30/2010) for the approval of Clean Development Mechanism (CDM) Projects under the Kyoto Protocol and for the establishment of a Designated National Authority (CDM-DNA) to promote CDM projects in the Sultanate. Oman also signed the Paris Agreement on 22/04/2016 and ratified it on 22/05/2019.

Table 3-5: Convention and protocols the Sultanate of Oman is involved in

No.	Title	Category
1	United Nations Framework Convention on Climate Change	Climate change and Stratospheric Ozone
2	Kyoto Protocol to the United Nations Framework Convention on Climate Change	
3	The Vienna Convention for the Protection of the Ozone Layer, The Montreal Protocol on Substances that Deplete the Ozone Layer	
4	Paris Agreement on Climate Change (UNFCCC)	
5	Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal	Hazardous and chemical waste
6	Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade	
7	Stockholm Convention on Persistent Organic Pollutants (POP)	
8	IMO conventions (IMO)	Marine protection
9	1973 International Convention for the Prevention of Pollution from Ships as amended by the protocol of 1978 (MARPOL 73/1978)	

The United Nations (UN) Environment Programme has credited Oman with having one of the best records on environmental conservation, pollution control and maintenance of ecological balance. Oman is even stated as having one of the world's most rigorously "green" governments. However, Oman still currently faces many environmental problems, including air quality and climate change. In addition, the regulatory framework has not yet specifically addressed concepts such as sustainability and renewable energy, in spite of the considerable global attention they have recently received.

3.3 The current Institutional Structure and Environmental Policy in Oman:

Establishing environmental institutions will help to provide effective responses to any changes in the status of the environment, as they can improve current policies and sign design-effective management strategies to combat environmental degradation.

Due to the growing interest in the environment in Oman, the Sultanate established an environment-oriented ministry in 2007 by Royal Decree No. 90/2007; it is presently named the Ministry of

Environment and Climate Affairs (MECA). This was followed on February 17, 2008, by the issuance of Royal Decree No. 18/2008; this determined the competences of MECA and the adoption of its organizational structure (Figure 3-1). It also included the establishment of the Directorate-General for Climate Affairs, which is responsible for assessing Oman's vulnerability to the risks posed by climate change and for focusing on strategies of adaptation and mitigation of climate change at both national and international levels. The inclusion of the word "climate" within the title of the ministry also suggests a renewed focus upon climate and "green energy" projects.

3.3.1 Ministry of Environment and Climate Affairs (MECA) structure:

The Ministry of Environment and Climate Affairs (MECA) is the government authority responsible for formulating plans and programs for the protection of the environment and the conservation of its natural resources. It does this through the application of policies that will ensure the protection of the environment, combat pollution and maintain the various ecosystems within the framework of the objectives of sustainable development; its remit also includes the protection of wildlife, the conservation of nature, and the preservation and sustainable use of resources. It is also, in coordination with the competent authorities, responsible for monitoring and assessing climate change and acting to avoid the many potential impacts of climate change on Oman's natural, economic and social systems. It is MECA's responsibility to manage the risks of climate change by taking the necessary adaptation actions, and by preparing national strategies that will mitigate greenhouse gas emissions and will confront the potential risks they pose (MECA 2018).

3.3.2 Laws and strategy regarding Oman's environment:

This section will identify the laws and strategies currently used to address Oman's environment, and will analyse the influence of specific legislation on the different emissions of interest in this study. It will highlight only the regulations that cover the major pollutants, emissions, and sources of emissions identified in Chapter Two, but the complete set of regulations are given in Appendix B3.

3.3.2.1 The National Conservation Strategy for Oman (NCS):

In 1986, the Sultanate announced a National Strategy for Protecting the Omani Environment. It aims generally at protecting the environment, evaluating and controlling pollution and finding and implementing solutions. The Council of Ministers adopted the National Strategy for Environmental Protection and Conservation in 1995. The most important elements of this strategy are summarized below:

- Renewable energy: Established the exploitation of local renewable resources as a national priority.
- Integrated resource management: Confirmed the importance of sectoral integration and collaborative approaches in national resource management.
- Monitoring and evaluation: Developed a system to monitor achievements regarding nature conservation and environmental protection.
- Community-focused: Confirmed the role and place of the human as the goal for development.
- Sustainability: Proposed policy frameworks for linking development activities and environmental protection initiatives.
- Environmental accounting: Recommended the introduction of natural resource accounting and environmental costs in national income ledgers.

However, no document outlining this strategy could be found, nor was there any other document describing a decision to withdraw it, and no information was available regarding its validity. It seems that this strategy has been replaced by the "National Adaptation and Mitigation Strategy" which is on its way to the Minister's office for approval (Malik Al-Wardy, Personal communication 2019). How far this National Strategy for Environmental Protection and Conservation is progressing, any revisions and evaluations made since 1995, and its most important achievements will be covered in the discussion section of this chapter.

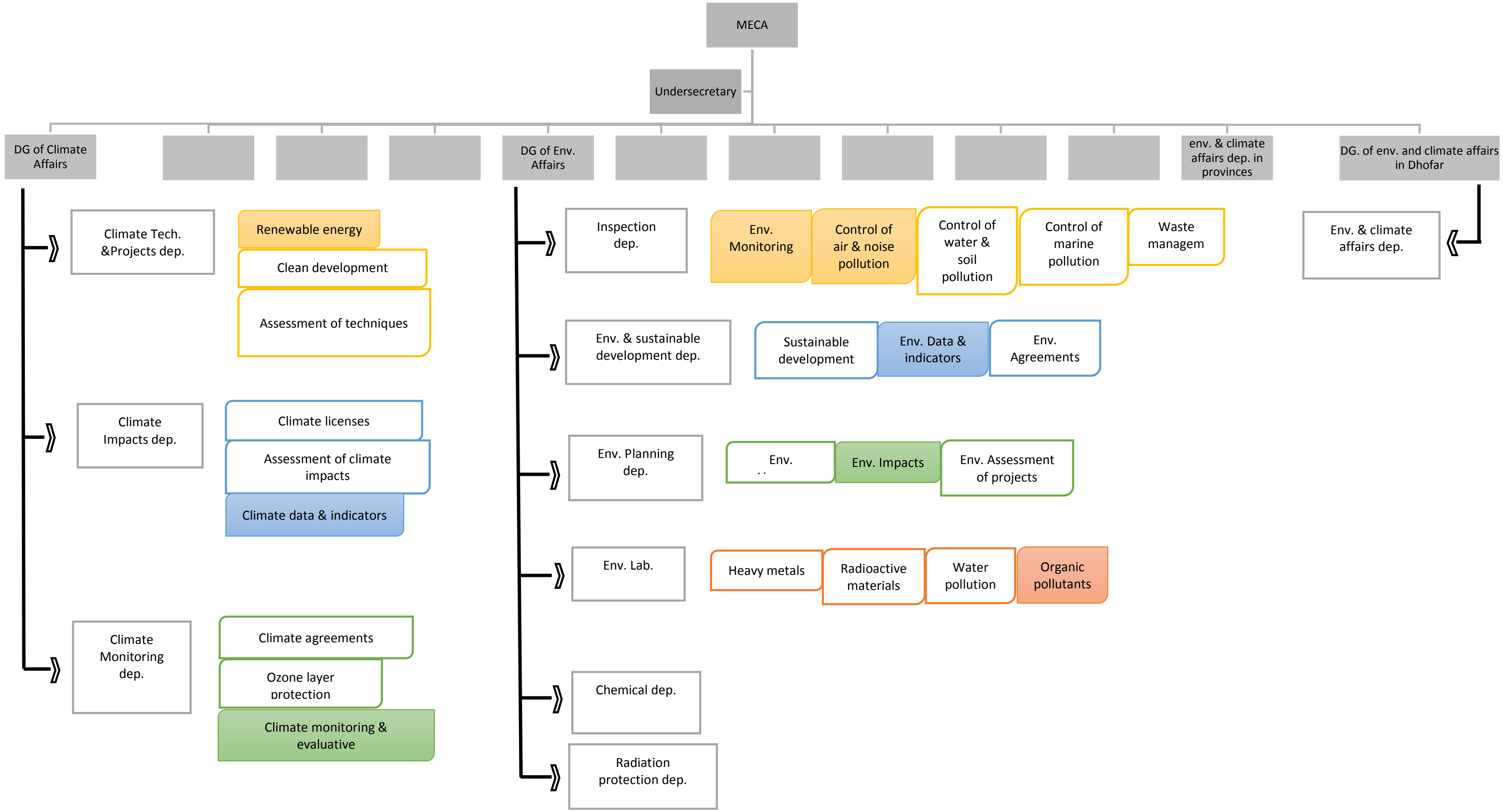

Figure 3-1: MECA organization structure related to air pollution and climate change (MECA 2018). https://www.meca.gov.om/en/module.php?module=hierarchical&

3.3.2.2 Oman's primary environmental law: Royal Decree 114/2001:

The principal environmental legislation in Oman is Royal Decree Number 114/2001, the Law on Conservation of the Environment and Prevention of Pollution (RD 114/2001), which replaced the previous basic environmental law, Royal Decree 10/1982. The law is composed of three chapters: (1) Definitions and general provisions, (2) Rules and principles to ensure the safety of the Omani environment; and (3) Penalties. These are divided into a total of 43 articles.

The Law on the Conservation of the Environment and Combating of Pollution defines terms such as "the environment", "environmental protection", "pollution/pollutants", "hazardous material", "dumping", etc. This law makes it mandatory for an owner of a place of work to obtain a license before setting up an establishment, and to follow the procedure specified by the Ministry of Environment and Climate Affairs (MECA) to prevent pollution by minimizing waste at the source of pollution. It also stipulates that such owners should refrain from carrying out or permitting any discharge and release of environmental pollutants in excess of the standards specified by the ministry, but excludes from its purview any emergency measures to save lives or to safeguard the place of work. The owner must maintain a register on the quantity, nature, and method of effluent discharge at the establishment. The legislative obligations under RD 114/2001 require a high level of commitment from the owner, such as use of "all necessary measures" to minimise pollution and adoption of "state of the art" techniques approved by MECA to minimise the generation of waste (Article 10 of RD 114/2001).

This law prohibits the discharge of hazardous material, sewage and waste into wadis (dry river-beds), aquifers, rain water disposal networks, falaj (water management systems) and their channels, and the use or disposal of treated sewage water without permission (Article 7 of RD 114/2001). Ships and vessels are barred from discharging oil and other environmental pollutants into the Exclusive Economic Zone of Oman. Failure to comply with these duties, or other breach of this legislation, can result in heavy penalties. Potential sanctions include suspension of activities, substantial and incrementally increasing fines for individuals and corporates, including fines linked to percentages of invested capital, and potential criminal sanctions for individual breaches by managers and directors acting in the course of their duties. The "polluter pays" principle is observed in relation to the remediation obligation set out in Article 41 of RD 114/2001, which requires that whoever causes environmental damage shall remove it at theirown expense and reinstate the pre-existing environmental status; they shall also pay any necessary compensation to those who have suffered consequent loss. If the polluter fails to remove the causes of the pollution within a specified period, MECA has the right to remedy the damage at the polluter’s expense. Penalties for the violation of this law range from OMR 200 to OMR 1 million, with imprisonment in certain instances.

According to Article (29) of Conservation of the Environment and Prevention of Pollution Law, "Oman believes that social, economic and environmental issues cannot be separated, and this is what sustainable development means." Since the beginning of the Omani renaissance with the accession of His Majesty Sultan Qaboos bin Said in 1970, the Sultanate has been committed to ensuring economic and social prosperity in the development process without prejudicing the rights of future generations. Oman's government is seeking to sustainably manage natural resources and to raise individuals’ level of awareness about preserving the environment, while implementing development projects that exploit environmental resources without damaging them.

To this end, the Sultanate imposes severe penalties on those who threaten environmental security. According to Article 42 of the Omani Environmental Protection Code, in some cases penalties can be as high as lifetime imprisonment or a fine of no less than 100,000 RO and no more than RO 1,000,000, plus requiring the polluter to remove the effects of the pollution they have caused. Such severe sanctions are intended to deter entrepreneurs and factory owners from violating the laws.

The law as described above does not specifically refer to air pollution, but covers all type of pollution; the term “air pollution” is not mentioned at all, except in the definitions section where the word “air” is explained. The focus of the law is to give a broad policy for the environment in total and in general. This is shown, for example, in the article in the law which reads: “Whoever causes environmental damage shall remove it at their own expense and reinstate the pre-existing environmental status, in addition to the payment of any necessary compensation to those who have suffered consequent loss”. Although it is general, it clearly includes air pollution.

3.3.2.3 Ministerial decision 118/2004 Air pollution from stationary sources:

Ministerial Decision No. 118/2004 on the Control of Air Pollution from Stationary Sources stipulates that owners must employ scientific methods specified by the ministry for the prevention of the emission of pollutants, and for their treatment and disposal. This law prohibits the emission of smoke over a specified density, and the burning of organsic or agricultural waste in the open. Approval must be obtained before installing a chimney, for example; if this is given, the chimney must conform to the height specifications stipulated; these will depend on its intended use.

Oman realizes the need to maintain clean air and to keep the pace of economic and environmental development goals in line with human development goals, which aim to provide a liveable and healthy environment. Ministerial Decision No. 118/2004 on the law of air pollution management is a confirmation of the Sultanate's interest in preserving air purity. In the same year, 2004, the sultanate began to establish a national network for monitoring air pollution. The network's stations are distributed in industrial areas to monitor air pollution levels and ensure that they do not exceed the permitted levels. A number of mobile stations were also established. The owner shall comply with the standards specified in Table 3-6, monitor the particulate and gas emissions from time to time, and report the results of this emission monitoring to the MECA. The standards shown here are numerical standards for sources of emissions which are related to this study; other sources have not been included but are attached to MD 118/2004 as an annexure (see Appendix B3).

Table 3-6: Limit of emission from different sources based on Ministerial decision 118/2004.

Pollutants from different sources	Limit	Unit
General		
Grit and dust (<76µm diameter)	0.050	g/m^3
Aggregate work		
Particulates	0.050	g/m^3
Asphalt works		
Bitumen fumes	0.030	g/m^3
Total particulates	0.050	
Cement works		
Particulates	0.100	g/m^3
Sulphur dioxide	0.035	
Lime works		
Particulates from kiln emission	0.100	g/m^3
Particulates from slacking	0.100	
Carbon monoxide	0.050	
Particulates from ancillary processes	0.050	
Petroleum works		
From catalytic crackers	0.100	g/m^3
Minimum efficiency of sulphur recovery units	99.9	%
Organic compounds from fume recovery units	0.035	g/m^3
Hydrogen sulphide	5	ppm v/v
Flaring in refinery and petroleum fields		
Carbon monoxide	0.050	g/m^3
Sulphur dioxide	0.035	
Nitrogen dioxide	0.150	
Carbon dioxide	5	

Unburned hydrocarbons	0.010	
Particulates	0.100	
Power plants		
Plant generated by natural gas:		
Nitrogen dioxide	0.150	g/m^3
Particulates	0.050	
Unburned hydrocarbons	0.010	
Carbon dioxide	5	
Plant generated by diesel oil (<0.5% sulphur):		
Sulphur dioxide	0.035	g/m^3
Carbon monoxide	0.050	
Nitrogen dioxide	0.150	
Particulates	0.100	
Unburned hydrocarbons	0.010	
Urea/Ammonia fertilizer factories		
Ammonia	0.020	g/m^3
Urea particulates	0.050	
Nitrogen dioxide	0.150	
Carbon dioxide	5	
Unburned hydrocarbons	0.010	
Firing sources (factory boilers)		
Generated by diesel oil:		
Carbon monoxide	0.050	g/m^3
Sulphur dioxide	0.035	
Nitrogen dioxide	0.150	
Particulates	0.1	
Unburned hydrocarbons	0.010	
Generated by natural gas:		
Nitrogen dioxide	0.150	g/m^3
Particulates	0.050	
Unburned hydrocarbons	0.010	
Carbon dioxide	5	

All the emissions analysed in this study (CO_2, CH_4, NMVOCs, SO_2, NO_x, CO, $PM_{2.5}$, NH_3, BC, and OC) are covered by Ministerial decision 118/2004 as shown in Table 3-6, which means that MECA should be controlling the emissions of these gases and pollutants. Article 11 of this regulation states: "Any person who violates the provisions of this regulation shall be punished with a fine not exceeding RO

3,000 and MECA may close the facility in case of imminent damage to public health or the environment".

3.3.2.4 Ministerial decision 41/2017 Ambient Air Quality:

This resolution aims at setting air quality regulations for the owners of a source of pollution or a work area in Oman, or any person responsible for such a source or workplace. The regulation contains nine articles. It prohibits the causing or leaving of air pollutants exceeding the limits specified in Article 2 of the regulation, and shown in Table 3-7. It is mandatory to establish a private control/monitoring station according to set specifications (Article 3). The owner must also be in compliance with international standards and periodically report about the controls (Article 4). When the controls detect that average values have exceeded the limit set, the private control station must be connected to the monitoring station established at the Ministry of Environment and Climate Affairs (article 6). MECA has a number of mobile and stationary stations for the detection of air quality, and there are also other stations which are set up by the private sector and which submit quarterly reports to MECA.

Table 3-7: Maximum concentrations in the ambient air based on the MD 41/2017.

Pollutant	Maximum concentration	Average period of measurement	Unit
SO_2	350	1-h	µg/m^3
	150	24-h	
NO_2	250	1-h	
	130	24-h	
PM_{10}	150	24-h	
$PM_{2.5}$	65		
NH_3	200		
NMHC	160	3-h	
CO	30	1-h	mg/m^3
	10	8-h	

However, a comparison of Omani and international standards reveals that Oman's standards are much less strict than those set internationally. For example, for $PM_{2.5}$ Oman has set a limit of 65 µg/m^3 daily compared with the 25 µg/m^3 recommended by the WHO, and its daily limit of 150 µg/m^3 for PM_{10} is three times higher than that in the WHO guideline. Oman's SO_2 and NO_2 limits are also far higher, and therefore far less strict, than those set internationally. In addition, certain targets set in the in the EU Air Quality Directive are missing from Oman's parallel MD 41/2017. For example, the EU Directive specifies target values of 50 (24-h) for PM_{10} and 200 (1-h) for $NO_{2,}$ to be achieved by 2010 (Maynard and Williams, 2018). It is worth noting here that the standards in the table for

Oman refer to areas around industrial plants and not to the general ambient environment; there are no AQ standards for the general population/ambient environment in Oman. Additionally, MECA is not monitoring or following the $PM_{2.5}$ parameters. This absence of monitoring data and the lack of transparency in Oman, influence the research design and recommendations that have been made in this thesis.

3.3.2.5 The Sultanate's policies for reducing climate change:

Oman signed the Paris Framework on Climate Change in 22 April 2016, and ratified it on 22 May 2019. It had also earlier signed the United Nations Framework Convention on Climate Change in 1992 and ratified it by Royal Decree No. 119/1994 and had also ratified the Kyoto Protocol to the Convention by Royal Decree No. 107/2004.

Oman has also ratified the Vienna Convention for the Protection of the Ozone Layer, as well as the Montreal Protocol on Substances that Deplete the Ozone Layer and their amendments in London and Copenhagen. The Sultanate's efforts in the matter have been a success, as the consumption of ozone-depleting-substances was reduced to zero, less than the levels set by the Montreal Protocol. The Ministerial decision which regulates ozone-depleting substances is under MD 243/2005 "regulation for the control and management of ozone-depleting substances", Table 3.3.

The Ministry of Environment and Climate Affairs, in collaboration with the United Nations Development Programme, carried out a project for building capacity in the field of climate change as preparation for the publication of the Sultanate's first national proclamation report on climate change. The report was formally approved, and sent to the Secretariat General of the Framework Convention on Climate Change in October 2013.

Ministerial Decision No. 20/2016, issuing the regulations for the management of climate affairs, consists of 17 articles and 4 annexes and enables the General Directorate of Climate Change at the Ministry of Environment and Climate Affairs to apply its provisions to any projects which could affect the environment and climate change. The main tasks of the Directorate are as follows:

- to develop and implement regulations and decisions on climate change adaptation and mitigation;
- to set the standards to be met;
- to set instructions;
- to issue permits; and
- to carry out emission reduction measures.

> The owner of any project, facility or work area listed must obtain a license from the Ministry. The license lasts two years, and can be renewed. The licensee is obliged to submit an annual report on GHG emissions. Existing projects have a period not exceeding three years to fall in line with the provisions of the regulations. Annex 1 lists the greenhouse gases involved; Annex 2 outlines which establishments and projects are subject to the licensing procedures; Annex 3 specifies the ranges of greenhouse gases allowed; and Annex 4 gives the fees to be paid for licenses.

While these measures might be seen as evidence that Oman is aware of the need to protect the earth from climate change and is making a concerted effort to reduce its global effects, the country's actual performance record on the environment does not reflect this. For example, in September 2019, there was a tweet from a resident of Bowsher Governorate about unpleasant odours and polluted air making it difficult for people to breathe in that area. The residents suggested that the source of the problem was the Mina Al Fahal oil refinery near Muscat. MECA's response was vague and gave no indication that it might take measures to reduce the emissions from the oil and gas processing. From the researcher's communications with employees in MECA, it appears that neither the Directorate of Climate Affairs nor the Directorate of Environment Affairs were willing to provide data or to cooperate with enquiries in any other way.

According to the Minister of Environment and Climate Affairs, Oman is working on the 'National Strategy to Adapt and Reduce Climate Change' which was expected to start in 2017, and was mentioned in section 3.3.2.1. However, the time of writing (August 2019), this strategy has not yet been approved. Oman's primary environmental law, Royal Decree 114/2001, has experienced similar delays; updates to it were referred to the minister's cabinet for approval in 2017, but it still has not been approved. Also worrying is the fact that the preliminary vision for Oman 2040 is committed to building a coal-fired power station; this decision suggests that the environment is not a priority.

3.3.2.6 Oil and Gas Law: Royal Decree 8/2011:

The oil and gas law currently in use in Oman is Royal Decree 8/2011, which replaces the previous basic Petroleum Law, Royal Decree No. 42/1974. This law RD 8/2011 makes it mandatory to obtain prior approval before engaging in the exploration, extraction, exploitation, storage or distribution of petroleum or mineral resources. Prior approval is also needed to undertake activities involving processing plants, pipelines, storage tanks, storage facilities, ports, jetties, offshore platforms or installations, sea and marine loading facilities, and pumps or pumping stations.

The law requires licensed operators to conduct their operations in a manner that minimizes air and water pollution; they must also ensure the safety of the health and wellbeing of their employees and the public. Any person violating this law is liable for loss or damage suffered directly or indirectly by a third party or by the government, as a consequence of the violation. The compensation to be made for such loss or damage is not limited to the direct loss incurred but also includes consequential and economic loss.

The Ministry of Oil and Gas (MOG) has general authority to supervise the activities of the rights-holder under the Exploration and Production Sharing Agreement (EPSA) and the Oil and Gas Law. The Ministry of Justice, pursuant to Article 6 of the Oil and Gas Law, has general judicial powers of enforcement and implementation of the law. Chapter 8 of the Oil and Gas Law sets out the level of punishment (which can include fines and/or imprisonment) for those found to be in contravention of certain articles of the Oil and Gas Law. Such fines are in addition to any other fines or penalties that may be imposed by other laws, including the Omani Criminal Law.

3.3.2.7 The Traffic Law: Royal Decree 28/1993:

Vehicle emission control in Oman is covered within two entities and by two regulations. The first controls the import of different type of vehicles and comes under the Ministry of Commerce and Industry (MOCI), while the second regulates the use of vehicles both on and off road and comes under the Royal Oman Police (ROP). MOCI regulates the entrance of vehicles into Oman; these vehicles must conform to the Gulf standards specified in GSO 42/2015 (motor vehicles - General Requirements). The process is usually done through the GCC Standardization Organization (GSO) in the Kingdom of Saudi Arabia (KSA). The Royal Oman Police regulates the use of the roads through the Traffic Law (RD 28/1993) and also lays down the traffic code. The law contains related rules such as vehicle registration, traffic rules, safety, measurements and penalties.

The Gulf Standards 42/2015 is a regulation concerned with the general requirements for motor vehicles, and aims to ensure high levels of safety, environmental protection, energy efficiency and anti-theft performance. It states that the engine shall comply with at least Euro IV exhaust emissions pollution limits (i.e. with ECE R 83 and ECE R 49). ECE R 83 and 49 are uniform provisions setting out the maximum emission level of pollutants (according to the engine's fuel requirements) before a vehicle is approved. Another regulation published and enforced by MOCI bans the import of vehicles more than seven years old into the Sultanate, for environmental and safety reasons.

The Traffic Law (RD 28/1993) regulates the registration of vehicles and all related activities within the country. Vehicles can be registered under various categories: private, taxi, commercial, rental, driving teaching, government, diplomatic, consular body, United Nations, agriculture tractor, motor cycle, export, and inspection. The law states that the following vehicles shall be subject to technical inspection on registration and on license renewal: commercial vehicles, taxicabs and buses, driving teaching vehicles belonging to the driving schools, and private vehicles which are ten years old or more from the year of manufacture. Second-hand vehicles imported from abroad, old vehicles, and vehicles sold in public auctions are all subject to technical inspection upon registration. If the technical inspection proves that the vehicle is defective, it shall be written off from the record, its plates shall be withdrawn and it may not be repaired or re-registered in the Sultanate. However, the emission test part of such inspections is regulated only by visual inspection, and vehicles fail only if emitting black smoke. The law states that "The motor vehicles may be seized if thick smoke emission is noticed or some substances or liquids are leaking from its tanks which may harm the road users or form a hazard to their security and safety".

The traffic law does not specify any emission test as part of the inspection procedure, and there is no annual inspection for the vehicles less than 10 years old.

3.3.2.8 Maritime Law: Royal Decree 35/1981:

This Act consists of seven books divided into 392 articles, which cover the following areas:

1. on board the ship
2. ship's personnel
3. regulation of marine activities
4. supplying debts
5. exploitation of the ship
6. marine accidents, and
7. marine insurance.

This Act shall apply to all maritime navigation except for military ships or ships operating for public interests. Actions concerning the establishment, transfer or devolution of ownership rights on the board of ships shall be carried out by a formal letter or by a definitive sentence (art. 18). Book I also includes provisions on: the ship's documents; the inspection on ships; the ownership of ships; the registration of ships; the registration and revocation of rights related to ships; ships' owners and suppliers of equipment. Book III contains provisions on marine activity contracts, and on sailor and supplier duties. The provisions of Book IV include: marine loans for exploitation; marine privileges; pawning of marine vessels'; the confiscation of ships; precautionary confiscation; and executive confiscation. Book V addresses matters related to the lease of ships, marine transport contracts, the transport of goods and the transport of persons.

3.3.2.9 Aviation Law

Air quality associated with Oman's aviation industry is regulated by the International Civil Aviation Organization (ICAO) which regulates all aviation industries worldwide. ICAO has 191 members and its regulations cover safety, security and the environment. Several factors have raised awareness of the damaging environmental impact of air travel: the global growth rate in traffic, awareness of the emissions that affect local air quality, and the steady increase in overall aircraft fuel consumption.

The current ICAO Standards for emissions certification of aircraft engines, which are contained in Volume II of Annex 16, Appendix 2 to the Convention on International Civil Aviation, were originally designed to respond to concerns regarding air quality in the vicinity of airports. To achieve certification, an engine must demonstrate that its characteristic emissions of HC (unburned hydrocarbons), CO (carbon monoxide), NO_x (oxides of nitrogen) and smoke are below the limits defined by ICAO.

In 2017, ICAO adopted a new CO_2 emissions standard for aircraft; this will reduce the impact of aviation greenhouse gas emissions on the global climate, making air transport the first industry sector globally to adopt a CO_2 emissions design certification standard. Contained in a new Volume III to Annex 16 of the Chicago Convention (*Environmental Protection*), the aircraft CO_2 emissions measure represents the world's first global design certification standard governing CO_2 emissions for any industry sector. The standard will apply to new aircraft type designs from 2020. Aircraft type designs already in production as of 2023 will have until 2028 to meet the standard; if they do not, companies will no longer be able to produce them unless their designs are sufficiently modified (ICAO, 2017).

3.3.2.10 Energy efficiency regulation:

Ministerial Decision 107/2018 rolled out energy efficiency standards for electrical appliances, adopting the GCC Standard GSO 2530/2016 on energy efficiency requirements and the minimum energy efficiency limits of air conditioners, which are also obligatory in Oman. The GSO 2530/2016 standard, called "Energy Labelling and Minimum Energy Performance Requirements for Air-

Conditioners", specifies the energy labelling requirements and the Minimum Energy Performance Standard (MEPS) requirements for any single-package of window type, split-system non-ducted air conditioners. It is an obligatory Omani standard, and is regulated in coordination with the General Authority for Electricity and Water, the Electricity Regulatory Authority, the Public Authority for Consumer Protection, the Ministry of Regional Municipalities and Water Resources, the Implementation and Follow-up Support Unit 'Tanfeedh'[12], and other related entities, institutions and companies in this field. Article 3 of the Ministerial decision stipulates that an administrative fine of not more than OMR 5,000 will be imposed on anyone who contravenes the provisions of this directive. The fine shall be doubled in case of repeated violations. Efforts are now underway to prepare standards for lighting appliances, and also for other devices and equipment. The report states that, "By 2019, all standards of different electrical appliances will be set and enforced."

3.4 Oman within the GCC Institutional structure and Environmental Policy:

Air pollution and climate change are two of the main environmental problems facing humanity worldwide. Due to their climatic conditions, the GCC countries are highly vulnerable to the projected impacts of climate change, which makes it very important to have joint activities and positions among the GCC countries.

3.4.1 Environment Institutional Setup in the GCC

Table (3-8) summarizes the status of the development of environmental organization for Oman and the other GCC countries in terms of all the regulations affecting air quality or climate change (GHG) emissions in the GCC, from 1972 until today. Appendix C3 contains the GCC Air Quality Policies.

Oman was the first of the GCC countries to establish a Ministry for Environment and Water; this ministry, along with the Council for Conservation of the Environment and Prevention of Pollution, were then merged into a new Ministry of Regional Municipalities and Environment in 1991. This is currently the Ministry of Environment and Climate Affairs (MECA).

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[12]Tanfeedh: is a government initiative that aims mainly at linking the strategies of the main vital sectors of Manufacturing, Tourism, Transport & Logistics, Mining and Fisheries to each other in order to diversify the national income resources and fulfil the objectives of the Ninth Five Year Development Plan 2016 – 2020. It also works towards a sustainable participation between the public and private sectors.

Table 3-8: National environmental institutions in GCC countries (1972-2002) (UN, 2003), and currently

Country	1972-1992			1992-2000			2000-2002			Current*
	Initial environmental institution	Date	Status	Initial environmental institution	Date	Status	Initial environmental institution	Date	Status	
Bahrain	Environmental Protection Committee	1980	Dissolved	Ministry of Housing, Municipalities and Environment (includes Environmental Affairs Agency)	1995	Functional	Ministry of State, Municipalities Affairs and Environmental Affairs	--	Restructured	Supreme council for environment. Bahrain will have an Air Quality Strategy in the near future.
				National Committee for the Protection of Wildlife	2000	Functional	General Commission for the Protection of Marine Resources, Environment and Wildlife	2002	Functional	
Kuwait	Environmental Protection Council	1980	Dissolved	Environmental Public Authority (EPA)	1995	Functional	Unchanged		Functional	Environmental Public Authority (EPA)
				Supreme Council of EPA	1995	Functional	Unchanged		Functional	Supreme Council of EPA
Oman	Ministry of Environment	Early 1980s	Expanded							Ministry of Environment and Climate Affairs (MECA) 2007
	Ministry of Regional Municipalities	1985	Expanded	Ministry of Regional Municipalities and Environment	1991	Expanded	Ministry of Regional Municipalities, Environment and Water Resources	2001	Functional	
Qatar	Environmental Protection Committee	1981	Dissolved	Environment Department, Ministry of Municipal Affairs and Agriculture	1995	Dissolved	Supreme Council for the Environment and Natural Reserves	2000	Functional	Ministry of Environment
Saudi Arabia	Meteorology and Environmental Protection Administration (in the Ministry of Defence and Aviation)	1980	Functional	Unchanged		Renamed	Presidency of Meteorology and Environment (in the Ministry of Defence and Aviation)	2002	Functional	Presidency of Meteorology and Environment (PME) in the Ministry of Defence and Aviation
	National Commission for Wildlife Conservation and Development (in the Ministry of Foreign Affairs)	1985	Functional	Unchanged			Unchanged			
	Ministerial Committee on Environment	1990	Functional	Unchanged			Unchanged			
							National Preparatory Committee (WSSD)		Functional	
UAE	Higher Environment Council	1975	Dissolved in 1993	Federal Environment Authority	1993	Functional	The Environment Agency – Abu Dhabi (EAD	1996	Functional	The Environment Agency – Abu Dhabi (EAD)
	Higher Environment Committee	1975	Reconstituted in 1981	Unchanged			Unchanged			

Source: Compiled from ESCWA, Governance for Sustainable Development in the Arab Region: Institutions and Instruments for Moving beyond an Environmental Management Culture (New York: ESCW A, 2003), pp. l3-16.

* Data provided from Abdul-Majeid Haddad, Regional Climate Change Coordinator, United Nations Environment Programme (UNEP)

3.4.1.1 Oman

Environmental institutions in Oman underwent a long series of development and enhancement, culminating in the establishment of the Ministry of Environment and Climate Affairs (MECA) in 2007 by Royal Decree 91/2007. MECA is the prime body in the sultanate responsible for overseeing all environmental issues in the country, and providing licenses, permits and clearance. MECA's role is to monitor industry's compliance with legislation and to check whether their activities meet the country's environmental criteria. Environment impact assessment (EIA) and other environmental status reports are reviewed by MECA for environmental approval. One of the steps taken was to restructure MECA's organization by removing municipal waste management and waste water management from MECA and handing these to the private sector. Bea'a (Oman Environment Services Holding Co.) was established in 2009 by Royal Decree No. 46/2009, with Its main responsibilities being solid and liquid waste management and management of sanitary landfills. Haya Water, a registered trademark of Oman Wastewater Services Company S.A.O.C, was established in December 2002 as an Omani closed joint-stock company wholly owned by the government; its main responsibilities are to develop, design, implement, operate and maintain the wastewater facilities in Muscat Governorate under the Royal Decree No. 69/2005. The work of non-governmental organizations (NGOs) has been undertaken in Oman via the Environment Society of Oman (ESO), which is a non-profit organization playing a major part in public awareness of environmental issues in Oman. The ESO is the only environmental association representing civil society, and its main aims are to help educate, raise awareness and enable public involvement in conservation efforts of Oman's natural heritage; they also carry out and collaborate in researching Oman's biodiversity. However, apart from raising awareness of climate change through promoting the Earth Hour event, it has no focus on air pollution, climate change, or any related issues.

3.4.1.2 United Arab Emirates (UAE)

The Environment Agency – Abu Dhabi (EAD) which was established in 1996, is committed to protecting and enhancing the quality of air and groundwater, as well as the biodiversity of the desert and marine ecosystems. By partnering with other government entities, the private sector, NGOs and global environmental agencies, EAD embraces international best practice, innovation and hard work to institute effective policy measures. The Environment Agency seeks to raise environmental awareness, facilitate sustainable development and ensure that environmental issues remain one of the top priorities on the national agenda. NGOs are working to protect the environment with community and public involvement, education, and action programs, and other national NGOs aim to promote the conservation of nature in the UAE. The UAE has a number of NGOs with a global reputation, covering such environmental issues as sustainability and recycling, such as the Emirates Wildlife Society and the Emirates Environment Group. None of the NGOs, however, focuses on air quality or climate change.

3.4.1.3 Kingdom of Saudi Arabia (KSA)

The Presidency of Meteorology and the Environment is the principal authority responsible for the environment in the KSA. It has a detailed and well-defined institutional structure covering almost all biophysical environmental aspects of the country. The institutional set-up is divided into two main subdivisions, Meteorology and Environment, but their activities are sometimes combined when they operate as a centre for meteorology and environment with an emergency team that acts in cases of natural disasters and floods as well as in erosion control. The only Saudi Environmental NGO is the Saudi Environmental Society (SENS) which is dedicated to supporting the government’s environmental protection efforts and enhancing public participation and voluntary work by all sectors of the community. SENS does not deal with either air quality or climate issues.

3.4.1.4 Qatar

The role of the Ministry for Environment in Qatar is to protect the environment through sustainable growth for future generations. It has six major units, including administration, quality and planning, and livestock and environmental management. The ministry is responsible for creating environmental legal frameworks and institutions that propose and develop policies and laws to protect and control the environment, and that ensure the quality of environmental health and safety. It also supports national, regional and international cooperation regarding related issues and activities. The Friends of the Environment in Qatar is an NGO that works in parallel with the Ministry of Environment; it targets local communities, and aims to provide public awareness on environmental issues such as recycling and biodiversity protection. It is not involved with climate change and air pollution issues, and its main activities relate to beach cleaning, plastic and recycling.

3.4.1.5 Bahrain

The Supreme Council for Environment (SCE) in Bahrain is a government entity in charge of the development of Bahrain’s future strategy for the environment and for sustainable development. It is also tasked with following up on the implementation of this strategy with relevant ministries, agencies and institutions. The SCE’s mandate includes protecting Bahrain’s natural habitat and human environment, ensuring the sustainability of its components, and preserving and developing its resources for future generations. Bahrain was also the first country in the GCC to establish an online forum, here called e-Environment Friends, where the public can exchange and share knowledge and ideas on environmental issues and awareness. Bahrain is also much more advanced than other GCC countries In terms of its independent environment-oriented NGOs, and the number of its environmental societies. These include the Environment Friends Society, the Bahrain Youth and Environment Society, the Bahrain Environment Society, and the Arab Youth Climate Movement (AYCM)–Bahrain. The latter is an independent body that is working to create a generation-wide movement across the Middle East and North Africa to find solutions to the climate crisis, and thus to assess and support the establishment of legally binding agreements in the region to deal with climate change issues within international negotiations.

3.4.1.6 Kuwait

The body responsible for environmental management and practices in Kuwait is the Environment Public Authority (EPA). The authority operates as part off the Higher Environmental Council. The authority's organizational structure is well-defined and covers almost every aspect of the biophysical environment. Most notably, Kuwait's EPA has initiated the ambitious Environmental Monitoring Information System of Kuwait (eMISK), a system aiming to establish, build and maintain a comprehensive geo-environmental database of Kuwait along with an enterprise-level GIS system that will enable access to the environmental data, and will also facilitate data update and analysis. Emission data for SO_2, NO_2, O_3, CO, PM_{10} is recorded instantly via several monitoring stations which are synchronized with MISK (EPA 2015). Kuwait can also be considered as the leader in the GCC for the establishment of NGOs, with the Kuwait Environment Protection Society (KEPS) established in 1974. This was done in response to the first conference on the human environment, held in Stockholm, Sweden, in 1972, and the resulting decision to establish UNEP at a global level.

In general, then, all the GCC countries have established similar environmental institutional bodies to serve the purpose of environmental conservation and protection. The majority of countries have enabling Environment Impact Assessment (EIA) legislation while others have specific localized legislation and regulations (Briffett, 2000; El-Fadel, 2004; Al Azri et al., 2013). Since air pollution deteriorates air quality and impacts on public health, these EIAs allow the probable environmental effects of a project to be identified, assessed and then either prevented, remedied or minimised at an early stage. The EIA can thus help allay any public fears created by a lack of information about a project by sharing facts about its likely effects. However, there are a number of weaknesses in the management of the environment. None of the GCC countries has any process whereby members of the public can participate in the EIA approval process. Also, although the law lays down requirements for environmental management plans, requirements for the mitigation of impacts and requirements for impact monitoring, the implementation of these regulations seems sometimes to be less effective than is desirable. Also, none of the GCC countries carries out any monitoring of their EIA system, nor is there any training or capacity-building to make the system more effective.

Another issue needing attention arises from the fact that the main environmental administrative bodies in the GCC countries are funded through governments and come under government control. As most of the government administrative institutions in GCC countries are centrally governed, they have their base in the capital cities. However, a number of countries are gradually starting to decentralize environmental management to the local level. The United Arab Emirates, for example, has established a number of environmental agencies under the supervision of the federal government. Oman, Qatar and Saudi Arabia have set up offices and directorates in remote regions, and these work in coordination with the central administration (Al-Saqri and Sulaiman, 2014). Nevertheless, these offices and directorates lack any independent decision-making authority, and thus have no real power.

GCC countries also restrict and control both the foundation and the work of NGOs in the region. While national NGOs have been actively engaged by playing a lead role in the clean-up of beaches, in recycling, in the conservation of wildlife and in spreading awareness about all these issues, NGOs such as Greenpeace in Western Europe, which use robust activism to put issues such as environmental pollution and climate change on the agenda, do not exist in the GCC countries.

3.4.2 Institutional Framework of the GCC

The main authorities of the GCC as a whole are the Supreme Council and the Ministerial Council. The Supreme Council is the highest authority and consists of the heads of member states. It holds a regular session at the end of each year and extraordinary sessions upon request. The Ministerial Council acts as the filtering mechanism for the Supreme Council and consists of the Foreign Ministers or other delegated ministers of the member states.

In 1985, aware of the similarity of the development and environmental conditions of the GCC states, but also of the poor integration between their plans for development and the environment, the GCC Supreme Council (6th session, Muscat Summit, 1985) adopted the document called “The Policies and General Principles of Environment Protection in the GCC States”. Those policies were to act as the basis for developing strategies for future environmental activities, and contained several principles, some of which were highly relevant to air pollution and climate issues, namely:

‘Recognizing the serious impact on environment and natural resources in GCC member states resulting from industrial and urban development operations and the need for sustained development without prejudice to the environmental considerations, the Supreme Council (28th Session, Doha, December 2007) approved the Green Environment Initiative and its GCC Environment Action and Implementation Plan.’

The Secretariat, in cooperation with member states, has been developing programs and activities for the Green Environment Initiative within both a short-term and long-term plan. Through this initiative, the GCC states have become a leading model for achieving integration between comprehensive development and the conservation of environmental resources. The Final Declaration of the Supreme Council (14th session, Riyadh, December 1993) stressed the importance of joint environmental action for converging policies, unifying environment laws and legislation, enhancing national and regional capacity, training of a labour force, raising environmental awareness among citizens and for the conservation of natural resources. The Final Declaration of the Zayed Summit (Manama, December 2004) also reiterated that conservation of the environment and renewal of its natural resources are essential factors for achieving the sustained development that will improve the conditions and welfare of GCC citizens. The Declaration has recently called on member states to adhere to its balanced development action principles (Cooperation Council for the Arab States of the Gulf, Secretariat General 2019).

Beside the reference laws which have been developed within the GCC framework of the joint environmental action (Table 3-4), the ministers in charge of environment affairs in the GCC states have adopted an action plan that includes diagnosing common environmental problems, reviewing and unifying the environmental standards and regulations in the GCC, and promoting awareness, research studies, training, and information exchange.

One of the regional organizations that aims to harmonize policies of the GCC countries is the Gulf Standardization Organization (GSO). This unifies the various standardization activities and follows up how they are implemented and compliance with them; this is done in cooperation and coordination with the standardization bodies of each member state. The purpose of the GSO is thus to develop the production and service sectors, foster intra-GCC trade, protect consumers, the environment and public health, enhance the GCC economy and its competitiveness and meet the requirements of the Gulf Customs Union and the Gulf Common Market. Two examples relevant to this study are the vehicle standards and the efficiency standards, which were discussed previously in sections 3.3.2.7 and 3.3.2.10. The principle of standardisation applies to many other areas, such as building codes and other areas affecting health and the environment. However, so far compliance with these voluntary and there should be consensus within the GCC member states in order to be implemented as compulsory standards.

The GCC countries are clearly similar in their level of economic development, their population growth and their pollution sources (such as sand storms) (Farahat, 2016). However, it appears that, overall, the systematic monitoring of air pollutants in the GCC is poor. The exception is Kuwait and its eMISK initiative, which aims to build and maintain a comprehensive environmental database not only of Kuwait but also of the whole GCC region, along with an enterprise-level GIS system that would allow access to and update and analysis of the environmental data for SO_2, NO_2, O_3, CO, PM_{10} via several monitoring stations, as described in Section 3.4.1.6. However, any attempt to upscale this initiative to the whole GCC would face many challenges, such as individual countries' different level of priorities, and an absence of transparency, so that thus far it is used only by Kuwait.

The first step for creating a unified plan would be the comprehensive and accurate measurement of air pollutants throughout the GCC. The resulting values would then be compared with the standards set in developed countries, though these would need to be adjusted to take account of local meteorological and environmental conditions. In the long term, such initial steps are needed in all GCC countries (Omidvarborna et. al, 2018) but a number of other steps would further improve the environmental performance. These include more research on environmental issues at both national and regional level, including an assessment of the steps needed to improve the efficiency and renewability of various sectors, such as the infrastructure of the transport sector, and to diversify the economy. These initiatives could be registered at an international level in order to obtain both recognition and support.

There is a good deal of evidence to show that the GCC countries are keenly interested in working together, such as the many environment-oriented policies established, the many steps already taken by every country, and the many declarations made. The problem is, however, that in reality these policies and recommendations are not being substantially implemented, nor is there much evidence of any serious intention to carry them out – evidence that could be shown, for example, by the existence of convincing action plans with details of responsibilities, deadlines, and review and follow-up strategies.

As the Gulf Cooperation Council (GCC) states are highly vulnerable to the adverse impacts of climate change, there is a definite need for harmonized laws and strategies to address climate change and air quality. Given that all the GCC countries have national economic diversification plans, the integration of climate change action (mitigation and adaptation) into these plans would go some way to improving their power and legitimacy. Indeed, a report on precisely this topic was published in 2018. Entitled "Plan for Prospects for Climate Change Integration into the GCC Economic Diversification Strategies", it noted that "despite the fact that the GCC states are among the world's highest per capita carbon emitters (Qatar ranked first and Oman thirteenth in 2014), national development plans do not include overarching national targets related to climate change, such as carbon intensity reduction targets, energy consumption reduction targets or an emission reduction target" (Al-sarihi, 2018).

3.4.3 GCC Nationally Determined Contributions (NDCs):

In accordance with Decision 1/CP.19 and based on the information mentioned in Decision 1/CP.20 taken by the Conference of the Parties (COP) on its nineteenth session, held in Warsaw from 11 to 23 November 2013 under UNFCCC which invites all parties to submit their Intended Nationally Determined Contributions (INDC) for the period post-2020, the GCC countries submitted their documents – individually - to present their sustainable development plans and programs at national level (Table 3-9), thus joining the global effort to limit climate change. The GCC countries will have to implement the measures set out in their NDCs if they are to qualify for the UNFCCC 's assistance with finance, capacity building and the transfer of technology.

Table 3-9: Summary of Nationally Determined Contributions (NDC) for GCC countries

Country	Current Policies & Programmes	Submission date
Qatar	Policies: The environment protection law 30/2002 sets out the national ambient air quality standards. The Qatar National Vision 2030 contains four pillars: Human, Social, Economic and Environmental development. Mitigation priority: Energy efficiency, clean energy and renewables. Adaptation priority: Water management, infrastructure and transport, waste management, and awareness.	23/06/2017

Bahrain	Policies: Environment law 21/1996 Decision No. 11/1999, for environment standard (air and water) and Decision 3/2001 for amendment of some limit in decision 11/1999 Decision 1/1998 for environment assessment of project. Decision 8/2002 for standards and inspection of emission from vehicles. Bahrain makes relatively minor contributions to global greenhouse gas emissions and its mitigation potential will largely depend on national circumstances, capacity and support. Being particularly vulnerable to the impacts of climate change, adaptation is a key priority.The four key areas are: coastal zones, water resources, human health, and biodiversity. The Kingdom of Bahrain is planning to undertake the following actions as their adaptation target for adapting to future environmental and social issues, which could also contribute to reduction in emissions: Improving the transportation network: bus routes were created across the country to increase public transport efficiency and attractiveness. Future projects include the GCC Railway Project, and the Bahrain Light Rail Project which may contribute to the reduction of personal vehicle use and emissions.	30/12/2016
Kuwait	Policies: Environment Protection Law(42/2014) The Environment Public Authority is currently preparing the regulations and guidelines for the Environmental Protection Law (42/2014), amended by Law (99/2015) which will include particular topics of climate change such as reporting system of emissions, adaptation and mitigation. Mitigation: Establishment of projects to reduce GHG, such as producing clean fuel, constructing a new refinery, producing energy from renewable sources and MSW, and creation of a mass transit system (metro) and railway project. Laws and regulation where the state of Kuwait is seeking to fulfil the increasing demand of its energy needs from renewable energy sources by 2030. Kuwait to study the possibility of a gradual reduction of subsidies on electricity and water, which will contribute significantly to rationalizing consumption and reducing greenhouse gas emissions. Adaptation measures: Strengthen coastal information systems, adapt to dust storms, create food security, use district cooling systems in the new residential cities, and adapt to lack of water resources.	23/04/2018

Saudi Arabia	Policies: Royal Decree No. 34, which approves Decision No. 193 relative to the adaption of General environmental regulatory system in the kingdom of Saudi Arabia. Ministerial decision No. 1/1/4/5/1/924 has approved the rules for implementation of the General environmental regulation and its amendment by Decision No. 1/1/4/2391. The actions and plans outlined in the NDC seek to achieve mitigation co-benefit ambitions of up to 130 million tons of CO2eq avoided annually by 2030 through contributions to economic diversification and adaptation. Mitigation options: Energy efficiency, renewable energy, carbon capture and utilization/storage, utilization of gas, methane recovery and flare minimization. Adaptation priorities: Water and waste water management, urban planning, marine protection, and reduction of desertification.	03/11/2016
UAE	Policies: The primary legislation for environmental protection in the UAE is Federal Law Number 24 of 1999 for the protection and development of the environment (Environmental Law) UAE Vision 2021, which is complemented by the 'Green Growth Strategy', and the National Innovation Strategy. Mitigation: The clean energy target is to increase the clean energy contribution to the total energy mix from 0.2% in 2014, to 24% by 2021. Energy Efficiency, by having green building regulations and appliance efficiency standards, and by moving towards district cooling and improving air conditioning efficiency. Transport: investment in light-rail and metro system, federal freight rail network within the GCC; the shift 25% of government vehicle fleets to compressed natural gas. Waste: developing a federal law to regulate and oversee waste management. Adaptation: The UAE aims to mainstream climate change adaptation in its environment management activities through developing a national biodiversity strategy action plan and a national policy on climate change adaptation. The main concerns are wetlands, coastal and marine environment conservation, water management, and food security.	12/09/2016

Oman	Policies: The principal environmental legislation in Oman is Royal Decree Number 114/2001, the Law on Conservation of the Environment and Prevention of Pollution (RD 114/2001). Ministerial Decision Number 118/2004 is for the Control of Air Pollution from Stationary Sources. The identified impact of climate change: Tropical cyclones & storm surges, Flash flooding, Heat waves, Sea level rise, Coastal erosion, Water scarcity and desertification, Reduction in fish stocks & impacts on marine environment and agriculture. Mitigation options (2020-2030): Reduction in gas flaring from oil industry; increasing the share of renewable energy; increasing energy efficiency projects in industries; developing new legislation on climate change which will support the adoption of low carbon and energy efficient technologies. Adaptation efforts will be in the following areas: Tropical cyclones, coastal erosion and sea level rise, Fisheries and marine environment; Water scarcity and desertification; Flood protection; Energy security; Food security; and the development of a national adaptation strategy on climate impacts. NDC target: in the absence of an NDC, GHG emissions are expected to be 90524 Gg by the year 2030. However, Oman will control its expected GHG emissions growth by 2%, aiming for 88714 Gg during the period from 2020 – 2030. The projections of GHG emissions for Oman are based on economic and social growth.	22/05/2019

The GCC countries have a lot of similarities (including economic, socioeconomic and cultural) which would suggest the advantages of their having a prior mutual agreement, on some points at least, for their submitted NDCs. However, the differences in each country's priorities and visions mean that they exhibit different levels of interest in registering their actions at an international level. Countries such as Oman and KSA have more progressive CO_2, reduction targets than do other countries, some of whom have not presented any plans for emission reduction. Each country also highlights climate change mitigation actions in different ways, with Bahrain highlighting the transport sector, Qatar, Kuwait, and the UAE the electricity generation sector, and KSA and Oman the oil and gas sector. However, they are all agreed that energy efficiency and renewable energy must be considered as targets for mitigation. (See Appendix D3)

3.4.4 Public Opinion of Climate Change in the GCC:

From February to May 2009, a survey was carried out to gauge public opinion on climate change; it was conducted on a voluntary basis and by questionnaires rather than interviews. For statistical purposes, countries were grouped into clusters, with the GCC group consisting of Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, and the United Arab Emirates. Questionnaires were sorted by the Pan Arab Research Centre (PARC), a Gallop associate, which prepared the statistical report (Tolba and Saab, 2009). All figures were rounded to the nearest decimal and the GCC results are summarized in Table 3-10.

Table 3-10: Public Opinion on Climate Change in the GCC countries

	Questions:	Answers		
1	I understand what climate change is:	Yes	No	
		96%	4%	
2	I believe the climate is changing	Agree	Don't know	
		99%	1%	
3	Climate change is primarily the result of human activities (industry, transportation, energy generation, etc.)	Agree	Disagree	Don't know
		89%	7%	4%
4	Climate change is a serious problem for the country of my residence	Agree	Disagree	Don't know
		83%	8%	8%
5	Do you think climate change will affect any one of the following sectors in your country? (you may select any number of options)	Health	84%	
		Drinking water	77%	
		Food	72%	
		Coastal Areas	62%	
		Forests	35%	
		Tourism	38%	
		It will not affect any sector	0%	
		No answer	0%	
6	It is of a high importance and benefit that my country participate in worldwide action to limit climate change	Agree	Disagree	Don't know
		95%	3%	2%
7	I will do what I can to reduce my contribution to climate change	Agree	Disagree	Don't know
		92%	4%	5%
8	My government is acting well to address climate change	Agree	Disagree	Don't know
		37%	44%	18%
9	In your opinion, what are the three main measures to mitigate the causes of climate change and adapt to it?	Reduce consumption (mainly energy)	65%	
		Educational and awareness campaign	54%	
		Ratify and implement international treaties and legislations	45%	
		Environmental planning and monitoring for mega-projects	41%	
		Forest development and protection	31%	
		Scientific research	33%	
		Develop crops that need less water	12%	
		Low-lying coastal areas protection	12%	
		No answer	-	

The majority of respondents, 96% of people in the GCC, understand what climate change is, with the highest percentage of those in Oman (100%). 99% of people in the GCC also believe that the climate is changing. In Oman, 100% of people agree that climate change is primarily the result of human activities (industry, transportation, energy generation, etc.), and 87% agree that climate change is a serious problem for the country.

The main answers to the question "Do you think climate change will affect any one of the following sectors in your country? " were Health 84%, Drinking water 77%, Food 72%, Coastal Areas 62%, and Tourism 38%.

The majority of people (95%) in the GCC say "It is of high importance and benefit that my country participates in worldwide action to limit climate change". At the country level, 100% of Omanis agree with this. However, the public's confidence in their governments is relatively low, reflecting the fact that the level of ambition in the NDCs is poor. This means that governments are not listening to their people, which is also reflected in the lack of community participation in governmental decisions. In addition, implementation of the mitigation options presented by the GCC countries in their NDCs are conditions for any UNFCCC assistance; the weakness in implementation so far suggests that the GCC governments are not seriously committed to participation in global mitigation.

Overall, only 37% of the total population in the GCC say, "my government is acting well to address climate change". However, in Oman the figure is 92%, making it the GCC country most satisfied with its government's action on climate change. This indicates that the confidence in government decisions and action in Oman is much higher than that in other GCC countries.

For the three measures needed to mitigate climate change causes and adapt to its effects, people in the GCC voted for reducing energy consumption as the most important measure to mitigate climate change (65%), with educational and awareness campaigns and ratifying and implementing international treaties and legislation coming in second and third place. However, at the country level, Oman's highest vote at 83% was for environment planning and monitoring of mega-projects, and, in spite of the damage caused by Cyclone Gonu in 2007[13], protection of low-lying coastal areas scored zero.

It should be noted that there is some discrepancy between the confidence of the Omani public in the government's action on and progress in combating climate change and the objective measurement of the government's actual performance. In spite of people's high level of confidence in the government, it is not performing well, as evidenced by its clear decline in the 2018 Environment Performance Index (EPI). However, if these facts were better known, the public could put pressure on the government to contribute more effectively to the regulation process, and could urge them to create greater awareness, sustainability, and renewable energy. Some possible measures include approaching their parliament representatives, demanding action in the media, and establishing non-governmental organizations concerned with air quality and climate aspects.

Recently, a report was published entitled "The 2018 State of Sustainability and Corporate Social Responsibility (CSR) in the MENA Region". The report examined eighteen MENA countries (including all the GCC countries) and sixteen sectors (Partner and Nbd, 2019). The main findings on the environment and climate change in the GCC are outlined below, with special attention paid to Oman.

The biggest challenges faced by organisations in MENA as they address the impact of climate change were found to be lack of awareness about climate–related risk (21%) and lack of climate change data specific to their organisations (19%). Across all MENA countries, the same factors lay behind the main challenges in implementing environmental strategies: a lack of awareness and a lack of relevant data applicable to the specific organisation. For the majority of the MENA countries, the budget is seen as a secondary issue.

Omani companies were more focused on CSR strategies (85%) than on environmental strategies (20%). The main environmental strategy challenges they saw themselves facing were lack of relevant climate change data specific to their organisations (27%), weak regulatory incentives (23%), lack of awareness of climate-related risks (23%), difficulties in integrating sustainability throughout the value chain (18%) and limited budgets (9%).

[13]Cyclone Gonu was a powerful Category 5 storm, according to the Joint Typhoon Warning Centre, which hit Oman in June 2007 and caused 50 deaths and about $4.2 billion in damage (2007 USD). It is the strongest storm to hit the Arabian Peninsula since record-keeping began more than 60 years ago.

In the organisations that do have an environmental and a holistic sustainability practice in place, the focus varied. In the construction and industrial sectors, the majority of actions are aimed at managing energy usage and GHG emissions in their operations, while Utilities, Retail and Service organisations are more focused on engaging their customers in environmentally beneficial practices and Personal Household Goods and Food & Beverage organisations invest more than others in managing energy use and GHG emissions in their supply chains. Oil & Gas and Chemical organisations invest most in renewable energy, while Chemical and Transport/Logistic organisations are focused on setting science-based targets for energy use and GHG emissions which they can monitor.

Oman ranks second after the UAE in terms of the percentage of organisations producing an annual sustainability report, with 49% of organizations in Oman reporting annually on sustainability, but 14% having no strategy at all.

This could lead to the following conclusion: Most organizations are led by the desire to progress and to create a more stimulating and attractive business environment than that of other organizations in the same field of interest; this is linked to a desire to meet the international criteria for global competition. However, the organizations admit that they could do better in the field of the environment and climate change if the government vision were clearer, if there were more awareness and if relevant data were available. They also believe that finance is not the reason that the government does not spend money on environment regulations, awareness and collection of information; rather, the problem arises from the government's lack of conviction about the need for environmental action, and the fact that it does not see the environment as a high priority issue.

3.5 Adequacy of environmental current policy in Oman:

For this thesis, a number of semi-structured interviews were conducted with people from different levels involved in the development and/or implementation of policy; these included policy- and decision-makers, members of the manufacturing and renewable energy industries, members of the oil and gas industry (both upstream and downstream), as well as parliamentarians and members of the media and the judiciary. This section will discuss and analyse these interviews in order to assess the adequacy of current environmental policies. Semi-structured interviews strike a balance between a structured interview and unstructured interview. In the semi-structured interviews, the questions are open ended thus not limiting the respondent's/interviewees choice of answers (Gubrium and Holstein, 2002, McCracken, 1988). The purpose is to provide a setting/atmosphere where the interviewer and interviewee can discuss the topic in detail. The interviewer therefore can make use of cues and prompts to help and direct the interviewee into the research topic area thus being able to gather more in depth or detailed data set (Creswell, 2003, McCracken, 1988, Patton, 2002). The interpretive approach used in the interviews is a paradigm based on the assumption that social reality is not singular or objective, but is rather shaped by human experiences and social contexts (ontology). It is therefore best studied within its socio-historic context and by reconciling the subjective interpretations of its various participants (epistemology). Because interpretive researchers view social reality as being embedded within and impossible to abstract from their social settings, they "interpret" reality though a "sense-making" process rather than through a hypothesis-testing process (Yanow D., 2000). The interpretive approach was judged to be the most suitable one for this thesis. As Yanow (2000) explains, "An interpretive approach to policy analysis is one that focuses on the meanings of policy, on the values, feelings, or beliefs they express, and on the processes by which those meanings are communicated to and 'read' by various audiences."

3.5.1 Aim of the Interviews:

The implementation of policies in Oman is the main way by which air pollution and climate change are controlled. The policy part of this research seeks to develop a comprehensive overview of the policies in Oman which impact on the emission of GHGs and air pollutants in order to determine the impact of policies on environment quality. Relevant policies include climate policies, air pollution policies, land planning policies and transport regulations. By evaluating the successes and failures of existing policies, the research will attempt to identify areas for future improvement.

One aim of the interviews is to get an overview of the policies, regulations, legislation and guidelines that govern areas related to environmental impact, and specifically those which are relevant to GHG and air pollutant emissions in Oman. Another aim was to analyse the policy-making processes in Oman and describe the way that environment policies are developed, implemented and enforced. The chapter will also investigate different views on the drawbacks of implementing the policies, and will assess the policies' effectiveness. The focus will be on Oman, but it is also studied as representative of the GCC countries in general.

The general subject of the interviews was "Policies of air pollution and climate in Oman", with a number of specific topics being addressed, namely:

- The current legislation covering air pollution and climate change (GHG emissions).
- Processes of air pollution and climate change policy-making.

- Implementation, enforcement and evaluation of policies.
- What the 2040 Vision means for environment policies and the renewable energy sector.

3.5.2 Method used to understand adequacy of environmental policy in Oman:

The research drew upon a mix of primary and secondary data sources which included government documents, legislation and statistics, which were detailed in the previous sections of this chapter. Another key source of information came from the semi-structured interviews with key stakeholders.

1. Before conducting the interviews, a summary of the policies governing air pollution and climate in Oman was developed, along with any case studies or stories related to those policies, and an outline of the general path for the implementation of the regulations.
2. The approach used is the semi-structured interview with an interpretive analysis. This was organised around a set of pre-determined open-ended questions, with other questions emerging from the dialogue with interviewees. The interviews were scheduled in advance at a designated time and location; each lasted between 30 minutes and an hour. Appendix E3.
3. A triangulated interview approach was carried out through interviewing a range of people who are involved in the policy-developing process, but who had different levels of interest and approaches. These people included:

- ✓ Policy makers
- ✓ Decision makers
- ✓ Environmentalists
- ✓ Business professionals
- ✓ Industries
- ✓ NGO
- ✓ Media
- ✓ Judiciary

According to the LEAP-IBC emission inventory analysis outlined in Chapter 2, the sectors contributing most to $PM_{2.5}$ emission and ambient concentrations in Oman are:

- Electricity generation,
- Oil and gas,
- Manufacturing industry and,
- Transport

Table 3-11 below details the different categories of participants, along with their titles and the organization each one represents. Twenty interviews were conducted and analysed. Two of them were with ministers, and five with Under Secretaries. Others interviewed were people from the Public Prosecution Office, along with representatives from the transport sector and a representative of the Parliament (the Shura Council). Industry was represented by six interviewees, four from the oil and gas sector, one from the renewable energy sector and another from the Chamber of Commerce and Industry. There are also interviewees from the media, one from a non-governmental organization and one environmentalist. The interviewees were chosen based on the categories from which information was needed: decision-makers, policy-makers, NGOs, industry, the media, and the judiciary, and all participated in semi-structured interviews.

Each interviewee answered the questions listed in Appendix E3; the answers provided the study with the information needed, according to the category each interviewee represented.

Table 3-11: Interviewees based on sectors contributing to $PM_{2.5}$ emission in Oman for 2010

Sectors / interviewees	Energy sector	Road Transport + Shipping + Aviation	Industry sector
Decision Makers	MOG	MOTC (Road), MOTC (Marine) PACA (Aviation), ROP (Vehicles)	MOCI
Industry	PDO ORPIC	-	OCCI
Renewable Energy Industry	Continental Shelf of Solar Technology,		
NGO	Environment Society of Oman		
Media	Al Roya		
Court	Public Prosecution Office		
Policy Makers	Ministry of Environment (MECA), Supreme Council for Planning (SCP) Parliament (Shura Council)		

Abbreviations: MOG: Ministry of Oil and Gas**, MOCI:** Ministry of Commerce and Industry, **ROP**: Royal Oman Police, **PACA:** Public Authority for Civil Aviation, **ORPIC**: Oil Refineries and Petroleum Industries Company, **MOTC:** Ministry of Transport and Communication, **PDO:** Petroleum Development of Oman, **OCCI:** Oman Chamber of Commerce and Industry, **NGO**: Non-Governmental Organization.

3.6 Interview analysis:

The interviews conducted for this study were analysed around eight issues: current air pollution and climate policies, implementation and enforcement, revision and evaluation, stakeholder's involvement, Oman's vision, renewable energy, awareness, and areas of potential improvement.

Table 3-12 below lists the organisations and stakeholders interviewed, and gives the codes that will be used to identify the different interviewees.

Table 3-12 List of interviewees and their codes

	Organizations	Code used in the analysis
Policy Maker		
1	Ministry of Environment and Climate Affairs	MECA
2	Supreme Council for Planning	SCP
3	Shura Council - Health and Environment committee	Shura
Decision maker		
4	Ministry of Oil and Gas	MOG
5	Ministry of Commerce and Industry	MOCI
6	Ministry of Transport and communication - Transport	MOTC_road
7	Ministry of Transport and communication -Ports and Maritime Affairs	MOTC_marine
8	Public Authority for Civil Aviation	PACA_aviation
9	Royal Oman Police	ROP_vehicles
Industry		
10	Chamber of Commerce and Industry	OCCI
11	Petroleum Development Oman	Oil_producer
12	Oman Oil Refineries and Petroleum Industries Company - Operation	Oil_Processor_1
13	Oman Oil Refineries and Petroleum Industries Company - Environment Services	Oil_Processor_2
14	Oman Oil Refineries and Petroleum Industries Company - Government Relation	Oil_Processor_3
Renewable Energy		
15	Continental Shelf of Solar Tech	RE_industry
NGO		
16	Environment Society of Oman	NGO_1
17	Environmentalist	NGO_2
Judiciary		
18	Public Prosecution	Judiciary
Media		
19	Al Roya Press & Publishing House - Journalist	Media_1
20	Al Roya Press & Publishing House - Manager	Media_2

3.6.1 Air quality and climate current policy in Oman:

This section will analyse the feedback given by the interviewees on air quality and climate policy. It seems that all the environmental regulations concerning both air pollution and climate policy for the energy, transport and manufacturing industries are centralized under the Ministry of Environment and Climate Affairs (MECA). MECA is also responsible for leading the implementation of criteria and regulations laid out in international agreements which Oman has ratified. It must address their implementation at the national level and ensure that there is no conflict with any national regulations.

The Law on Conservation of the Environment and the Prevention of Pollution, Royal Decree RD 114/2001, covers the three sectors most relevant to this study: energy, transport and industry. During the interview *MECA* said that the ministry is developing both a strategic plan to prevent the impacts of climate change, and also, in cooperation with Sultan Qaboos University (SQU), an "Initial National Communication under The United Nations Framework Convention on Climate Change". However, to the best of the author's knowledge these documents have not been approved at the time of writing (Malik Al-Wardy, Personal communication).

MECA said that the environmental law in Oman is one of the best laws in the region and is based on international standards and criteria. He said that the law focuses on sustainable development and that this is a priority for Oman. However, RD 114/2001 has been in the process of being updated for more than three years now and, based on the updated information, is in the cabinet (the council of ministers) at the time of writing.

SCP said he is not aware of the policy, but is sure that when they come across any environmental Issues within the "5-year Plan" or "Strategic Plan", they will take care of them. He is confident that any environmental aspects in the strategic plan will be addressed.

The main feedback on this context came from *MECA*, which can be considered both as a policy maker and a decision maker. He said "every project in Oman has to go through an environment license application, in which there are different requirements for different businesses based on whether they are small, medium or large enterprises, and according to how far they may affect the environment. All of these projects should comply with the environment law of Oman 114/2001". *OCCI* made an identical statement, noting that every industrial or commercial project has to get permission from MECA before starting any process. Additionally, all projects must be carried out within the designated industrial areas in Oman, and not in any other places. He also noted that there are particularly strict regulations for crushers, and that these are also monitored by MECA.

MOG, MOCI, MOTC_road and MOTC_marine all agreed that MECA manages and oversees policy RD 114/2001, and that all entities have to follow that policy by law; none of them specified the name and number of any Royal Decree or any Ministerial Decision that took precedence over it. This suggests that most of the decision-makers are not aware of the details of the environmental law. Some of them mentioned MECA's strictness about how they complied with the limits. For example, *MOTC_marine* complained about the strength of MECA's guidelines for the environment and the fact that MECA participates even in the meetings of the maritime organization in order to ensure that their voice is heard on environmental issues. That means that MECA does actively participate in relevant meetings to ensure that its laws are complied with.

PACA seems to have their own regulations as they come under the umbrella of the International Civil Aviation Organization (ICAO) and have undertaken their own initiative by volunteering in the Global Market-Based Measure scheme which aims to minimize the environmental footprint of the aviation industry by 2021. In the road transport sector, *ROP* has its own specifications and regulations which different vehicles must comply with; these are in line with MECA's laws. Limits for emissions are agreed between MECA and entities such as the Ministry of Commerce and Industry (MOCI), the Royal Oman Police (ROP) and the Ministry of Transport and Communications (MOTC).

However, the vehicle policy in Oman does not specify which body is responsible for regulating air pollution from road transport. The import of motor vehicles into Oman falls under the GCC Conformity Certificate scheme which is run by the GCC Standardization Organization (GSO) which started in 2005 and followed the decision of the Ministerial Council of the GSO to have a common GCC Conformity Certificate based on the relevant Gulf Standards for new motor vehicles. The Emirates has since established its own vehicle regulations and has upgraded its gasoline and diesel quality to EURO 4 criteria in order to accomplish its targets and make cleaner fuel a priority. Oman, however, continues to follow the older regulations.

The Oil_producer said: "The oil and gas sector of Oman, such as Petroleum Development of Oman (PDO), are exploration and production companies which have their own specifications and regulations. These are generated from national regulations issued by MECA but based on ministerial decisions and Royal Decrees. When anything is not covered by those regulations, PDO then uses the best practice and international standards, such as the Shell Company standards, to meet all environmental requirements". This indicates that gaps do exist in the policy for the oil and gas sector, and that these need to be addressed, since company standards (Shell) should not be applied without being evaluated and adapted by the government for national-level use, and only then enforced.

Oil_processor_2 was extremely insistent that there is only one law that covers the activities of Oil Refineries and Petroleum Industries Company (ORPIC), and that this was RD 114/2001.

It is worth noting here that the *Oil_producer* is from a government-private share company, whereas *Oil_processor* is in a wholly governmental sector, where the laws are likely to be more rigorously applied. That is because many of the activities undertaken by companies are not covered by existing laws, so that companies introduce their own specifications for these areas.

There was unexpected feedback from *NGO_1*, who said "I am sure the policies which cover air pollution and climate change are available but I don't know them", while *Env_act* said "there is a piece of legislation whereby it is obligatory for all government and non-government entities to report whatever chemical products they have and whatever gases they produce". This shows how the only NGO concerned with the environment of Oman is perhaps not taking air pollution and climate change issues as seriously as it could.

Judiciary explained that for air pollution issues they follow article 7 of RD 114/2001 which states that: "It is not allowed to use Oman's environment for the disposal of environmental pollutants in such quantities and types that may adversely affect its intactness and its natural resources or nature conservation areas and the historical and cultural heritage of the Sultanate. No pollutants shall be disposed of in the natural ecosystems unless in accordance with the regulations and conditions issued by a decision from the Minister." They also base judgments on article 11 of the same law, which states the following: "No owner shall, by omission or commission, increase the level of environmental pollution in ecosystems or in nature conservation areas, above the pollution standards and discharge specifications to be specified by a decision from the Minister."

However, legal records show that no cases related to air pollution or problems caused by air pollution came to court in 2010 or in the next three years. This could be seen as an indication that there are no problems with air quality and that industries are complying fully with the rules, but it could equally signal a lack of transparency or awareness, or a weakness in enforcement of the law.

3.6.2 Implementation and enforcement of policies (practices):

This part of the analysis will discuss the views and ideas of the interviewees on how well policy is implemented. As decision makers, *MOG, MOCI, MOTC_road, MOTC_marine, PACA,* and *ROP* agreed that policies are never completely implemented, with implementation always being dependent on the availability of human and financial resources. *MOTC_marine* raised the issue of penalties, noting that they are not high enough to prevent either individuals or companies from violating the limits set. When *MOG* talked about priorities in Oman, he said that the environment is considered secondary to the provision of clean water and electricity. However, *PACA* and *ROP* believed that the policies which cover their sectors are sufficiently implemented.

OCCI expressed a somewhat different view, arguing that legislation is too strict, and means that industries have no space to improve and compete. He said: "MECA is highly strict in their policy and the pressure of these policies on manufacturers is a big issue to them, an obstacle to their development." O*il_producer,* while agreeing that MECA has become stricter in the development and enforcement of regulations and policy, explains this as part of a world trend. 'We are committed to the Paris climate agreement", he said," so laws are stricter not only on emissions but on all environmental issues".

Although NGO_1 is not aware of all environmental regulations, they do see a degree of improvement in the enforcement of policy. *Env_act,* however, talked about the need for more awareness, more trained people, and more judiciary support so that policy could be properly implemented, implying that the laws are not sufficiently enforced. This same issue was raised by *Judiciary* when he said there are no judges specialised in environmental cases; in his view special environmental investigators are needed, as well as a department within the public prosecutor's department specifically concerned with the environment. In addition, judicial control officers need to be further educated on how to deal with cases related to air pollution and climate.

The policy maker, *MECA,* said "policies must be implemented sufficiently, otherwise the environment in Oman will be negatively affected; but if that happens then the law will penalize the violation, and all types of violation and penalties are stated clearly in the law."

It can be concluded here that perspectives on the implementation of environmental policy are widely varied, sometimes based on the interests of the interviewee. Where some people think that it is never possible to have 100% implementation, others believe that environmental policy is already being fully implemented. In general, though, it is clear that there is room for a good deal of improvement in policy enforcement, with references to the need for greater human and financial resources, awareness and capacity-building, and, above all, the need to question whether the environment is being adequately prioritised as a key issue in overall policy in Oman.

MOCI described the penalties for not complying with the law as not very harsh, but felt that this would be overcome with the updating of regulations. It is worth mentioning here that, to the best of the author's knowledge, the revised version of the environment law, known as RD 114/2001, is in the minister's cabinet and awaiting approval at the time of writing. *MOTC_marine* thinks we need more enforcement of policy. He also noted the lack of regulation of air pollution specifically for the maritime sector, but believed that as soon as a law was passed, it would definitely be implemented. He said that they are currently working with MECA to develop regulations that would lower the acceptable level of emissions and would also regulate a number of practices such as switching off the engine while stopping in a port. *MOTC road* said MECA deals directly with the companies engaged in all road projects, and addresses all environment-related issues, and that therefore he has never come across any cases of the law on environmental issues being broken. *PACA* said that they had never received any air pollution complaints about aviation, and attributes this to the fact that environmental policies are adequately enforced. He gave the example that "Oman recently implemented a regulation that banned the landing of older planes in Muscat airport for environmental reasons" and added that this regulation was being very strictly enforced. However, in my opinion, compliance is not measured by a lack of notification of pollution incidents, and it is also likely that no pollution cases have been brought to court because of the high value placed on tolerance in Omani culture. *ROP* said "the environmental policies in Oman are adequately implemented and enforced", and noted that vehicles that do not pass the compulsory pollution test will not have their annual licences renewed. However, the technical inspection that includes emission checks is only compulsory for vehicles that are more than 10 years old. *ROP* added that they also have inspectors on the roads "who stop cars which are emitting visible pollutants. "

A number of interviewees expressed the opinion that emissions and air quality were not a major problem in Oman. While *SCP* admitted to not being aware of the effectiveness of the law to keep Oman's air quality within acceptable limits, he did feel that, "In general Oman has been very careful when it comes to air pollution as we feel that the city of Muscat does not yet have a level of pollution that we need to worry about." He therefore believes pollution is within acceptable limits. It seems that these issues have never been raised at the level of national policy-making, even by MECA. *ROP* similarly believes that the emission regulation for vehicles is strict and prevents pollution, although he did point out that ”Muscat and other Omani cities are not compact like London, Paris or Cairo”, a factor which would make pollution less visible. His opinion, however, is based on visual observation only; he is not taking vehicle technology into account, nor is he aware that adopting a higher EURO level would result in a cleaner environment.

In the opinion of *shura,* Omani environmental law is among the best in the GCC region and covers most environmental issues. However, for the researcher, this comparison does not make for a very strong argument, as the GCC countries are similar to Oman in terms of their limited environmental progress, and do not provide a high standard of comparison. One criticism made by *shura* was that “the penalties do not adequately reflect the seriousness of the violations.“

MOG thinks that we have to be realistic and accept that zero pollution, while ideal, is an impossible goal; at the same time, he believes that Oman should choose to reduce pollution as much as is possible. He praised Oman’s following of the EURO criteria in its fuel system as very positive, because, as he said, ‘they (the EU countries) look at the industry, they look at the technology, and they come to a conclusion that today we can reduce the SO_x ppm from 10 to 5 for example”. While his opinion is valid, the researcher feels that Oman, which has adopted EURO III criteria, could do more to reduce pollution by adopting more stringent EURO criteria. It is worth noting that Oman Oil Refineries and Petroleum Industries Company (ORPIC), when asked why they were not producing a higher quality of gasoline and diesel, like that required in EU countries, commented that the Ministry of Oil and Gas (MOG) were the ones responsible for giving directives about fuel quality, but that they had not done so in this case. (Personal communication, 2018)

There are different opinions about how strictly the laws are enforced. *MECA* claimed that enforcement is very strict, with specific penalties even for supplying wrong information. “Exceeding the emission limits would definitely be penalised, with different penalties based on the type of violation, all of which are stated in the law”. However, *shura* believes that a degree of flexibility is sometimes applied, compliance being more rigorously enforced at some times than at others, but he said the executive authorities, the judiciary and MECA, are the two entities concerned with enforcement. *Env_act,* however, does not agree with *MECA*, stating unequivocally that, “environmental policies are not enforced adequately.”

The views above confirm, as has been noted earlier, that each interviewee has his/her opinion based on his/her career and experiences, with *MECA*, for example, both being the body which rules on the implementation of RD 114/2001 and also believing that the law is being fully enforced. Although many of the interviewees do agree that there are some weaknesses in the law, such as the inadequacy of penalties imposed, they also believe that steps can be taken to overcome these in the near future. The only interviewee who feels strongly that environmental law enforcement in Oman is inadequate, is *Env_act*. The researcher finds this opinion more realistic than the others expressed, since *Env_act* has a wider knowledge and more balanced view of the situation, being a former employee of both the Ministry of Environmental and Climate Affairs (MECA) and of the Environment Society of Oman (ESO).

Media_2 has been a reporter for eight years, but has never come across cases where any punishment was imposed on a company or a factory as a result of their air pollution emissions. However, in the last eight years the media has published a number of reports or even feature articles[14] about complaints from the public concerning pollution-related issues, such as the increase of SO_2, the level of chest infections, the spots left on walls outside buildings, and the smell of smoke from the illegal burning of garbage. He added that within the last two years there had been no media perception of air pollution as a crisis, or even as a problem significant enough to be covered in a feature or major report or interview; the only reference to major environmental problems in Oman would be limited to a columnist's remark in their column. The number of even low-visibility reports on pollution issues is very limited, and would usually come from a location outside Muscat, such as Sohar.

Media_1 said the regulations about the hunting of endangered animals are clear, strict and rigorously enforced, and that many organizations and bodies in Oman take this issue very seriously and follow any cases. Many cases are brought to court, with penalties being implemented rigorously. The media publishes a large number of articles on this topic, with His Majesty's concern for endangered animals also resulting in a high degree of public interest in them. She also mentioned that in environment-related cases there often was an overlapping of responsibility between different entities such as MECA, MOCI, the Office for Conservation of the Environment within the Diwan of the Royal Court,-and several others, with the number of bodies involved dependent on the specific case. This meant that it was difficult for journalists to cover these, unless the bodies concerned collaborated with each other and with the media. Journalists also, she explained, had to

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[14]A feature in journalism refers to a special investigation conducted by a journalist who then writes an article focusing very directly, and sometimes dramatically, on the issue or event. For example, they may investigate a specific complaint people made and do interviews to get various views on the issue.

adhere to the Publications and Publishing Law. Her views were consistent with those expressed by *Judiciary.* The statistical data show that eleven environmental cases passed through the courts in 2015, with numbers decreasing to four in 2016 and only one in 2017. Interestingly, all the cases involved endangered species and nature reserves; not one involved air pollution.

Judiciary talked about the process by which any cases of air pollution violation would be brought to court. Several steps are involved; the first would be receiving an official report from MECA judicial control officers with a description of the case and photos of the location. The judiciary would then call the offender and ask for an explanation, with the case then being referred to the public prosecution (the Attorney General) for a decision. A number of criteria must be met before the judiciary will accept a case; for example, the technical report must be signed by a qualified person, and any records involved must come from calibrated measuring stations. Where the case involves an environmental issue, an environmental expert would also be consulted before any decision to prosecute is taken.

Points made by the media and judiciary representatives can be clearly summarised:

1. There has been no media coverage of cases involving air pollution. The reasons for this include lack of media interest in the subject, the overlap of different entities involved in a case, and the difficulties of getting people to work with/talk to the media. OR the manipulative reputation of the press.
2. Most of the environment-related stories in the press are about endangered species. One reason is that wildlife conservation comes under a very active and powerful government organization which frequently contacts the media with potential stories. Pollution-related issues are not brought to the media's attention in the same way.
3. One gap in the enforcement of climate-change-related law could arise from a lack of awareness of the different steps that must be followed in attempting to bring a case of non-compliance to court.

3.6.3 Revision and evaluation of policies:

Revision of policy as discussed here is the process of carefully reading a policy and ensuring that it takes into account any changes happening either nationally, regionally, or internationally. The policy must then be adapted and edited, in consultation with specialists in economics, politics, the environment or any other relevant field. Ongoing revision of policy is essential, therefore, to ensure that policies best reflect and fit the current situation.

Policies must always be subject to a period of evaluation during which practices must be explored and stories collected in order to inform the process of revision. This evaluation period is an important tool which allows issues to be raised before an evaluative decision is taken. Evaluators must basically decide whether a law is effective and best kept as it is, whether it is too strict or too lenient, or whether there are gaps in its coverage which need to be filled.

All the decision-makers, *MOG, MOCI, MOTC_marine, MOTC_road, PACA,* and *ROP,* agreed that there had been periodic revision of policies, but *MOG* claiming that the revision of the environmental law had not brought a great deal of improvement. He expressed his desire for Oman to reach the same level of technology as that used, for example, in preparing IPhone and EURO specifications; if this were done Oman could be more competitive in the global market. He expressed" the hope that there are people who are working hard to come up with a new version of environmental limits", implying that Oman's environmental laws are outdated and prevent its oil and gas company from competing globally. Without specifying how often new versions of products, laws and criteria were needed, he noted that those from top companies and bodies were presented periodically, were always an improvement, and tended to involve stricter criteria.

It is clear that the decision-makers do not agree on how often policies should be revised. The main responses varied: when there is a need for it, every two years, or whenever international regulations are updated. In the researcher's opinion, revision of the environmental law and its regulations should take account of a number of specific factors, and should be based on evaluation of how far its targets had been reached and how effective it had been. It should also be responding to the findings of ongoing new national-level research studies, to any new issues that had arisen nationally, and to all its global commitments. There should thus be a continuous and cyclical process of revision, implementation and assessment.

NGO_1 had no knowledge of how frequently the policy is revised, while *Env_act* noted that policies are usually revised in order to meet new challenges. This meant that revision should not be seen as an improvement when, for example, it lowered the environmental criteria for the ostensible benefit of the economy.

Shura was convinced that no specific time period had been set for review of environmental policies, noting that the last revision document, RD 114/2001, was published over fifteen years ago but its implementation was only started in 2016, a delay which he saw as an indication that policy is revised only when there is a need for it. He explained that all legislation was revised and evaluated by the members and committee members of the Shura Council, and would be voted on for approval. He said that law RD 114/2001 had been reviewed by members of the committee, who had discovered the problem that the penalties set for violations do not act as a viable deterrent.

SCP was also not aware of there being any specific period set for revision, but pointed out that it is usual for environment policy, whether an overall policy or one geared to specific sectors, to take a long time to develop.

MECS saw the work on the main guidelines and regulations as the main change and improvement occurring in the last few years. He cited RD 114/2001, the Law on Conservation of the Environment and Prevention of Pollution, and the fact that its revision had started in 2017 and was still being worked on. Another improvement was the fact that monitoring devices are now located all over Oman, and have been placed to cover the main industrial regions. *MECA* added that "Oman also now has a strategy for prevention of the impact of climate change that is based on the Paris Agreement, and is also committed to the Kyoto Protocol ". The researcher, however, wishes to point out that although at the time of the interview (2017) this strategy was said to be in its draft form and already in the minister's cabinet awaiting approval, she had not been granted access to it, nor been given any information about it, until now.

SCP said that he remembers MECA having requested a budget for drafting an environmental policy for industrial areas. *Shura* believed that the environmental policy which had been reviewed by the council would be published in the near future. He saw this as the only probable change in the environmental policy of Oman, besides the guidelines and regulations included the policy, which he did not think would be significantly different from those existing now.

There was a variety of views about whether policy evaluation was taking place. *MOG* noted that such evaluation was the responsibility of MECA, and that although his ministry had given MECA their opinions on methods for measuring pollutants, limits allowed and other factors related to the oil and gas industry, he did not know if MECA was evaluating their policy at that point. *MOCI* believes that MECA is evaluating the policy, but did not say which evaluation tools were being used. He did, however, give some examples of how MECA could evaluate policy; these included conducting a government study to collect data on how frequently people are visiting hospitals, another study to assess the views and satisfaction levels of people living close to industries, as well as research into the manufacturers' feelings about the regulations. *MOTC_marine* and *PACA* both noted that their situation was different; since they are members of international organizations IMO and ICAO respectively, their policies and national bodies are evaluated by those organizations. *MOTC_road* agreed with *MOG* about it being MECA's job to evaluate environmental policy. They noted, however, that MECA had never asked for their comments or views regarding evaluation of any parts of the environmental policy, and added that while they had had some discussion and collaboration with different MECA committees, there had been no interaction with the policy committee. *ROP* talked about traffic policy, explaining that the ROP have their own evaluation specialist within the ROP, and are evaluating their own regulations with reference to international reports and standards.

NGO_1 did not know if the environmental policy was being evaluated or not, while *Env_act,* who noted that revision and evaluation are intertwined, believes that MECA and other entities would only issue a piece of legislation after a thorough investigation had been carried out.

MECA itself explained parts of the evaluation process, noting that five years ago in 2013 national and international experts had been consulted about a variety of environmental regulations. In response to their advice, "the waste management sector split away from MECA and is now Be'ah, which has developed its own separate piece of legislation. The same happened with the sewage sector, which is now Haya." More controversially, *MECA* also said that different entities share responsibility for implementing the environmental law, and that evaluation is based on their experience. This conflicts with other points of view expressed, which put all the evaluative responsibility onto MECA, but saw little evidence that the experiences and advice of other bodies were sought or taken into account.

Interviewees made a number of points about the strengths and weaknesses of Oman's environmental position. For *MOG,* the weak point of the oil and gas sector is flaring, so they as the ministry supervising the oil and gas operating companies, have adopted a zero flaring initiative and have made it compulsory for companies to present their plans for zero flaring for each particular system. *MOTC_marine* said there had been changes for the better in maritime regulations, and praised MECA for its efforts in this field. For example, MECA had spent millions of riyals on installing monitoring systems in different ports of Oman in order to control emissions. They had also insisted that any factory wanting to start business in a port should abide by strict requirements before being approved, and had trained staff and hired experts to ensure that emissions were kept under the acceptable limits. *MOTC_road* said there were no new regulations for road specification and classification, but that rules and regulations for traffic were revised and updated whenever necessary. *PACA* talked in general about the main changes in air pollution/climate-change-related legislation relevant to the aviation sector. The aims, he explained, were the "preparation and implementation of national programs which would include measures and actions to mitigate climate change by addressing emissions from greenhouse gases and other harmful factors, while taking into account the compatibility of such measures with the programs and sustainable development plans in Oman."

OCCI thinks that there is nothing new in the regulation, except that they are stricter than before. He gave an example of crushers having to be at least 3 km away from any community, and argued that this made it extremely difficult to find a suitable location.

NGO_1 and *Env_act* felt unable to comment specifically on the main changes in air pollution/climate change-related legislation, but *NGO_1* noted the possibility of a new or updated policy, while *Env_act* expressed the view that there is a great room for improvement in terms of building awareness and recognition of climate change. However, he did not believe that there was any consensus on this, even amongst policy-makers.

Shura noted that whenever there is rapid industrialization there is bound to be a lot of changes and impact, and also explained that Oman's geographical location[15] demands that it pay special attention to the environment. He thinks that Oman started well by establishing MECA a long time ago, when no one else in the region was paying attention to these issues, but felt it was unsatisfactory that Oman's environmental law, published 17 years ago, had never been revised. His overall view was that Oman needs to have "a balance between economy and environment, and also to be more organized". He praised parliament for uniting the health and environment committees into one committee under the parliament; for him, this had made the link between health and environment very clear to both members of parliament and the wider community.

It can be concluded here that although there has been revision and evaluation of the environmental law, there is no systematic procedure for this, and, except *Shura*, many of the people who should be part of it are not involved in it or even aware that it is taking place. Also important is the lack of consensus among policy-makers in recognising the dangers of climate change, although MECA and other entities are working on a strategy to prevent its impact.

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[15]This is a reference to Oman's location, which makes it prone to many hurricanes and at the same time subjected to the transfer of emissions from neighbouring countries. Also notable is the Khareef season, or the monsoons, which begin from mid-June and last till the beginning of September, with the rains making the mountains and countryside of the southern region green.

3.6.4 The Environmental policy development (Involvement of Stakeholders):

Stakeholder participation in the policy development process is widely advocated, but there is no structured, empirical research indicating that stakeholders have any involvement in or influence on environmental policy development in Oman.

Oil_Processor_2 said there is no proper communication between them and the Ministry of Environment and Climate Affairs (MECA), and pointed out that he could see no effective way that environmental policy in Oman could be structured and developed. Also, although they would like to be consulted on policy, at present they are merely adhering to regulations made without their input. They feel that they have much better interaction with the Ministry of Oil and Gas (MOG), where they have been consulted in many cases, than with MECA, where they merely implement policies but do not feel they have a voice in any decisions.

Not surprisingly, *SCP* is not part of the environmental policy-making process, but does believe it starts with oil and gas companies in coordination with MECA, a belief not supported by information from *Oil_Processor_2*.

MOCI was not aware of any changes in air pollution/climate change-related legislation relevant to the manufacturing and construction sector, but this is because this is not under his ministry.

OCCI expressed dissatisfaction with MECA in its relations with industry, saying that MECA had never consulted them about any of their regulation, although OCCI is a consultant party and works as the link between government and the private sector.

NGO_1 is not part of the process for developing environment policy in Oman and is therefore unaware of how the process works. This position also makes them feel unable to campaign for any change, but in any case, their main interest is in endangered animals and wildlife rather than in air pollution. Their role is simply to communicate their views and recommendations to MECA or the Ministry of Agriculture and Fisheries (MOAF) if they become aware of the need to address a particular issue; even here, they can only act if they having the evidence such as a scientific study. Their interest is only for nature in general such as endangered animals and wildlife but not air pollution in particular.

What is clear from all these communications is that MECA does not consult stakeholders or invite their comments on its draft policies; nor does it share the new policies once these are approved.

Oman, then, has placed a high priority on environmental issues and has established a range of institutions whose job is to set standards and norms, implement policies and enforce laws. Despite the prominence accorded to the environment, however, the interviews show that public participation in environmental governance remains weak, with no clear policy for integrating stakeholders into the environmental governance process. However, *Shura,* whose institution is central to the country's policy-making, has a complete picture of the policy development process and was able to present a logical system for developing environmental policy in Oman, as shown in figure (3-2).

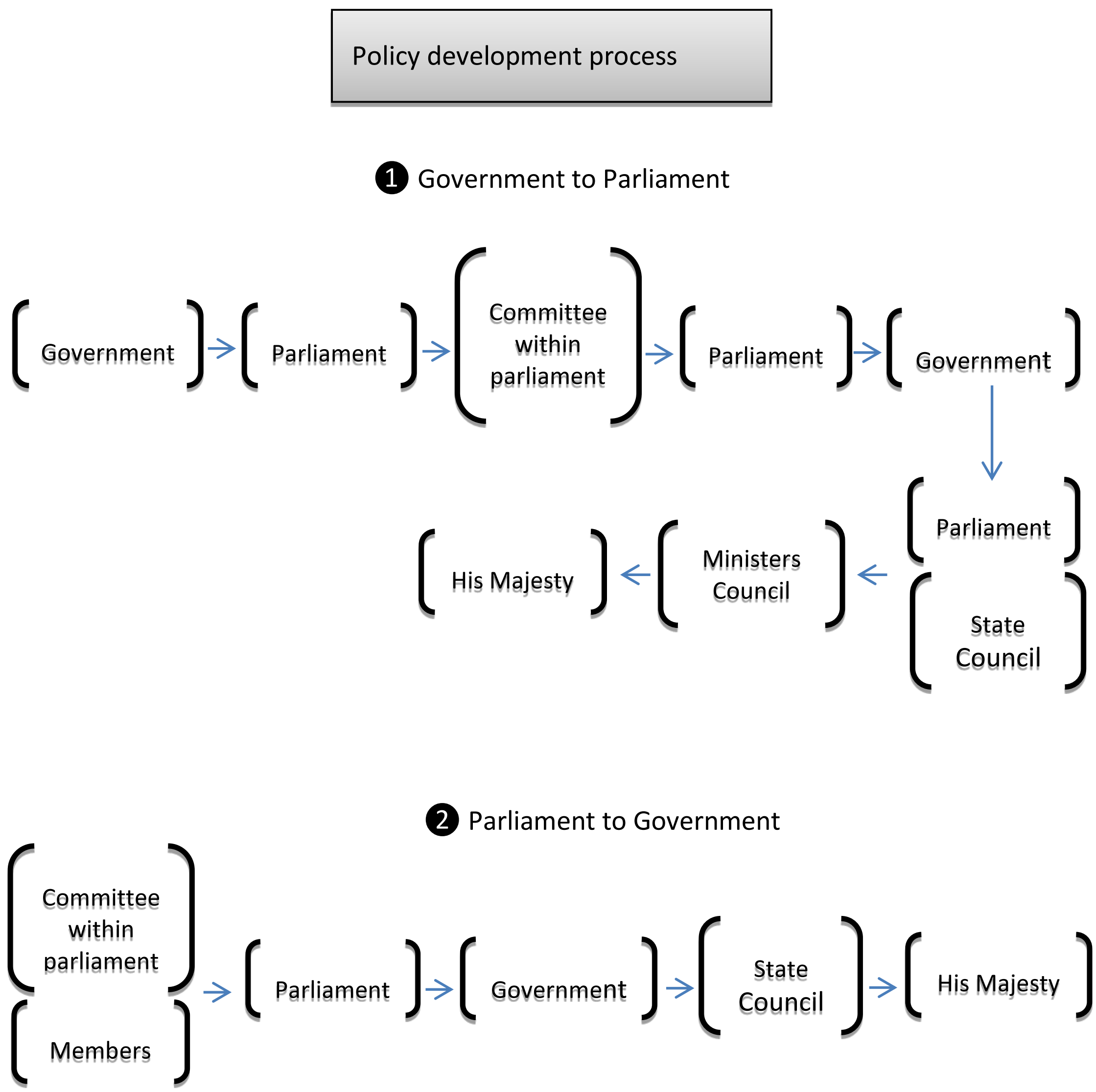

Figure 3-2: Policy development process in Oman

3.6.5 Future (vision) of Oman:

All the interviewees were asked for their vision of Oman in the future, with special reference to climate change and the environment. *MOG* believes that the oil and gas industry will still be in existence 20-30 years hence, although it will be producing more petrochemical products than gasoline and diesel. He said we will be using electric cars, but that these will be made of plastics and rubber which come from petrochemicals. He also predicted that gas will be widely used for generating the electricity needed to charge electric car batteries. He thinks that in 20-30 years we will be most concerned about the management of solid waste, waste that is dumped and is entering our ecosystem, and is more dangerous than air pollutants. *MOCI* thinks that the future will be better for the environment since new technology in industry will avoid pollution. People will be able to do many jobs from home through computers, which will reduce the use of transport, and many small business and enterprises may disappear and be replaced by online shopping. *MOTC_marine* believes the environment will benefit from an increase in people using public transport, which will all be electric. In the maritime sector, he hopes that ships will work on solar energy by that time. *MOTC_road also* has a very positive vision in terms of the environment, as his ministry plans to pave more roads and thus reduce air pollution, as well as using better technology for road paving and construction. They are also planning to create a large road network for public transport and raise awareness about the benefits of using it. *PACA* pointed out that ICAO predicts that the number of aircraft will at least double by that time, and that the number of tourists using aeroplanes for traveling will increase by 50%. Based on these expectations, ICAO plans to continue updating their regulations in order to remain in line with indicators for sustainable development. This is extremely important for Oman, especially because the aviation sector is one of the sectors that it hopes to rely on in the diversification of the economy. *ROP*'s wish for the future is to have trains that arrive on time, and more reliance on public transport to minimize the number of passenger cars. *OCCI* thinks Oman is already taking good care of the environment; industry's current share of the economy is 14%, but they expect this to rise in the future, along with a reduced dependence on oil and gas.

Most organisations, *MOG, MOCI, MOTC_marine, MOTC_road, PACA,* and *ROP*, had no idea about what laws were in the pipeline, but saw this as coming under MECA. *MOG* mentioned Oman's signing of the Paris Agreement and wondered whether it would become law; however, this was again seen as MECA's job. *MOCI* talked about renewable energy and how the government is pursuing this. They have already formed a team called "Tanfeeth"(mentioned earlier in section 3.3.2.10) to introduce and facilitate the licensing program intended to encourage this business; the team will also promote and set the regulations for the use of wind and solar as alternatives to oil and gas. *MOTC_marine* talked about their current collaboration with MECA to develop a policy that would provide better environmental regulations for the ports. He cited the promotion of the use of solar energy for producing electricity within the port, and a plan to make it compulsory for cranes to be electric instead of diesel-fuelled. *PACA* noted the environmental regulations for air transport were under the umbrella of the International Civil Aviation Organization (ICAO). *MOTC_road* explained that the law regarding transport has already been published, with the regulations explaining the law in the process of being published and expected to be available within six weeks. Indeed, and at the time of writing, these revised regulations have been published, but make no reference at all to air pollution.

Other interviewees shared their knowledge of possible laws in the pipeline, with *NGO_1* and *SCP* not being aware of any, and *Env_act merely* suspecting that there were. *OCCI* believes that the existing regulations are now in the process of being revised. He was the one voice expressing active dissatisfaction; he felt that any law currently being studied or revised by the government was sure to ask for more restrictions, when, as a representative of industry, he believed that the law was already imposing too much regulation on their activities. *MECA,* by contrast, focused on its environment-protecting plans, such as adding more monitoring devices to control air quality, and establishing an environment-monitoring section within the ministry, which would use cameras to monitor and control emissions. These surveillance cameras would use calibrated images that would work within a wide range of daylight illumination, and could capture air pollution conditions, including the concentration of particles mass ($PM_{2.5}$), weather, temperature, humidity, and wind, all of which are related to the air quality level. *MECA* also outlined their plans for Salalah, whereby they would move all crushers away from populated areas and reduce the emissions produced by waste disposal.

Most of the interviewees could be seen to have their own vision for Oman's environmental future, such as more electric vehicles, more paved roads, the development and greater use of public transport, electronic governance, the diversification of the economy, and the use of solar energy in the maritime sector. However, the representative of the energy sector in Oman seems to be disregarding the problem of air pollution, believing that it will not be a problem for Oman; he failed even to mention any plan to replace the use of oil and gas with renewables like wind and solar. It should be noted here that Royal Decree 40/2018, issued early in 2018, puts electricity under the Ministry of Oil and Gas (MOG) and transfers to them all the powers and prerogatives associated with the electricity sector that formerly belonged to the Public Authority for Electricity and Water (PAEW). This part of the interview did also ask about the penetration of renewable energy into an energy sector formerly dominated by oil and gas. This has in fact started to happen, and will be further discussed in the following section.

3.6.6 Renewable energy future in Oman:

RE_industry thinks the renewable energy business in Oman has been progressing faster this year (2017) than in the previous couple of years, and noted that a few months ago a new regulation was introduced to monitor the installation of solar panels in homes. In addition, the government had begun to grant licenses for companies in the solar panel installation business. He talked about how customers' needs and requirements had changed; in the past they had only wanted to light specific places when there was a power failure but now they wanted to install a general solar energy system for their homes. He also pointed out that Oman had one problem with solar panels which did not exist in most other countries, "the dust which accumulates on the panels with time and reduces their efficiency. They need cleaning more often than elsewhere, especially as Oman is a dry country and there is rarely rain to help clean them."

However, *RE_industry* explained that Oman was already making significant strides in renewable energy. One example was the Glass Point technology being used in the solar power facility Miraah, which is expected to be one of the world's largest solar power plants. Oman's first wind energy power plant project is also under construction in Salalah and, to the best of the author's knowledge at the time of writing, it had started operating in the second half of 2019.

MOG said "we are making small steps in renewable energy". He and *Oil_producer* both mentioned a potential renewable energy project in Duqm[16] which was being discussed with new companies. *RE_industry* explained more about the Miraa project, whose aim was "to produce around 6,000 tonnes of steam from solar." The steam produced will be injected to enhance oil recovery and will avoid "the CO_2 emitted from Oman's current use of conventional electricity to produce steam, an amount of about 300 tonnes".

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[16]The Duqm Special Economic Zone is a model of an integrated economic development composed of zones: a sea port, industrial area, new town, fishing harbor, tourist zone, a logistics center and an education and training zone, all of which are supported by a multimodal transport system that connects it with nearby regions such as the Arabian Gulf countries, the Middle East, East Africa and Southeast Asia.

It can be seen from this that the interviewees all feel that the government is making progress towards the 2040 Vision goal of having 38% of its energy from renewables, with a number of achievements cited by representatives of different entities. Another project is the Sahim initiative, launched in 2017 by the Oman Authority for Electricity Regulation, and using a UK firm's technology for a rooftop solar PV scheme which will provide up to 250,000 residential solar PV assets totalling 1 GW in capacity. The project includes all stages, from pre-installation through commissioning, operation, remote monitoring and maintenance. Also significant is the statement to the media made by the Undersecretary of the Ministry of Oil and Gas in June 2019, saying that the Sultanate has raised its 2030 target for renewable energy share from 10% to 30%. Public awareness of the advantages of renewable energy is also growing, and will be discussed in the following section.

3.6.7 Awareness:

Media_2 described their efforts to cover the air pollution story, but explained that it was difficult to communicate with companies and other stakeholders responsible for the issue, as they did not want to cooperate directly with media and tended to refer journalists to their statements or press releases. *Media_2* explained that from a journalist's point of view this would be seen as "as lack of transparency" but added that "we can't say that to companies otherwise they will see you and your newspaper in a bad light, which may affect their future cooperation."

The reporter also explained that for more than five years their newspaper had published a weekly page, entitled "A state and a case", that discussed the problems of the local people and their challenges in life, including the challenges of individuals and local companies in everyday interaction with government bodies." Issues of environmental pollution are covered in the column, including air pollution, but there are fewer cases of air pollution than of other types of environmental pollution, such as the polluting of the water of falajes and wadis."

Media_1 also described another initiative they had initiated to fulfil part of their responsibility to raise environmental awareness. This was the "Oman Environmental Forum", an annual symposium which covers a number of topics and brings together a wide variety of participants, including school and college students, regional and international experts, researchers, the private and government sectors, NGOs and environmentalists.

These interviews indicate that the media is not using the press to bring the real cases of air pollution in Oman to the attention of the public. There are several possible reasons for this: lack of transparency, lack of interest, and the bad reputation of the press. However, some members of the media have worked to raise awareness through organising an annual symposium where different levels of people with different levels of knowledge share and discuss environmental issues. The researcher herself had the opportunity to participate in one such event, the Oman Environmental Forum held in Muscat in April 2018. The overall theme was Citizenship and Environment, with environmental citizenship, environmental policy, environmental investment and environmental awareness as key topics. The UN was involved in the symposium, and the researcher was part of the panel discussing awareness.

3.6.8 Area of improvement:

A number of the interviewees made suggestions for improvements in Oman's handling of air pollution. *NGO_1* explained that air pollution, air quality legislation and health were not covered in their mandate, as they were a relatively small organization, with only seventeen staff, and are focused on the conservation of endangered species, with their research and advocacy concentrated on whales, dolphins, sea turtles, Egyptians vultures and frankincense trees. As the only environment-related NGO in Oman, what had suggested was the formation of other environmental NGOs who could target those areas.

Env_act raised the issue of policing the regulations, arguing that issuing even the best legislation will make no difference if it can't be implemented. Ensuring the implementation of the regulations was vital; without this, the problem would remain.

Judiciary suggested that there should be judges specialising in environmental cases, backed up by environmental investigators, and also a department under the public prosecution which is specifically concerned with the environment. Judicial control officers would also need training and capacity-building to enable them to deal with this area.

MOTC_marine pointed out that, although 80% of the freight transport around the world is by sea, little attention had been paid to reducing the air pollution created by ships. He noted that there had been far more progress with passenger vehicles, with increasing numbers of electric cars.

Env_act stated that major improvement is needed in building awareness and the recognition of climate change. However, he felt that there is no consensus on this, even amongst policy-makers.

NGO_1 pointed out that there is not enough coordination between ministries at present, and that better coordination would help to enforce and strengthen policy. *Env_act* addressed the same point, recommending the establishment of a central policy-making body to address environmental issues, as well as the need to pay attention to the concept of sustainable development, which he thinks has been ignored.

In short, the interviewees' overall perspective was that a lot could be done to overcome challenges regarding air pollution and climate policy, such as: the establishment of NGOs which focus on air pollution and climate change; the establishment of environmental policing, with environmental investigators and judges; capacity-building and the raising of awareness within the different organizations; the restructuring of organisations involved with environmental causes to overcome obstacles; and finally, the creation of dialogue within ministries and companies, and between all stakeholders, in order to develop a better understanding of air pollution and climate change issues and to find solutions for the challenges associated with them.

3.7 Discussion

3.7.1 Summary of the interviews:

In summary, the interviews indicated that the current legislation on air quality and climate change in Oman has the potential to cover all the pollutants which are studied here (CO_2, CH_4, NMVOC, SO_2, NO_x, CO, $PM_{2.5}$, BC, OC, and NH_3); it is also capable of covering the different sources of these pollutants, namely the power, oil and gas, transport and industry sectors. The regulations which cover GHGs and climate change seem to be better established and better defined than those dealing with air quality; this is not surprising, since the climate regulations are derived mostly from obligations to international treaties and agreements, while there are no such international obligations related to air quality. Although all the questions posed referred to air pollution and climate change policy combined, it is noticeable that the issue of air pollution drew most of the attention from the policy- and decision-makers interviewed, and their answers largely highlighted air pollution and made little reference to climate change.

The structure of MECA as an organisation reflects a different relationship in the relative importance of air quality and climate change. MECA has two Directorate Generals; one is dedicated to climate affairs while the second covers all other environmental issues, including air, water, soil, and marine pollution, as illustrated in Figure 3.2. As human resources are the main driver for the process of implementing, revising, evaluating and updating the regulations, the organizational structure explains why air quality issues are paid less attention than climate regulations. This can also be seen in the fact referred to earlier, wherein Oman's primary environmental law, (RD 114/2001), which governs all environmental issues including air pollution, was passed in 2001 but then not revised until 2017. At that point it was forwarded to the Shura council for review and comment, but at the time of writing, the law is still under revision.

Another key issue concerning both climate and air quality regulations is the lack of the stakeholders' voice or involvement in the environmental regulation development process. The stakeholders here are the industries, the bodies which actually carry out the implementation of the law, as well as NGOs, and others with an interest in the issues. Also lacking, more for climate regulations than for air quality, is national – level studies agreed by all involved, showing the impact of environmental damage on the country. Oman has no studies on climate change which support the decisions the country has taken to comply with obligations laid down in international climate policies.

Discussions of climate policy often focus exclusively on carbon dioxide (CO_2), but these emissions are only one of the ways in which human activities affect global climate. Methane and other forms of atmospheric pollution also play an important role. International agreements, national policies and corporate strategies addressing climate change all involve setting priorities for reducing emissions of different climate pollutants (Allen, 2015). In Chapter Two, Oman's largest emissions for the year 2010, after CO_2, were estimated to be methane (CH_4) followed by SO_2, NMVOCs, and NO_x respectively, and the main sources of those emissions were found to be the power sector, oil and gas, the manufacturing industries and transport. Apart from the transport sector, these sources seem to be well covered in the policy, MD 118/2004. Although the transport sector may appear to be covered under the traffic law, the inspection procedure this imposes does not specify any emission test. The transport sector contributes heavily to the CO, $PM_{2.5}$, NO_x, and BC emissions, and revising the inspection procedure is therefore important. Indeed, the traffic law fails to address the pollution emitted from vehicles, nor does it specify which organisation is responsible for controlling vehicle pollution. This could be done, for example, by the Directorate General for Standards and Metrology (DGSM) which is Oman's national standards body and is within the Ministry of Commerce and Industry (MOCI).

The Ministry of Environment and Climate Affairs (MECA) of Oman has responsibility for eleven air quality monitoring stations across the country; these are distributed to five governorates, as listed below:

- The governorate of Muscat: one in Al Qurum near Mina Al Fahal port and the other near the Rusayl industrial zone (two)
- Wilayat of Salalah near the Raysut industrial zone in the Dhofar governorate (one)

- Wilayat Sur near the Sur industrial zone in the governorate of South Al Sharqiya (one)
- Nizwa near the Nizwa industrial zone in Ad Dakhiliyah Governorate (one)

There are six more stations in Al Batinah North Governorate, distributed as follows:

- Sohar Industrial Port area (three)
- residential area near Sohar Industrial Port (two)
- Sohar the free zone (one)

These air quality monitoring stations measure seven kinds of pollutants, namely: carbon monoxide (CO), ozone (O_3), sulphur dioxide (SO_2), hydrogen sulphide (H_2S), nitrogen dioxide (NO_2), non-methane hydrocarbons (NMHCs), and suspended particulates (PM_{10}) but not ($PM_{2.5}$). There are also a number of monitoring stations belonging to factories and private companies operating in the Sultanate. However, several issues regarding the monitoring stations need to be resolved. First, the absence of regular maintenance and follow-up of these stations may result in unreliable air quality data. Second, there are no monitoring stations in residential areas, so the safety of air quality for residents is not assessed. Third, the air pollution monitoring data is not publicly available, which means that there is no information for those doing academic studies and or seeking to make policy recommendations.

Levels of awareness regrading air pollution and climate change varied greatly between those interviewed, with only *MECA* and *Env_act* showing any interest in or knowledge of the impact of either issue. Indeed, there is little awareness about environmental issues in the country at large, and air pollution and climate change are no exceptions. Among those actually involved in the policy making process, levels still varied significantly. The Environment Society of Oman (ESO), the only NGO in the country responsible for public awareness of environmental issues, focuses only on the protection and conservation of Oman's natural heritage, as mentioned in section 3.2.1, and so is not involved in such issues as air pollution, climate change, energy efficiency, renewables, and the like. An investigation into levels of awareness about renewable energy in Omani government's power sector found that ministries and regulatory bodies in Oman primarily supported the increased exploitation of fossil fuels, a key reason for the slow adoption of renewable energy sources (Hatmi *et al.*, 2014). A public opinion survey carried out in 2017 by the Arab Forum for Environment and Development (AFED) in twenty-two Arab countries, including those in the GCC, revealed that one of the most important environmental challenges in the region is weak environmental awareness, a finding in line with survey results from ten years earlier (Saab, 2017). In the 2018 Environment Performance Index

(EPI), Oman ranked 179 out of 180 countries in the air pollution category, and its scores had dropped from 60.13 in the 2016 EPI report to 51.32 only two years later. Abdul-Wahab (2008) linked the progressive deterioration of air quality in Oman with lack of both awareness and proper regulations, both common in developing countries.

Although climate change might well be held responsible for the natural disasters recently experienced by Oman, such as the cyclones Guno (June 2007), Phet (June 2010), Nanauk (June 2014), Ashoba (June 2015), Chapala (October 2015), Mekunu (May 2018), and recently Vayu (June 2019), the coverage of these by the media was limited to the efforts to minimize the losses, with no linkage made to climate change. However, after Cyclone[17].Mekunu in 2018, the statement from the minister's office suggested the impact of climate change as a cause; this can be considered as an important step forward in awareness at the policy-making level.

The sectors identified in Chapter Two as the major sources of Oman's emissions are discussed in the following sections, from a policy point of view.

3.7.1 Power sector:

Although Oman currently depends entirely on oil and gas for its energy requirements, the main contributor to CO_2 emissions from Oman is not this, but the power sector, as noted in Chapter Two. Oil output is declining and industry sources speculate that natural gas supplies may be over-committed. This is beginning to result in an awareness of the need for a more diversified energy mix with a more secure supply, if the country's economic growth and environmental objectives are to be met. The other options, based on availability and economic security, are solar and wind power. Solar energy density in Oman is amongst the highest in the world, and there is significant wind energy potential in coastal areas of south Oman and in the mountains north of Salalah. There is little potential in Oman for development of the other renewable sources, biogas, geothermal energy and wave energy technologies (PAEW, 2016). A report by the Authority for Electricity Regulation (AER) notes that existing Oman legislation lacks statutory mechanisms specifically designed to accommodate renewable energy or to facilitate its introduction on a wide scale. For example, there are currently limits on the supply and sale of surplus production of electricity. Potential new entrants are keen that market rules be amended to allow distribution and supply companies to connect renewable energy projects to their systems. However, a number of positive steps have been taken

[17]https://www.omandaily.om/?p=597473

since 2010, and there are signs that the government does want to make progress in this area, recognising the positive impact it would have on both the environment and the economy. For example, the Oman 2040 vision sets a percentage share of the country's power generation for renewable energy, and the Undersecretary of the Ministry of Oil and Gas declared in the media that they were increasing the 10 % percentage share planned for 2030 to 30%. However, still more could be done in this area by improving policy, and by encouraging residents and businesses to adopt renewable energy. The hot and arid/semi-arid climate of Oman and the other GCC countries, as well as the lack of rainfall, also facilitate the production and transport of aerosols which considered as challenges to the use of solar energy. For example, frequent sandstorms during May–October result in natural pollution, and dust storms could also influence the performance of alternative energy sources (solar panels); a number of studies have recently explored how this issue affects the GCC countries (Said and Walwil, 2014; Kazem *et al.*, 2015; Menoufi, 2017). One found that 48% of the accumulated dust in Asian countries was deposited naturally on solar panels (Omidvarborna et al., 2018). Research and innovation in this area clearly need to be supported, along with the development of new projects which will overcome the main challenges to renewable energy in the region, such as dust. If this can be achieved, it will increase the efficiency of renewable energy, reduce the expenses involved and result in a much wider adoption of renewable energy.

Oman has already made it clear that it is preparing to adopt renewable energy technology, and has announced the development of the solar industry as an energy target. In December 2017, The Oman Power and Water Procurement Company (OPWP) announced a tender for a 500 MW solar PV project to be located at Ibri. This is the first in a series of renewable energy (RE) IPP tenders that are planned as part of the effort to meet the Government's target of a 10% RE share of electricity generation by 2025 (OPWO, 2017). The 2040 target is to have renewable energy contributing 35-39% to electricity generation; the other major contributors are gas, which is set to decline, and coal, which will start to operate in 2024 (Oman 2040 vision).

Oman has confirmed a shortlist of six renewable energy pilot projects to be installed. Four of these projects are solar and two are wind projects:

1. 100 kW solar PB project in Hiji.

2. 292 kW solar project in Al Mazyonah.

3. 1500 kW solar project, location not yet confirmed.

4. 28 kW solar project in Al Mathfa including battery storage.

5. 500 kW wind project in Masirah Island.

6. 4200 kW wind project in Saih Al Khairat, Wilyiat of Thumrait (Hossain, Hawila and Kennedy, 2016).

The Dhofar Wind Power Project located in the Dhofar Governorate will have an installed capacity of 50 MW, making it the first large-scale wind farm in the Gulf Cooperation Council (GCC) region. The wind farm (13 wind turbines) will help meet Oman's growing demand for energy. It will reduce domestic reliance on gas for electricity generation; this can then be redirected toward more valuable industrial uses and will preserve natural gas resources. The first turbine from the wind farm has already been connected to the grid and has produced the project's first power. The wind farm will see its twelve remaining wind turbines commissioned, tested and connected to the grid in sequence. Once fully commissioned by the end of 2019, the wind farm is expected to generate enough electricity to supply 16,000 homes, equivalent to 7% of the total power demand of Dhofar Governorate.

Oman is also moving forward in a rooftop PV scheme called the "Sahim" initiative; this was launched in May 2017 by the Oman Authority for Electricity Regulation (AER). The Sahim initiative has been structured in two phases:

- Sahim I allows large households and businesses to install small-scale grid-connected PV systems at their own cost, and to receive an export tariff (the bulk supply tariff) for any excess electricity which is exported to the grid, under a feed-in-tariff-like scheme.
- Sahim II will aim to promote wider-scale deployment of small-scale grid-connected PV systems. This would involve somewhere between 10% and 30% of residential premises in Oman, or around 250,000 rooftop installations, which equates to roughly 1GW of solar capacity. Funding solutions will be secured by running competitions for private developers to build, own and operate such PV systems at premises designated by AER, rather than by having the customers instal the systems at their own cost.

However, there is also a plan to build a less-environmentally friendly coal-fired power station in Duqm, as mentioned earlier in section 3.3.2.5. A project which were opposed by people because of fear of the air pollution it might create. The Oman Power and Water Procurement Company (OPWP) initiated the procurement of a Clean Coal IPP in 2018, following a feasibility study that assessed various technical and economic aspects related to the coal project. At present, the project has not yet been approved, meaning that some issues still need to be resolved. In the feasibility report the OPWP carefully assessed the options available for importing coal. This included an assessment of the various qualities of coal available in the market, of the infrastructure required to handle coal import and transportation, and of the issue of the distance of the plant location from the port. OPWP would give the bidders fixable as to where they sourced the coal, provided that its quality and technical specifications met the standards set out in the proposal documents. The project is based on the use of low-ash and low-sulphur coal, with the sulphur content expressed as a range. However, this range is one of the coal specifications that is yet to be finalized, considering the impact of sulphur content on emissions. There was also an assessment of the various technologies available in the market, with the preference going to the ultra-supercritical pulverised coal technology, which seemed to have the greatest advantages (Zulaikha Bait Ishaq, Personal communication). The researcher's communications with many people who are involved in this project led to a debate in the thread, and the project authority subsequently launched a survey on Twitter which revealed that 77% of the respondents do not support the construction of a coal-fired power plant in Duqm. However, no decision has yet been made, and the researcher's quest for information about the project suggested that most of the people contacted were reluctant to speak openly or to give out any information.

3.7.2 Oil and gas sector:

MECA's control over the exploitation of energy and natural resources is stated under article 27 of RD 114/2001, which requires that institutions engaged in exploitation of natural resources set up controls to ensure their conservation. Government concessions for the exploration and production of oil, gas and other resources include provisions that ensure commitment of the concessionaire to observe the provisions of this law.

According to Article 9 of RD 114/2001, no "source" (that is, process or activity that may directly or indirectly cause environmental pollution) or "area of work" may be established before obtaining an environmental permit confirming its environmental soundness. An application for a permit must be made to the Ministry of the Environment and Climate Affairs (MECA).

Before the application for the environmental permit can be approved, a detailed Environmental Impact Assessment (EIA) may be required. The question of whether an EIA is required is a matter to be determined through liaison with MECA (Article 16, RD 114/2001). In practice, an EIA is required at virtually every stage of an upstream or downstream oil and gas project.

Where an EIA is required, the "owner" of a source/area of work (a widely defined term which would include the operator of an oil or gas concession) must procure a qualified company, approved by MECA, to prepare the EIA.

Ministerial Decision 118/2004 issued by MECA controls the level of air pollutants released from stationary sources; these include flaring in refineries and petroleum fields. The directive lays down numerical limits for emissions relating to flaring; these limits are for carbon monoxide, sulphur dioxide, nitrogen dioxide, carbon dioxide, unburned hydrocarbons, and particulates.

Reduction in gas flaring in the oil industry is one of the mitigation options presented in the NDC of the Sultanate of Oman. At the same time, the *MOG* believes that the weakest point of the oil and gas sector is its flaring activity, as mentioned in section 3.7.3, and it is for that reason that the government is forcing oil and gas operating companies to present their plans for zero flaring by 2030 for each particular system. However, the implementation of this zero flaring in oil and gas does not appear to be clearly defined, and seems to be optional rather than compulsory. Another area which could be improved involves venting, which has never been regulated by either the oil and gas law or environmental law.

3.7.3 3.8.4 Industry:

The industry sector emits all types of pollutants, with the major emission in Oman being SO_2. The industrial process emissions come from mineral extraction and processing, chemical production, and the energy industry’s own use in oil refineries. The policy regulating this sector is under Ministerial decision 118/2004, but enforcement of this seems to be lax. While *Media_2* did mention a few cases of the general public complaining about issues such as an increase of SO_2, chest infections and smell and smoke from the burning of garbage, he had never, in eight years of reporting, come across a case of a company or a factory being punished for polluting the air in any way. This surely indicates a failure of the relevant authorities to take action on air pollution; it is not the fault of industry that they have not been prosecuted. The issue was not only raised by a journalist; there are also no judicial records of cases related to air pollution. Rather, the environmental issues that came to court all involved threats to endangered species and nature reserves. There was also, in the research interviews, no mention by anyone of any systematic inspections being carried out, either by decision-makers or by industry representatives.

The manufacturing industry sector in Oman is expected to achieve high growth rates of an average of 10% during the Ninth Five-Year Development Plan for the period 2016-2020. Its contribution to gross domestic product, at current prices, will rise from 10.5% in the Eighth Plan period, to about 14% in the current period. The sector is considered an important economic sector, and represents the growth engine for non-oil activities. It can provide a large number of work opportunities for new entrants to the labour market and increase the export value of non-oil activities. However, if this ambitious sector starts to grow without strict rules and a solid base, then the challenges of transparency, deficiency of records, enforcement of laws etc. might be difficult to resolve later. The emission of air pollutants from industry is likely to rise significantly, and failure to implement and enforce regulations will result in an ever-growing problem. It must also be noted that many industrial activities, such as construction, crushers, metals, and the like, have not been included within this study for reasons explained in Chapter Two; but these are important and additional sources of emissions and clearly need to be addressed in the policy.

3.7.4 Transport sector:

The transport sector contributes to the emission of CO_2, CO, NO_x, $PM_{2.5}$ and others, but there is a gap in the policy which should properly control this sector. As explained previously, the transport sector is covered by two laws: the traffic law under the ROP and the GSO standards for cars under MOCI,. The issue of fugitive PM from driving on unpaved roads is covered under yet another body, the Ministry of Transport and Communications (MTC). The MTC is embarking upon the implementation of major projects related to the construction and establishment of roads. Following on from Ministerial Decision No 77/2008, which formed the basis for the Department of Road Transport, there have been important bilateral agreements with regional and international organizations to facilitate road transport with neighbouring countries. In addition, the Omani Land Transport Committee has a mandate to coordinate road transportation planning across government agencies. Although the building of new roads by MTC will significantly decrease PM from unpaved roads, there is little effective coordination between MTC, MOCI (responsible of importing vehicles) and the ROP (responsible for the actual driving on Omani roads). Nor do they seem to have any common plan to improve vehicle technology standards (EURO) and thus improve air quality. Another point needing attention is fuel quality; this should be in line with the vehicle engine quality (EURO), and is an area where MOCI should work with MOG to provide higher fuel quality rather than importing EURO 4, 5, or 6.

There has also been a sharp growth in air transport in Oman. Over the 1975-2010 period, the number of departures rose more than 6-fold, from 5,400 to 34,637. Over this same period, the number of passengers more than doubled, rising from 173,000 passengers in 1975 to nearly 407,000 in 2010. Air transport activities are coordinated by the Air Transport Department of the Civil Aviation Authority (PACA) and the Sultanate is a member of the International Civil Aviation Organization (ICAO) and the Arab Civil Aviation Organization. This entity, PACA, seems to have no coordination with MECA and all the regulations which govern this sector are under the control of ICAO.

3.7.5 GCC policy:

The mainstreaming of climate and air pollution policy into broader sustainable development objectives is discussed in the following section: it is essential both in terms of the harmonization of policy within the GCC countries, and for the benefit of the region through economic diversification and sustainability.

The GCC states are poor in natural resources other than oil and natural gas and the potential for solar energy; however, the region still needs to develop comprehensive and detailed environmental strategic plans to ensure the sustainable development of the region's existing natural resources. GCC countries are rich in renewable resources, but the energy sector is still characterised by a heavy reliance on fossil fuels, which has had an adverse impact on the environment and resulted in high carbon intensity.

Klemes et al., 2012 recommended the adoption of an integrated, multi-disciplinary approach that combines advances in cleaner production technologies with the political implementation of policies and programs designed to ensure sustainable societal development. Nash (2009) studied the promotion of sustainable consumption and production patterns and concluded that the absence of mandatory and quantifiable targets and deadlines has weakened the region's ability to decouple economic growth from resource use.

In spite of the fact that the legal systems of the GCC have undergone dramatic, radical and progressive change and development in the past 25 years, and that this change is continuing, environmental legislation has not been taken very far in GCC countries. There have been some attempts to initiate this in the past but it has not received as much attention as economic development, although international obligations have forced GCC countries to take some serious action. The GCC countries have begun a process of addressing environmental sustainability that started with their accession to UNFCCC and the Kyoto protocol in 2005, under which they are obligated to take steps to reduce greenhouse gas emissions (Ramadhan and Naseeb, 2011); this also applies to Oman. The GCC countries are major oil- and natural gas-producing countries, are among the top 25 countries for per capita carbon dioxide emissions, and are perceived as the main actors blocking international climate change negotiations (Reiche, 2010). However, there has been an evolution in policy development aiming to promote energy efficiency and renewable energy and to mitigate climate change. Achievements include Dubai's green building code and Abu Dhabi's pioneering initiative of Masdar City, the first carbon-free city in the world. Another major initiative by the GCC countries was the organisation of the 18th United Nations Climate Change Conference (COP 18 and CMP 8) which took place in Doha, Qatar in 2012. Oman itself is also building the Ibri II Solar Independent Power Project (IPP), the first and largest utility-scale solar project in the sultanate, as well as the Dhofar Wind Farm. Miraah (Arabic for mirror) solar thermal project is another example of renewable energy which will harness the sun's rays to produce the steam used in oil production. Although there has been considerable progress in formulating environmental policies in the GCC states, environmental governance still lacks many dimensions. There is a need for additional policy tools, especially the engaging of stakeholders (NGOs, the private sector, local communities etc.) in drafting policies. This would improve the execution, monitoring and reporting of environmental issues, would help to achieve the collective goals and would increase cooperation at national and regional levels. Environmental institutions also need to be greatly empowered if the region is to achieve better implementation of environmental policies.

3.8 Conclusion:

The environmental law of Oman (RD 114/2001) has been under an updating process since 2017 and is now in its final stage, in the Minister's cabinet. This law covers all environmental issues including air pollution but does not address climate change. Complementary regulations under this law set detailed limits affecting air pollution, air quality and the sources of emissions (MD 118/2004, MD 41/2017). MECA is also currently working on a proposal of a 'National Strategy to Adapt and Reduce Climate Change'. There is no public access to this document, as only specific people have been tasked with commenting on it or providing any feedback during its development, and at the time of writing it is in the Minster's cabinet for approval.

The interviews conducted in this study showed that Oman lacks a well-defined and systematic approach to the process of developing a policy to regulate sources of air pollution and GHGs. There is not much evidence of involvement of stakeholders from different levels of industry and NGOs, nor does the process seek any contribution from the public. The revision and evaluation of environmental policy to limit the control of air pollution is driven mostly by international agreements and obligations, rather than by responsibility taken at national level. Specific criteria for revising the law should look at the country's needs as shown by national studies; these should target issues central to the country's future, such as emissions of CO_2, SO_2, and $PM_{2.5}$. However, these criteria have not been developed. There are also weaknesses in the evaluation of the policy and in the policy-updating process; evaluation is not a well-established practice, and there has been no consideration of the criteria needed in an evaluation process, such as effectiveness, efficiency, and coordination with other existing policies. The implementation of the law appears to face remarkable challenges related to insufficient human resources, the need for capacity-building, a lack of technology, and failure of stakeholders to coordinate. The analysis in this chapter indicates that a lot both inspectors and polluters are failing to carry out many of the duties required of them. Another area needing attention is the notable lack of interest in air pollution and climate change within different levels of society, and the resulting lack of awareness. There is also a shortage of information provided to the public and in the media, and which reflects a lack of transparency in government. Overall, then, Oman's current policy regarding air pollution and climate change cannot be considered to be adequate, given the size of the problem, and there is no effective control regime that can reduce the pollutants covered in this thesis.

If the country is to face the new environmental challenges and regularly update its policy, there is an urgent need for new regulations and an institutional commitment to environmental governance. An analysis of the gaps in current environmental policy development is essential if the policy is to be improved, along with an analysis of the factors needed for adequate enforcement. This study believes that Oman has a great opportunity for improvement in this area; it will succeed in developing and effectively implementing a comprehensive procedure for the policy making process, if the following points are taken into consideration:

(1) The process of introducing or updating the law should focus on addressing the priority environmental challenges, problems, and threats the country faces both currently and in the future, and at regional and international levels. This is difficult to achieve without political support, human capacity, institutional coordination and financial resources.

(2) The engagement in the policy development process must be linked effectively with the raising of awareness, more adequate implementation of the law, and the incorporation of different dimensions of the law. All concerned stakeholders should be involved in the development of the policy, including the public. This is another way of enhancing awareness at community level, highlighting awareness of issues such as resource scarcity, efficiency and the benefits of adopting a low-carbon economy. A policy which covers many dimensions

will become holistic and closer to reality and will also make people more willing to implement the law. Without public engagement, no real action will be implemented.

(3) It is important to have a period of time for implementation before enforcement begins. This will allow the discovery of any gaps in the practicality of the law, and will also highlight issues such as the need for capacity building, human resources or monitoring stations.

(4) There should be a systematic revision process, with tools to evaluate the law in the light of changing technology, information, research, and new data. This will make the law more dynamic and representative of actual needs. To do this successfully, political will is extremely important. What is essential, then, is an exceptional change in the level of awareness within the government, effective coordination between air quality and climate policy, with powerful organisation to develop and deliver air quality and GHG reductions.

(5) The structural, cultural and socioeconomic similarities of the GCC states give them the opportunity to have effective synergies that could be achieved from regional cooperation, such as sharing information through, for example, The Statistical Centre for the Cooperation Council.

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4 Estimating baseline emission scenarios and developing mitigation policy scenarios for Oman

4.1 Introduction:

The aim of Chapter Four is to explore a set of emission scenarios that include a baseline scenario and a number of alternative mitigation scenarios. The baseline scenario illustrates emission projections under the circumstances of current trends and policies, whereas the alternative mitigation scenarios illustrate the future for different sectors under a different set of policies and socio-economic conditions.

This study has produced one Business As Usual (BAU) baseline scenario for Oman to 2050 and eleven mitigation scenarios which present different climate and air quality policy regimes. The method used to estimate those scenarios will be described in Section 4.2. Section 4.3 will go on to discuss different measures that could reduce emissions in Oman, policies that are relevant and could be used to implement different measures, and the challenges that might be faced during their implementation. This chapter will also review the literature on emission scenarios for Oman and on other countries and will compare different emission and mitigation scenarios within the GCC and in other countries. The end of the chapter will discuss the results, as well as the uncertainties in the scenarios.

As highlighted in Chapter 3, the current and principal environmental legislation in Oman that affects emissions of air pollutants and GHGs is Royal Decree Number 114, or RD 114/2001, the Law on Conservation of the Environment and Prevention of Pollution; this was first published in 2001 and is currently being subjected to a review and updating process which was initiated in 2017 and is still being finalised. There is no indication that the changes being considered will bring any improvement to air quality in Oman, and there is no clear picture of plans for a climate policy strategy beyond 2020 nor any major discussion in the country about it. The only indications of this are references to Oman's adherence to the Paris Agreement and the submission of Oman's INDC. As a counter to this absence of discussion about possible future mitigation policy choices, this study explores a number of mitigation option scenarios in order to provide information useful for policymaking in the country. Additionally, imagining these policy scenarios being applied not only in Oman but in all GCC countries makes it possible to compare the future effects of these policies and assess their impact on emissions in Oman itself and across the region. The scenarios were also developed in the belief that if Oman is to have a thriving industrial economy in the future, it is essential that it rise to the challenge of managing future levels of air pollution and their impact. The different emission scenarios developed in this chapter use the existing emission inventory outlined in Chapter Two as a starting point, and refer to alternative environmental policies suggested in Chapter Three, with population and economic growth as drivers for future estimates.

4.1.1 Emission scenarios:

In general, a scenario is a self-consistent story-line of how a future system might evolve over time. It involves the understanding of how trends can evolve, when driven by certain forces (social, technological, demographic, etc.) and under a particular set of policy conditions; it can also show how high or low the degree of certainty would be. In simple terms, a scenario development process is the exercise of building, exploring and assessing different visions of the future. It can be a strategic tool for both opening up people's minds and for making and guiding decisions when different levels of uncertainty are given.

Most scenarios, as noted by Rotmans et al. (2000), are hypothetical, describing possible future pathways and dynamic processes, and representing sequences of events over a period of time. Scenarios consist of states, driving forces, events, consequences and actions which are causally related, and start from an initial state (usually the present), depicting a final state at a fixed time horizon. Alcamo (2001) adds to this explanation by emphasising that the "perhaps the most important function of both scenarios and environmental assessments is that they act as a crucial bridge between environmental science and policy. They influence policymaking by summarising and synthesising scientific knowledge in a form that can be used by policymakers to develop policies. They help policymakers visualise the different aspects and connections of an environmental problem, as well as its large time and space scales. Conceivably, scenarios and environmental assessments can also help decision-makers devise the policy steps needed to solve a problem".

Emission scenarios describe possible future atmospheric emission trajectories as an outcome of different driving forces such as economic activities, social trends and technology changes. They often take a forecasting approach, taking an emission inventory as the starting point (in LEAP-IBC this is termed 'Current accounts' with 2010 as the base year). These forecasting scenarios are also sometimes known as emission projections. Emission scenarios can also take a back-casting approach. The purpose of the back-casting scenario is to investigate the necessary path and the measures required to reach the desired end-state. Emission scenarios are often long-term-orientated, with time scales of 25 years or more.

Emission scenarios are by nature always quantitative and typically make use of mathematical models that simulate societal, economic and technological developments and their interactions.

However, scenario experts have also combined qualitative and quantitative elements in emission scenario exercises. The IPCC emission scenarios are perhaps the best-known examples of an emission scenario exercise that used a mixed (qualitative and quantitative) approach with narrative storylines providing input to mathematical models that calculated future greenhouse gas emissions under the different worlds described in the storylines.

Air pollution poses many risks to Oman (see Chapter Five) and these are likely to become more acute if current development patterns persist. Moreover, it is foreseeable that new risks from air pollution will arise if the issue is ignored or not taken seriously. It is therefore most important to determine the various ways that emissions might develop in future.

Emission scenarios and projections not only allow a better understanding of current trends but also allow an assessment of the potential effectiveness of different emission policy interventions. These can then be compared to the result of allowing current trends to continue, as described in the baseline scenario. Another purpose of emission scenarios is to help raise awareness about the emergence of new or intensifying environmental problems and to contribute to the policy process of designing and assessing emission reduction strategies that can address them.

Emission scenarios are also used internally within policy-making organisations to evaluate different policy options, including the option of non-action. They can also be used by governmental agencies to track progress towards the meeting of emission targets and air quality standards.

4.1.2 Baseline scenario (BAU):

The baseline scenario in this study is named “Business As Usual” (BAU) and is composed of the current accounts (2010), historical data to 2017 and future projection to 2050. The base year data set has been developed from government agency statistics and from the databases of international organizations. It explores situations in which no further climate and air pollution policies are implemented beyond what was in place in the year 2010. This means that energy consumption from 2010 to 2050 is driven by growth in the population and economy but not by energy-efficiency or climate change policies. The combustion technologies/abatement measures in future years are assumed not to change beyond the year 2010. In practice this means that air pollution emission factors for the year 2010, as described in Chapter Two, have been applied for the entire period 2010-2050. The BAU also includes the planned introduction of coal and renewables for electricity generation.

The BAU scenario was developed to show what the future might look like on the basis of the perpetuation of current policies, taking into account all existing policies, but excluding any future government target or policy. The model therefore uses historical trends of demographic and energy-related data in Oman to project the energy demand and supply to the year 2050.

4.1.3 Mitigation Scenarios:

Mitigation scenarios are designed to meet specific emission reduction targets for different sources of emission, and simulate the effect of implementing specific policy interventions.

The mitigation scenarios developed in this study involve the implementation of specific mitigation options, usually individual technologies or measures, and investigate their effectiveness in reducing SLCP, air pollutant or GHG emissions. Aside from the BAU scenario, eleven other scenarios have been developed and are summarized in Table 4-1; more detailed description will be provided within Section 4.2.

Table 4-1: Main characteristics of the baseline and the eight mitigation emissions scenarios

	Scenario name	Policy / measures input	Scenario overview
1	(BAU) baseline scenario	100% implementation of climate and energy policies which came into force before 2010	Describes how an energy-environment system will evolve into the future under the assumption of implementation of current government policy.
2	Power generation:		Designed to achieve reduction in emissions targeting a specific sector. They involve measures, new policies or combination of measures and policies.
	Renewable energy Scenario (RES)	Development of renewable energy in the power sector by increasing the share of solar and wind energy at expense of natural gas and diesel. Solar and wind energy ↑ Natural gas and diesel ↓	
	Zero Coal Scenario (ZCS)	Cancel the plan for producing electricity from coal	
3	Oil and gas sector:		
	Fugitive Reduction Scenario (FRS)	Avoid fugitive emissions by using advanced technology.	

	Zero Flaring Scenario (ZFS)	Zero flaring / upstream.	
4	Industry sector:		
	Efficient Industry Scenario (EIS)	Efficient industry	
	Clean Fuel Scenario (CFS)	Low sulphur fuels	
5	Transport sector:		
	Electric Vehicle Scenario (EVS)	Penetration of electric vehicles	
	Public Transport Scenario (PTS)	Improving the public transport system	
	Paved Road Scenario (PRS)	Having more paved roads	
6	Residential, commercial and public services sectors:		
	Residential Efficient Air Conditioning Scenario (REACS)	AC energy efficiency regulation in residential sector	
	Commercial Efficient Air Conditioning Scenario (CEACS)	AC energy efficiency regulation in commercial sector	

4.1.4 Emission scenarios for Oman from the literature:

A review study by Omidvarborna et al. (2018) indicates that the major contributors to the overall air pollution in GCC countries were sand and dust from natural and anthropogenic sources, such as cement, metal, stone cutting industries, from chemical industries such as refineries and petrochemicals, and from transportation activities . However, there is a lack of scientific studies on this topic, and no organized data with a specific focus on particular areas and/or industries.

According to data from the World Bank, the CO_2 emission trend over the Gulf region increased in the period 2004 to 2010, with the highest emitting countries being Saudi Arabia and the Emirates, (www.data. worldbank.org; Farahat, 2016; Farahat et al. 2015) (Figure 4-1).

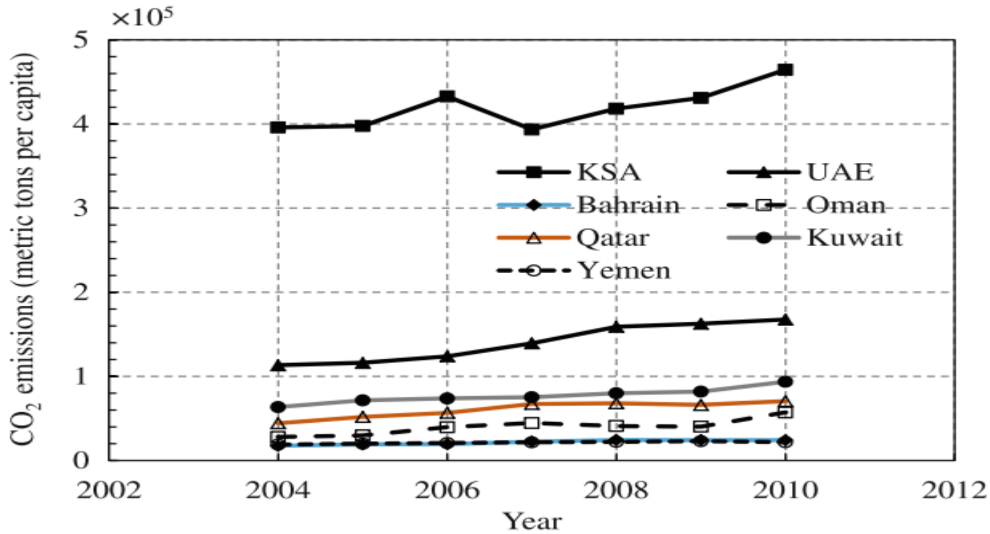

Figure 4-1: CO_2 emission over the Gulf region during the period 2004–2010 using World Bank data (www.data.worldbank.org; Farahat, 2016; Farahat et al. 2015)

Figure 4-2 below (Lahn and Preston, 2013) shows that the GCC countries use much higher amounts of energy than other states with similar per capita GDPs, suggesting that energy resources could be deployed more efficiently.

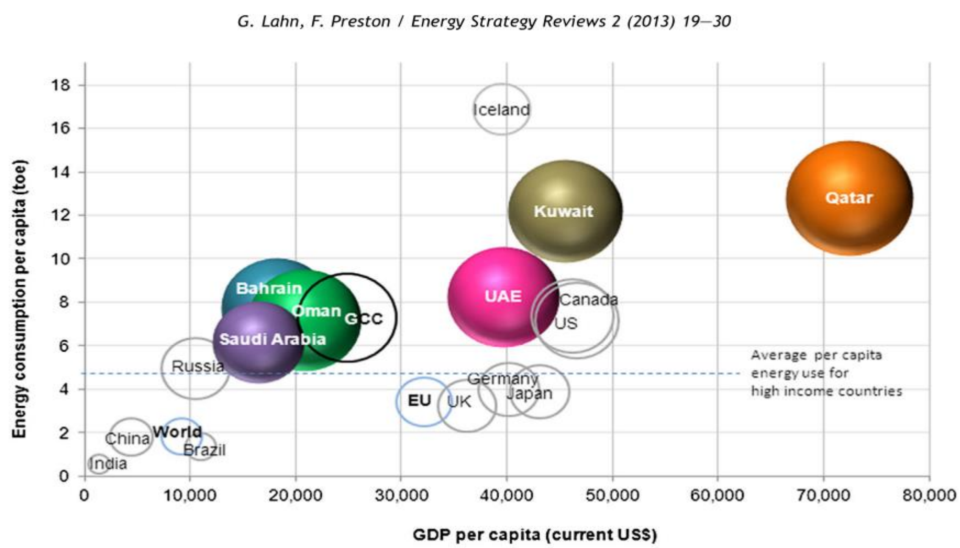

Figure 4-2: Energy intensities relative to population in GCC countries and selected country comparisons. Energy is total primary energy consumption whereas bubble size indicates per capita fossil fuel consumption (Lahn and Preston, 2013).

Charabi et al. (2018) revealed that GHG emissions in Oman have been steadily growing, at the rate of 10% per year between 2000 and 2015 (15.654 Gg to about 65,913 Gg). This growth rate in GHG emissions is significantly above both the population growth rate of 4.2%/year and the GDP growth rate of 8.9%/year for the same period (World Bank, 2017), indicating that Oman's economy has become more carbon-intensive. At the same time, the population's consumption of CO_2-equivalent per person per year increased from 6.9 to about 15.7 tonnes, which makes the population patterns also more carbon-intensive.

Farzaneh et al. (2016) suggested different policies that could dramatically change the future course of the Middle East region (including Oman), bringing the CO_2 emissions from its energy system to zero by 2100. They outlined two factors which could play a major part in decreasing the CO_2 emissions of Middle East countries: improvements in energy productivity and a change to energy sources with lower CO_2 emission factors such as gas, renewables and nuclear. Their results indicate that nearly 43% of the global energy of the Middle East region could be supplied from non-fossil fuel resources by 2100.

In their baseline scenario, CO_2 emissions for the Middle East will increase from 7.6 tonnes per capita in 2010 to 11.7 tonnes per capita in 2030 and 27 tonnes per capita by 2100. The baseline scenario was based on demographics and socioeconomic historical trends, and demonstrates the short- and long-term situation that could result from the aberrant consumption of fossil fuel resources in the region. However, the zero CO_2 scenario, shown in Figure 4-3 below, shows that for Oman there could be a big reduction in emissions between 2010 and 2030 and then a steadier reduction up to 2100.

The zero emissions scenario incorporates the broad policy commitments and plans that have been announced by countries of the Middle East to tackle energy insecurity, climate change, local pollution, and other energy-related challenges. Those commitments include support for renewable energy, energy efficiency targets and potential nuclear power plants; all aim to reduce greenhouse gas emissions by 2100.

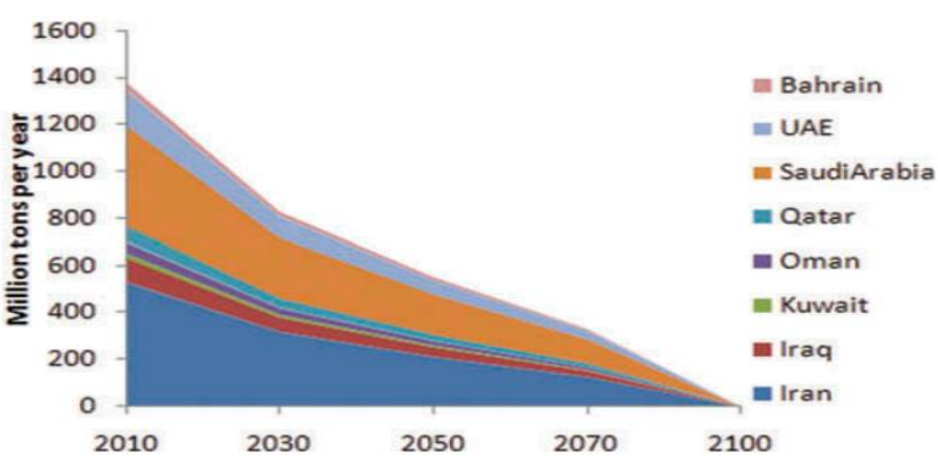

Figure 4-3: Trend of CO_2 reduction in different countries (based on the zero CO_2 emissions scenario). Oman is in the purple (Farzane et al., 2016).

El Fadel et al. (2013) investigated the implications of using renewable energy (RE) for power generation for residential consumption in the Middle East and North Africa (MENA) region, examining various RE penetration targets for 2010 (the base year) as well as those projected for 2040 (the end year). With the assumption of RE percentage contributions per scenario for Oman as in Table 4-2, Oman would achieve reductions in GHG emissions in the range of 10–20%, based on their RE reference targets, which translates into 0.5 tCO_2e emissions per capita. The current (2010) estimated emission per capita for Oman is 1 tCO_2e, which indicates that the policy scenario would result in a significant reduction of 50% in tCO_2e per capita (El Fadel *et al.*, 2013).

Table 4-2: Oman-specific power generation percentage energy source contributions per scenario, (El Fadel et al., 2013).

Reference Scenario (same as current accounts)					
Oil	Solar	Hydro	Nat. gas	Wind	Coal
18	0	0	82	0	0
Policy Scenario					
Oil	Solar	Hydro	Nat. gas	Wind	Coal
15	5	0	75	5	0
Revolution Scenario					
Oil	Solar	Hydro	Nat. gas	Wind	Coal
6	33	0	28	33	0

Saleh et al. (2017) used a building simulation program to investigate the potential of the implementing several energy-efficient retrofitting strategies for a residential building located in a typical hot-climate area of Oman. The house model was calibrated using actual weather data and electricity bills for the same year. The calibrated model shows that improving the AC efficiency, using insulation for both walls and roof, upgrading to LED lights, and improving the air tightness would have a significant impact on energy consumption. The results from the study indicated that when combining the best strategy in each category, the annual energy consumption for the building could be reduced by as much as 42.5% (Saleh *et al.*, 2017). This result is similar to that estimated by Alalouch et al. (2019) below.

Alalouch et al. (2019) examined the potential for saving energy in electrical consumption if the concept of energy-efficient houses was implemented in Oman. Energy consumption in the residential sector in Oman was critically analysed and forecasts were made based on the sector's growth rate and historical consumption. Base-case-validated simulation models were then generated for a typical residential dwelling in different cities; the simulation used a dynamic building simulation software, and covered a wide variety of climate conditions in Oman. The study then developed and simulated a variety of modified design cases that met the minimum requirements for code compliance in residential buildings for four Gulf Cooperation Council countries, after which an economic analysis was performed.

The researchers concluded that the energy consumed by the residential sector could be reduced significantly by 2040 (by 13.2% in a warm tropical climate to 48% in a hot dry climate) if proper building codes were put in place and if energy efficiency measures were properly enforced in new residential buildings. Figure 4-4 depicts the forecast energy consumption in the residential sector up to 2040 for three scenarios, namely, business-as-usual, minimum saving (warm tropical climate, with GCC thermal regulation) and maximum saving (hot dry climate, with Saudi Building Code). It is worth mentioning that the Saudi Building Code was launched in 2018, with its application being mandatory for large engineering projects from 2019, and compulsory for small residential buildings from 2021. It has also been available to all since its launch, and could be followed on a non-mandatory basis from that time. Such a code has not yet been laid down in Oman yet.

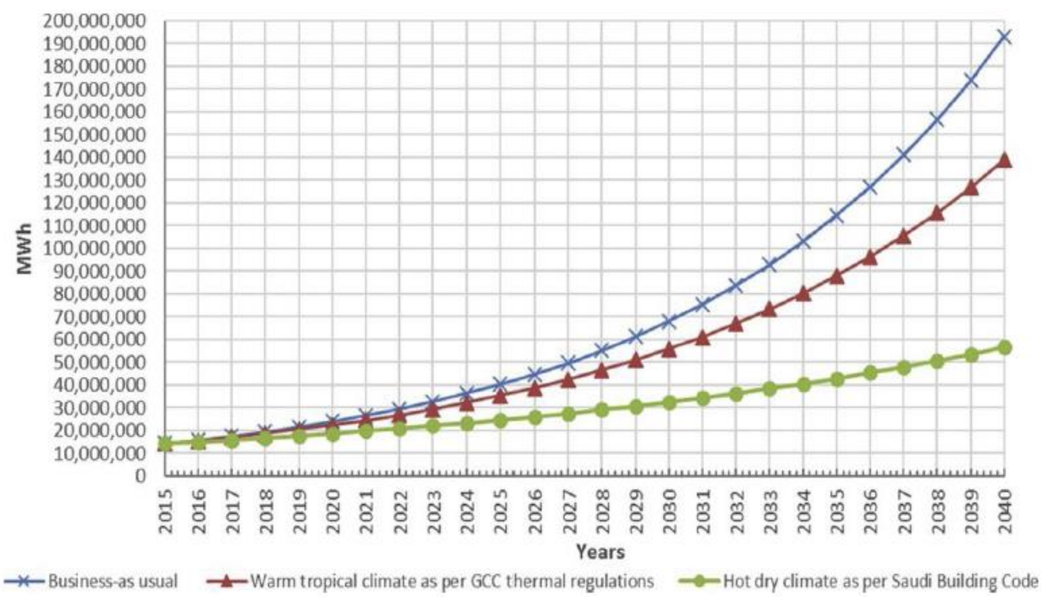

Figure 4-4: Forecast scenarios of energy consumption in the residential sector in Oman up to 2040, (Alalouch et al., 2019)

The significant reductions in energy consumption indicated in these studies can help both policy makers in government institutions in Oman, as well as property owners, to move forward and undertake large retrofitting campaigns that would help resolve the current energy dilemma in the country.

In conclusion, the fact that there are very limited studies of emission scenarios for Oman in the literature could be seen as an indication that air pollution is not taken as seriously as it should be. The limited studies also indicate that the impact of poor air quality and climate change constitute a serious problem for Oman and the region in general. This is considered by this study as a gap which needs to be addressed through improvements in knowledge, awareness and policy making.

4.2 Method for estimating baseline and mitigation scenarios:

In creating a baseline scenario, it is necessary to consider how the overall activity within each sector is likely to change in the future. Other factors to be considered include whether the proportion of fuels and technologies are likely to change into the future, whether the energy intensity in a particular source sector is likely to improve, or if the emission factors associated with energy consumption in a sector are likely to change. These variables may be affected by a multitude of different factors; these include socio-economic changes within the country, such as changes in population and GDP; technological developments; and specific policy interventions by local or national governments, such as the end of pipe technologies that would affect the emission factor.

It is therefore of primary importance to set socio-economic drivers such as population growth rate and GDP growth rate. In this study, data from the National Centre for Statistics and Information (NCSI) is used as the principal driver for historical population and GDP time-series; this data is then used to develop the baseline scenario and to determine various mitigation scenarios. The baseline scenario was constructed to 2050, with 2010 as the base year. Results of the baseline scenario were then used as a reference to compare with the mitigation scenarios. The baseline scenario is based on business-as-usual assumptions. It does not include new climate or energy policies, except for those implemented prior to 2010. Figure 4-5 summarizes the LEAP-IBC framework used to estimate the baseline emission scenario and development of mitigation scenarios.

In this study, a business-as-usual baseline scenario was generated, as described in Section 4.2.1. It describes how an energy-environment system will evolve into the future under the assumption of full implementation of current government policy (Scenario 1). The mitigation scenarios in this study (Scenarios 2 to 10) were designed to achieve reductions in emissions that target specific sectors in Oman (power generation, oil and gas, industry, transport, and residential and commercial sectors), as described in Table 4-1. They involve the comparison of specific mitigation options, usually individual technologies or groups of technologies, new policies, or a combination of measures and policies. They examine the integrated effects of simultaneously implementing multiple policies and measures in those sectors which contribute most to air pollution in Oman, and are evaluated against the backdrop of the baseline scenario, which simulates the events assumed to take place in the absence of mitigation efforts. The mitigation scenarios have been divided into different sets, with each set of policies and measures described individually in Sections 4.2.5 to 4.2.9 and all other assumptions remaining the same as in the baseline scenario in Section 4.2.4.

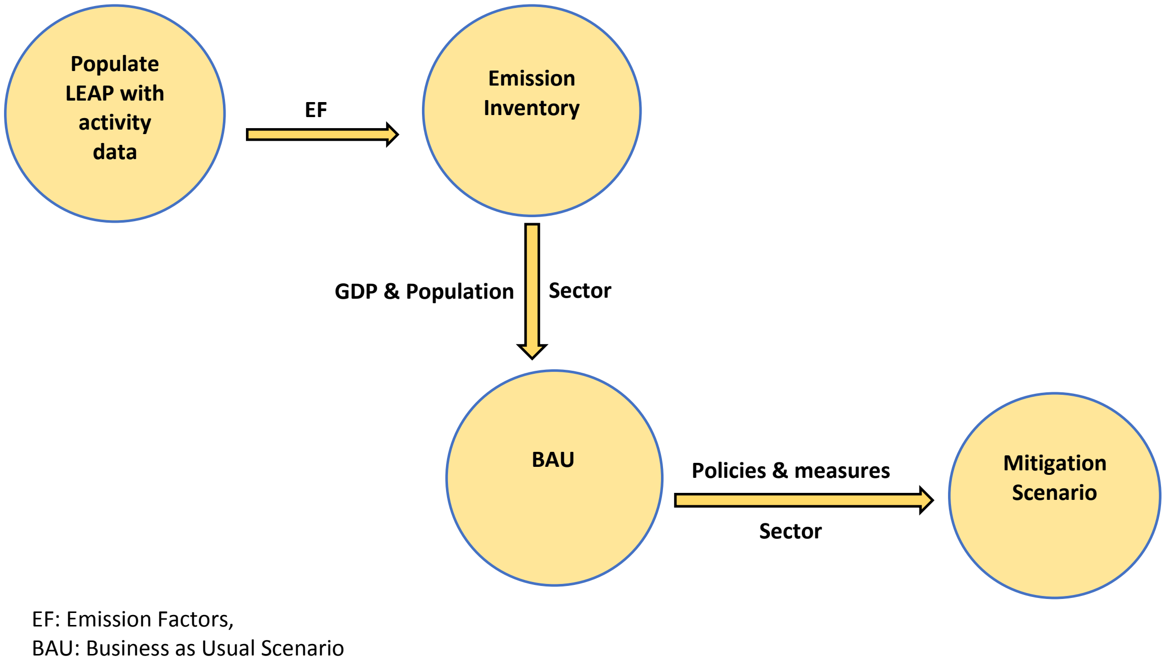

Figure 4-5: LEAP-IBC framework to estimate the baseline emission scenario and to develop mitigation scenarios

4.2.1 Business As Usual Scenario (BAU):

This section describes the data sources, drivers and other basic assumptions required to model the baseline projections of Oman's emissions and their impacts in each of the Demand, Transformation and Non-Energy sectors included in the default LEAP-IBC template.

4.2.1.1 Key assumptions and data input:

The key assumption in LEAP-IBC includes data related to the following: demographics (population and population fractions), economics (GDP, GDP growth, average income, and value added), disease rates, crop production, and transport (% dry days). Table 4-3 presents the demographic and economic data for Oman in 2010, with the baseline scenario mostly scaled in line with GDP percentage growth, shown in Table 4-4, and with the population growth rate shown in Table 4.5. The population fraction for different sets of ages were also populated in LEAP-IBC based on data from WHO, as well as on the $PM_{2.5}$ exposure-response-function-related disease rates which cover Ischaemic Heart Disease, COPD, Stroke, Lung Cancer, ALRI Disease, and Cardiopulmonary Disease. A detailed method was used for transport assumptions; this is described fully in Section 4.2.2.

Country-specific activity data was used when it was available, or could be calculated from available data. In the absence of country-specific data, the study used general data from the International Energy Agency (IEA), Food and Agriculture Organization (FAO), the International Renewable Energy Agency (IRENA) and the World Bank.

Table 4-3: Demographic and economic data of Oman in 2010

	Data	unit	Source
Population	2.773	Million people	National Centre for Statistical and Information (NCSI)
GDP	58.64	Billion US$	World Bank (Data)[18]
GDP growth	21.2	% / year	

The GDP figures in Table 4-4 are based on the Oman 2040 vision. The average annual GDP growth between 2000 and 2017 was 3.6%, with this growth projected to increase to 6% per annum between 2030 and 2040.

Table 4-4: Historic, current and projection of annual growth of GDP (%)

Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
GDP %g	25.2	-0.3	3.3	7.5	14.5	25.3	19.1	13.1	44.7	-20.6	21.2
Year	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
GDP %g	18.6	11.5	2.4	4.6	-13.8	-3.0	7.3	2.3	2.5	2.9	
Year										2030	2040
GDP %g										*6	*6

Source: NCSI, *Based on Oman 2040 vision, 2000-2017 average annual GDP growth is 3.6%, and for 2030 and 2040 is estimated at 6%, (%g is %growth)

Table 4-5: Historic, current and projection of population in Oman.

Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Pop(000)	2402	2478	2538	2341	2416	2509	2577	2743	2867	3174	2773
Year	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Pop(000)	3295	3623	3855	3993	4159	4414	4560			4740	
Year											2040
Pop(000)											6860

Source: NCSI, 2020 and 2040 are estimated based on the high fertility scenario and adopting the policy of reducing the proportion of expatriates, (Pop is Population)

[18] https://data.worldbank.org/indicator/ny.gdp.mktp.kd.zg

The estimated population of 5 million in 2019, based on the latest United Nations estimates of March 2019, represents a sharp increase over the 2010 census figure of 2.77 million, as can be seen in Figure 4-6. The average annual percentage growth in population between 2010 and 2019 has been 4.7%. The largest city, and the capital, is Muscat, with a population of around 800,000. Nearly 50% of the population lives in Muscat and on the Batinah coastal plain northwest of Muscat. Despite Oman's being the 70th largest country in the world, with a total land area of 309,500 km^2, it is one of the least densely populated, with just 16 people per square kilometre, which ranks it at 122nd in population density.

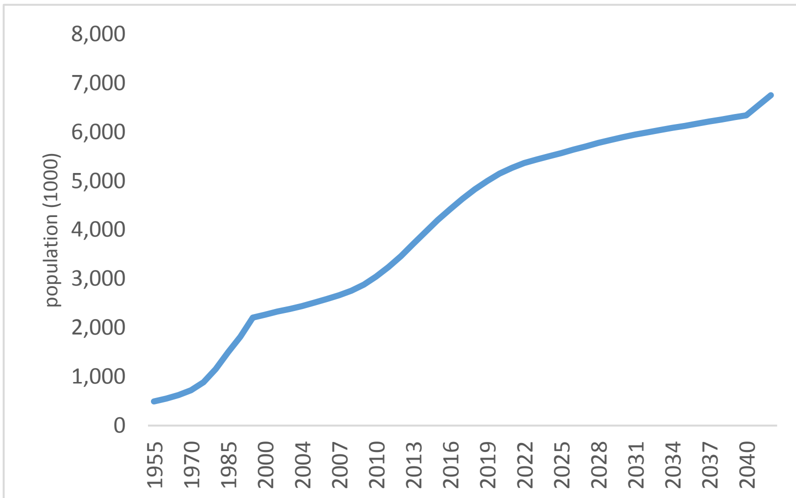

Figure 4-6: Oman population growth 1955-2050

Source: United Nations, Department of Economic and Social Affairs, Population Division (2017). World Population Prospects: The 2017 Revision, DVD Edition

Two more important data sets, particularly relevant to the transport sector, are the percentage of dry days in a year, (part of the key assumptions discussed in Chapter Two) and the fraction of total distance travelled on unpaved roads. These inputs are required to estimate unpaved road dust emissions (PM_{10} and $PM_{2.5}$) from the transport sector. The data in Table 4-6, which shows the length of paved and unpaved roads in Oman from 2010-2017, was used to estimate the distance travelled by different types of vehicles on unpaved roads. These estimates were made for baseline and mitigation scenarios, assuming the same volume of traffic in both.

Table 4-6: Paved and unpaved road lengths from 2010-2017

Road Lengths of	paved road (asphalted)	unpaved road (graded)	Unit	Reference
2010	28,903	30,460	km	Statistical year book, 2011 (NCSI)
2011	29,685	30,545		
2012	31,365	31,622		
2013	32,605	31,446		
2014	34,557	31,486		
2015	35,522	31,744		
2016	36,958	32,336		
2017	37,718	32,475		

4.2.1.2 Demand basic assumption:

The Energy Demand mentioned earlier (in Section 2.3.2.3 of Chapter Two) is represented by seven sectors in LEAP-IBC: Transport, Industry, Energy industry own use, Residential, Commercial and Public Services, Agriculture/forestry/ fishing, and Non-Specified Other. The data input for Oman's future projection of these sectors, except for transport, were obtained from Burke and Csereklyei (2016) who estimated the elasticities of sectoral energy use with respect to national gross domestic product (GDP) based on per capita data for 132 countries over the years 1960–2010. The assumed elasticities for Oman are shown in Table 4-7.

What is elasticity?

The % change in energy use associated with a 1% change in gross domestic product (GDP) (Burke and Csereklyei, 2016), is called energy-GDP elasticity, and this concept will be used in this study as one of the main data input assumptions for the baseline and mitigation scenarios. This concept is developed by using per capita data for 132 countries to estimate elasticities of sectoral energy use with respect to GDP; these are then used to decompose the aggregate energy-GDP elasticity into sectoral contributions. The Burke and Csereklyei (2016) approach involves studying final energy use by five sectors – residences, agriculture (including fishing), transport, industry, and services – as well as other energy use not allocated to these five sectors. In addition to energy-GDP elasticities, they also present electricity-GDP elasticities by sector; if economic growth induces a relative shift toward electricity, electricity-GDP elasticities should exceed the energy-GDP elasticities. Their models will allow GDP elasticities to vary according to the level of GDP per capita.

Table 4-7: Summary of elasticity data for different sectors which are used in this study

Energy Demand Sector	Elasticity	Driving factor	Reference
Industry	0.97	GDP	(Burke and Csereklyei, 2016)
Energy Industry Own Use	0.97		
Residential	0.78		
Commercial and Public Services	1.18		
Agriculture and Fishing	0.53		
Non-specified other	0.98		
Transport	Stock turnover model		

The elasticity for the residential and commercial/public services sectors was selected based on the assumption that the energy used in these two sectors is all electricity (electricity-GDP elasticity of 0.78, and 1.18 respectively). However, the assumptions for the industry, agriculture and fishing, and energy industry own use sectors were based on the assumption that primary solid biofuels are excluded from energy use in these sectors (the energy-GDP elasticity excluding primary solid biofuels is 0.97, 0.97, and 0.53 respectively). The elasticity for the non-specified other which are "other" category not covered by the previous six sectors is 0.98 (Burke and Csereklyei, 2016).

Demand from the transport sector assumed in this study is based on a stock turnover model and the use of vehicle survival patterns model developed by Han *et al.* (2011). The model is used here as described in Chapter Two (section 2.4.1.3), to estimate the decrease in vehicle numbers with the growth of vehicle age for Oman; these figures are important for the projection of Oman's vehicle ownership and scrappage.

4.2.1.3 Transformation basic assumption in electricity generation:

Electricity generation in power stations is Included under the 'transformation' category in LEAP-IBC, as noted in Chapter 2. As a part of Oman's fuel diversification plan, the Oman Power and Water Procurement Company (OPWP) is planning to reduce the share of natural gas fuel in Oman's electricity generation from its current value of 100%, to 83% by 2024. The resulting 17% reduction of natural gas in Oman's will be replaced by renewable energy development (solar and wind) and the Duqm 'clean coal' independent power project (IPP); this was outlined in the OPWP's seven-year statement in 2018 (OPWP's 7-year statement, 2018). The Oman 2040 vision document states that no indigenous coal from Oman will be used for this electricity production. Instead, sub-bituminous coal for the power plants will be imported from overseas. More details of this are provided within Chapter Three (Section 3.8).

There will not be any reduction in the amount of gas consumed in the power generation segment in terms of absolute numbers. However, the number of steps announced by OPWP to increase efficiency, along with the planned increase in renewable energy use and the setting up of a coal-fired plant, mean that the growth rate of natural gas consumption will decrease substantially. These assumptions are shown in Table 4-8.

Table 4-8: The planned percentage share of different source of energy for electricity generation in Oman in 2024

Source of energy	natural gas	solar energy	Coal
%share	83	10	7

Source: (OPWP, 2017)

4.2.1.4 Fugitive emissions basic assumptions for the oil and gas industry:

Also included under the transformation category are the energy-related industry sectors that emit so-called 'fugitive emissions', emissions mainly related to non-combustion activities in the oil and gas industry. No activity data can be given here for the baseline scenario, as projections for the oil and gas sector are driven by the growth in the demand for oil and gas. However, fugitive emissions (including flaring) from the drilling of new oil and gas wells are driven by predictions of the number of new wells that will be drilled and the amount of gas flared. So far, almost 1,100 new wells a year have been drilled across Oman by different operators. These wells include both fracking and conventional wells and both oil and gas (Ahmed Al-Salmi, personal communication). The numbers are based on each field's development plan; this designates the age of the field and the number of wells that will be drilled and exploited until they are depleted. This information is used to estimate the projection for future oil exploration and production, which is shown in Table 4-9.

Table 4-9: Assumption for oil and gas drilling 2018-2050

Source of energy	Assumption	Reference
Drilling (oil exploration)	1100 wells/year	Ahmed Al-Salmi (Personal communication)

The data input for flaring, shown in Table 4-10 below, is based on historical data for the actual volume of gas flared between 2008 and 2017.

Table 4-10: Historical data of volume of gas flared from oil and gas industry

Year	(1000) m^3/year	Reference
2008	1404572	NCSI
2009	1443337	
2010	1293910	
2011	917862	
2012	1297166	
2013	1535396	
2014	1568866	
2015	1427679	
2016	1667324	
2017	1735907	

Source: NCSI statistical year book 2018

4.2.1.5 Non energy basic assumption:

Non-energy sources of emissions, as mentioned earlier (Section 2.3.2.5 of Chapter 2), are represented by five sectors in LEAP-IBC; fugitive emissions from the oil and gas industry, industrial process emissions, solvent use, agriculture, and waste. The data for Oman's future projection of these sectors was obtained from Burke and Csereklyei (2016), who estimated the percentage growth of different sectors; other projections have been estimated based on historical trends or have been kept the same as those for the most recent year. Table 4-11 shows this data and the assumed percentage growth for the different sectors.

Table 4-11: Summary of data sources

Sector	Assumption	Reference
Urea (chemicals)	1.1% growth	Alexandratos and Bruinsma, 2012
Sulphuric acid (chemical)	1.1% growth	
Fertiliser application	1.1% growth	
Livestock enteric fermentation and manure management	Cattle (1.2%) Sheep and goat (1.1%) Poultry (1.7%)	
Agriculture residue burning	0%*	Ministerial Decision No. 118/2004 on the Control of Air Pollution from Stationary Sources

*it is assumed that the practice is banned and the ban is enforced

The main industries covered here in the category of industrial process emissions are minerals (cement and lime) and chemical production, namely of urea and sulphuric acid. The projections of urea and sulphuric acid production used here are based on long-term projections for 2030 and 2050 for the Middle East/North Africa region made by Alexandratos and Bruinsma (2012) and shown in Table 4-11.

The estimate for cement and lime production is based on Oman's cement consumption for the period from 2000 to 2017, and on its lime production from 2005 to 2017; the figures are shown in Table 4-12. Since cement production from the two main cement companies in Oman are the only sources providing the country with cement, the demand here is considered as production. The projection of cement consumption from 2018 to 2020 was provided by the Oman Cement Company (OCC).

Table 4-12: Historical data of cement and lime industry and projection for cement industry

Year	Total Cement Demand (2000 – 2016) & projected (2017 – 2020), 000 t	Limestone production (2005 – 2017) 000 t
2000	1,490	
2001	1,557	
2002	1,759	
2003	2,025	
2004	2,160	
2005	2,293	2,502
2006	2,686	2,732
2007	3,213	3,098
2008	3,763	3,845
2009	4,823	3,353
2010	5,024	4,638
2011	5,295	4,995
2012	7,053	6,488
2013	7,948	5,489
2014	7,393	8,724
2015	8,717	12,156
2016	9,731	12,471
2017	10,397	18,062
2018	11,114	
2019	11,884	
2020	12,714	

Source: OCC, NCSI and Minerals Year Book

The agriculture sector in the non-energy branch covers the following activity data: number of each type of livestock, and amount of fertilizer application by type and crop production.

The livestock projections (cattle, sheep, goats and poultry) in this study basically rely on the assumption of the growth in number of animals (percentage increase per year) from an FAO analysis (Alexandratos and Bruinsma, 2012), as illustrated in Table 4-11. However, the FAO gave no assumption for camels, and the projection used in this study is based on historical data in Table 4-13, on figures giving the growth rate for camels in Oman as 3.7% between 1989 and 1994 (Musa, Salim and Samra, 1997). As shown in Figure 4-7, the camel population is only 2% of total livestock in the country. However, if we decide to adapt the 3.7% growth as an assumption for future projection, we must note that this is a higher growth percentage than that for other livestock, whose growth rate is a maximum of 1.7%.

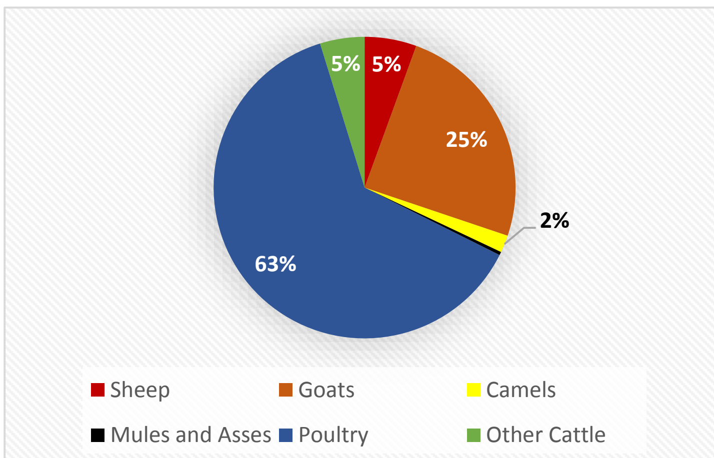

Figure 4-7: Percentage of different livestock in Oman in 2010

Table 4-13: Historical data of number of camels in Oman

Year	Number of camels	Reference
2003	110,520	Year Book for agriculture and fisheries
2004	116,000	
2005	117,300	
2006	119,640	
2007	122,070	
2008	124,520	
2009	127,010	
2010	129,560	
2011	132,150	
2012	134,800	
2013	242,850	

Other sources of emissions in the agricultural sector include fertiliser application and the on-field burning of crop residues. The assumption of growth in fertiliser application is obtained from the long-term projections made by the FAO and covering the period to 2050 (Alexandratos and Bruinsma, 2012) (Table 4-11).

Disposal of agricultural crop residues by on-field burning practices is banned in Oman and the ban is enforced by the Ministerial Decision No. 118/2004 on the Control of Air Pollution from Stationary Sources (Chapter 3). It is therefore assumed that this activity does not take place in Oman, as is shown in Table 4-11.

The non-energy section covers the treatment and disposal of waste, including incineration/burning, the disposal of solid wastes in landfills, and aerobic and/or anaerobic treatment of municipal sewage.

The assumptions used in this study for the methane emissions from MSW landfills are as follows:

- The MSW generation rate in 2040 is subjected to a decrease from 1.2 'current accounts' to less than 1 kg/capita/day, which is converted to 0.365 t/capita in 2040 (Be'ah).
- The projection for the proportion of the population whose waste is collected is linked directly to the population size. Be'ah, the national waste collection body, declared that waste was collected for 100 % of the population in 2010; this study has therefore assumed that 100% of the population is covered by waste collection in future years.

As there is no untreated sewage discharge in Oman, there are also no methane emissions from domestic waste water treatment. The Oman Wastewater Services Company S.A.O.C (Haya) turns all sewage into treated water which is then used for irrigation, plantations, fountains, and playgrounds. Human waste is converted into fertilizer.

4.2.2 Mitigation scenarios for the oil and gas sector:

Two mitigation scenarios have been developed for the oil and gas sector, and target the reduction of BC, $PM_{2.5}$, NMVOCs, and CH_4. The first is the 'Fugitive Reduction Scenario' (FRS): In this scenario, energy consumption from 2010 to 2050 is driven by measures aimed at reducing fugitive emissions in the oil and gas sector by 30% in 2030 and by 75% in 2050, compared to the figure for 2010. The second is the 'Zero Flaring Scenario' (ZFS): in this scenario, energy consumption from 2010 to 2050 is driven not only by economic growth but also by an intention to reduce flaring emissions from oil and gas production and refineries to zero in 2030. The mitigation options suggested for the oil and gas sector were listed in Table 4-1 and are summarized in Table 4-14.

Table 4-14: Key assumptions of oil and gas sector mitigation scenarios: Fugitive Reduction Scenario (FRS) and Zero Flaring Scenario (ZFS)

	(BAU)	Measure of mitigation scenario
Fugitive Reduction Scenario (FRS)	no activity data required, as the projection is driven by the growth in the demand for oil and gas	Extended recovery and use—rather than venting—of associated gas, and improved control of unintended fugitive emissions from oil production. Reduced gas leakage from long-distance transmission pipelines. Avoid fugitive emission by advanced technology. Emissions control of venting and flaring of CH_4, NMVOCs, and CO_2 as follows: (2030,50,2050,75)
Zero Flaring Scenario (ZFS)	Based on actual historical data of volume of gas flared from oil and gas industry as illustrated before in table 4.10b	Elimination of flaring by 2030 based on Zero flaring initiative from oil and gas production; Methane flaring: (2030,0) NMVOCS flaring: (2030,0) And from the refineries; Flaring: (2030,0)

4.2.3 Mitigation scenarios for Power sector (electricity generation):

Electricity demand in the Main Interconnected System (MIS) is expected to grow strongly in the medium term. OPWP's base case assumption for the MIS is for 9% growth per year in electricity to 2021. This study proposes two scenarios it considers to be the most effective in dealing with the high level of emissions from this sector: the 'renewable energy scenario' and the 'zero coal scenario'.

The Renewable Energy Scenario (RES) encourages the country to look to new energy sources such as solar and wind. The assumption in this scenario is that it is possible to have a higher percentage share of renewable energy (solar, and wind) for generating electricity than that stated in the government plan. This would lower the percentage share for natural gas and diesel. The Zero Coal Scenario (ZCS) suggests that if the government pulls back from their decision to set up a new coal-fired project, Oman's future plans will no longer include the use of coal for generating electricity. These mitigation options suggested for the power sector are summarized in Table 4-15.

Table 4-15: Key assumptions of power (electricity generation) sector mitigation scenarios: Renewable Energy Scenario (RES) and Zero coal Scenario (ZCS)

	(BAU)	Measure of mitigation scenario
Renewable Energy Scenario (RES)	OPWP plans to develop 2,600 MW of installed capacity of renewable energy (RE) projects by 2024, or renewable energy will generate at least 10% of electrical energy by 2025*. Coal:(7% in 2024, 50% in 2030) Diesel:(3% in 2016)	More ambitious vision for using renewables, going far beyond the government vision, as follows: Solar:(40% in 2030, 50% in 2050) Wind:(10% in 2030, 20% in 2050) NG:(50% in 2030, 30% in 2050) Diesel: (0%)
Zero Coal Scenario (ZCS)	Coal will be utilized to fuel up to 3,000 MW of generation capacity by 2030*	Coal: (0%) Diesel: (3% in 2016) NG: (97% in 2016)

*Source: (OPWP, 2018)

4.2.4 Mitigation scenarios for manufacturing industry sector:

Two mitigation scenarios are suggested for the manufacturing industry sector: The Efficient Industry Scenario (EIS) and the Clean Fuel Scenario (CFS). Both were developed for greater efficiency and the use of cleaner fuel, and are summarized in Table 4-16.

Table 4-16: Key assumptions of industry sector mitigation scenarios: Efficient Industry Scenario (EIS), and Clean Fuel Scenario (CFS)

	(BAU)	Measure of mitigation scenario
Efficient Industry Scenario (EIS)	No change in energy intensity	To reduce growth of the final energy intensity in the industry sector to (0%, 2018) and, (-2.0/100)
Clean Fuel Scenario (CFS)	The percentage share of fuel in the manufacturing industry is: HFO: 78% NG: 16% Electricity: 6%	To shift from using HFO in the industry to cleaner fuel as a preventive action to reduce pollution as follows: HFO: (2050, 0%) NG: (2050, 50%) Electricity: (2050, 50%)

4.2.5 Mitigation scenarios for road transport sector:

Among the numerous mitigation measures available for the transport sector, the study is exploring only those recommended for Oman, and seen as most suitable for the specific socio-economic context of the country. Three mitigation measures have been selected as control measures for transport emissions. These are the Electric Vehicles Scenario (EVS), which would increase the market penetration of electric cars; the Public Transport Scenario (PTS), which would improve the public transport system, and add trams; and the Paved Road Scenario (PRS), which would improve the road system by increasing the ratio of paved over unpaved roads. These three measures, illustrated in Table 4-17, were all selected because of their potential for emission reduction. A combination of the first two scenarios outlined would see an increase in the number of electric vehicles and the use of public transport, and would also mean that energy consumption from 2010 to 2050 would be driven by the desire not only for economic growth but also for a shift to cleaner vehicles and public transport. The paved road mitigation scenario would aim to have 97% of roads paved by 2050, and thus to further reduce PM emissions in the transport sector.

Table 4-17: Key assumptions of transport sector mitigation scenarios: Electric Vehicles Scenario (EVS), Public Transport Scenario (PTS), and Paved Road Scenario (PRS)

	(BAU)	Measure of mitigation scenario
Electric Vehicles Scenario (EVS)	Gasoline and diesel vehicles are projected based on the stock turnover model described in section 4.2.1.2	penetration of electric vehicles: Passenger cars: (20% in 2030,80% in 2050) Light commercial vehicles (20% in 2030, 80% in 2050) Heavy duty vehicles (10% in 2030, 30% in 2050) Motorbikes (50% in 2030, 100% in 2050) Urban buses (50% in 2030, 100% in 2050)
Public Transport Scenario (PTS)		Improving the public transport system, and adding trams. The assumption here is reduction by 20% in 2030 and by 40% in 2050 in passenger cars km travelled. This would reduce the number of vehicle users, and the money used in other forms of private transportation. It will also reduce road traffic accidents in Oman, and reduce demand for petrol and diesel
Paved Road Scenario (PRS)		Unpaved roads play a major role in the emission of $PM_{2.5}$, so having more paved roads will help to reduce $PM_{2.5}$: By 2030, 30% of unpaved roads will be paved, and by 2050, 70% of unpaved roads will be paved.

4.2.6 Mitigation scenario for Residential and commercial and public services sector:

It is known that most electricity consumption in residential buildings is used to power air conditioners, lighting appliances and water heaters. "Compared to other appliances, air conditioners are considered the most energy-consuming appliances," stated a report by the Implementation Support & Follow-Up (ISFU) unit set up by the Diwan of the Royal Court and tasked with accelerating Oman's economic diversification.

The annual growth rate of the residential sector is estimated at a high 28.5%, which could result in a similar increase in residential electricity consumption. However, as shown by the study conducted by Alalouch *et al.*, (2019b), described earlier, considerable amounts of energy could be saved if proper building codes were put in place. If this were done for the period between 2015 and 2040, his estimates were for reductions of from 13.2% in warm tropical climate areas to 48% in hot dry climate areas.

This study has thus developed two mitigation scenarios to reduce emissions from residential and commercial sectors; these are illustrated in Table 4-18. The first is the Residential Efficient AC Scenario (REACS), and the second the Commercial Efficient AC Scenario (CEACS); both are based on the assumption of a 48% reduction in energy consumption by 2040, as shown in the study by Alalouch et al., (2019).

Table 4-18: Key assumptions of residential, commercial and public services sector mitigation scenario: Efficient AC Scenario (EAS)

	(BAU)	Measure of mitigation scenario
Residential Efficient AC Scenario (REACS)	No change in energy consumption	Reduction of energy consumption by 48% in 2040
Commercial Efficient AC Scenario (CEACS)		

4.3 Results and Discussion:

This study has developed a range of different scenarios, from the pessimistic assumption of the Business As Usual scenario (BAU), in which no further air pollution and climate policy will be in place, to optimistic scenarios where climate and air pollution measures are integrated and implemented. It has presented scenarios focusing on the different sectors - oil and gas, electricity generation, the manufacturing industry, and transport - which had been identified as the major sources of emissions in Oman in the base year 2010.

4.3.1 Emissions trends:

Table 4-19 and Figure 4-8 show the total emissions for different gases and particles (CO_2, CH_4, SO_2, NMVOCs, NO_x, $PM_{2.5}$, CO, NH_3, BC, and OC) in the business-as-usual (BAU) scenario for Oman in 2010, and also the progression for 2020 to 2050. In the BAU scenario, CO_2 emissions are projected to grow from 50 Mt in 2010 to 140 Mt by 2030, and to 315 Mt by 2050. Emissions of CH_4 and SO_2 are expected to grow to 125 Mt by 2050. As can be seen from Figure 4.6, NOx and CH_4 have similar emission growth trends, while CO_2 and SO_2 emission growth trends are significantly steeper.

Table 4-19: Total pollutant emissions in kt for Oman for the BAU scenario

Effects	2010	2020	2030	2040	2050
CO_2	49,948	88,777	140,399	215,334	314,867
CH_4	564.8	687.5	743.9	945.0	1,248.7
SO_2	159.6	222.9	435.9	740.2	1,255.4
NMVOC	142.1	172.6	206.1	267.9	323.7
NO_x	136.9	156.3	247.2	419.7	705.3
$PM_{2.5}$	60.8	138.2	215.6	300.5	309.3
CO	50.8	69.1	99.5	153.9	201.0
NH_3	17.8	20.3	23.4	28.1	34.0
BC	3.9	4.9	5.6	7.5	10.7
OC	0.9	1.1	1.6	2.8	4.6

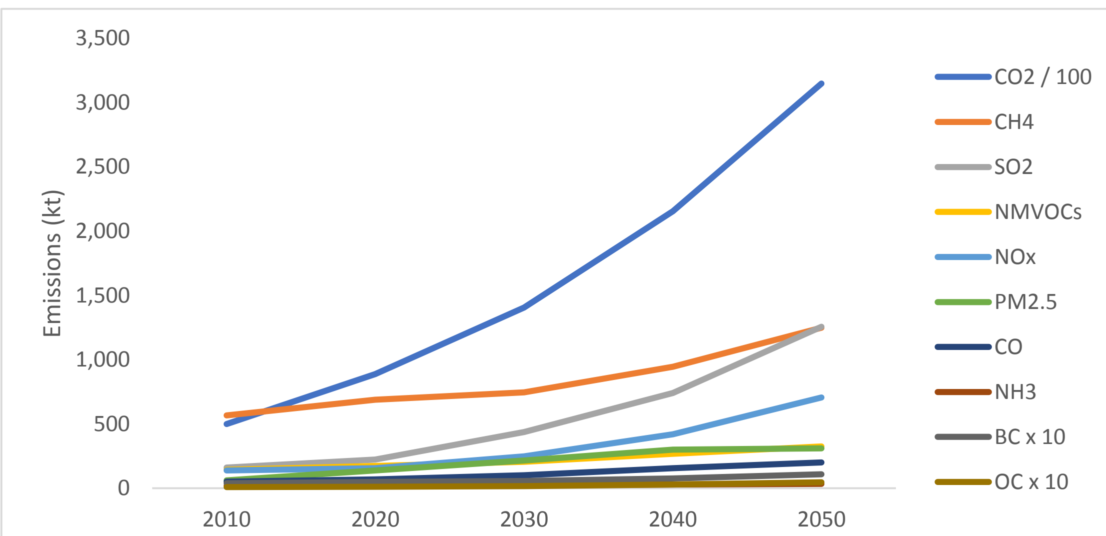

Figure 4-8: Baseline scenario emissions estimate from 2010 to 2050

The following sections will present the results of the mitigation scenarios for the major sectors in Oman; the discussion of each sector will also note the implications for policy. Table 4-20 lists the twelve scenarios developed in this study, and the abbreviations used for each. The final all-measures scenario, AM, presents what would occur if all the mitigation measures were combined.

Table 4-20: The 12 scenarios which developed in this study with abbreviation

Sector		Scenario	Abbreviation
	1	Business - as - Usual	BAU
Oil and gas	2	Fugitive Reduction Scenario	FRS
	3	Zero Flaring Scenario	ZFS
Electricity generation	4	Renewable Energy Scenario	RES
	5	Zero Coal Scenario	ZCS
Manufacturing industry	6	Efficient Industry Scenario	EIS
	7	Clean Fuel Scenario	CFS
Transport	8	Electric Vehicle Scenario	EVS
	9	Public Transport Scenario	PTS
	10	Paved Road Scenario	PRS
Residential	11	Efficient Air Conditioning Scenario	REACS
Commercial and Public services	12	Efficient Air Conditioning Scenario	CEACS
(2-12) All measures combined			AM

4.3.2 Oil and gas industry mitigation scenario:

The oil and gas industry, which includes gasoline service stations, gasoline transport and depots, oil refining, oil transport, oil production, gas distribution, gas transmission and storage, gas processing, gas gathering and gas production, contributed the following amounts to Oman's 2010 emissions: 92% of NMVOCs, 69% of CH_4, 11 % of CO_2, and 4% of SO_2,with minor contributions to CO and NO. These figures, were presented earlier in Chapter Two, and Figure 4-9 illustrates the considerable change to which these emissions would be subjected in a BAU scenario.

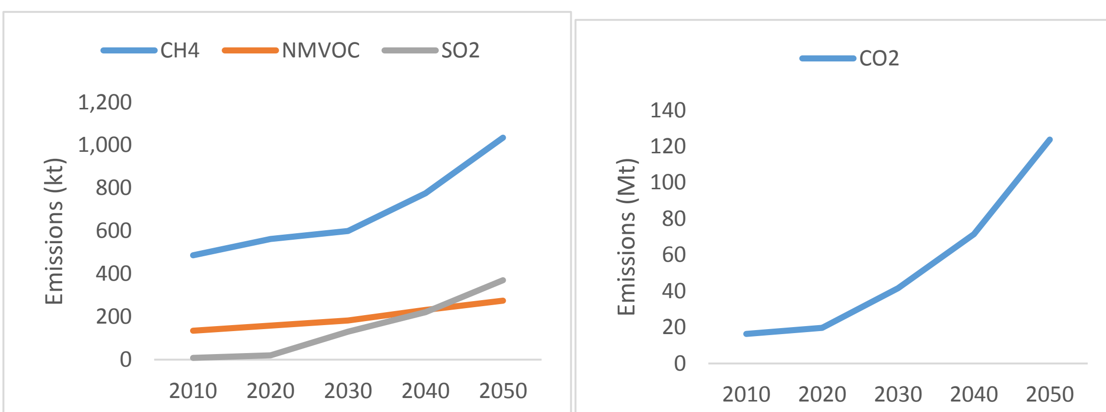

Figure 4-9: Baseline scenario emissions estimate from 2010 to 2050

As outlined in Section 4.2.3, this study has developed two scenarios to reduce emissions of CO_2, CH_4, NMVOC, and $PM_{2.5}$, by the oil and gas sector: the Fugitive Reduction Scenario (FRS) and the Zero Flaring Scenario (ZFS). The following Figures 4-10, 4-11, and 4-12 present the results that would be obtained in each of these scenarios.

Fugitive Reduction Scenario (FRS):

FRS targets the fugitive emissions of CO_2, CH_4, and NMVOCs from oil and gas production. In Figure 4-10, the total fugitive emissions in BAU (2020 – 2050) are represented by the combined blue and white parts of each column, while the white part of the columns represents the reduction in emissions (mitigation) that would be achieved by the given years. Thus, by 2050, almost 800 kt of CO_2 emission out of 1,000 kt could be prevented via FRS. Even greater levels of reduction would be achieved in emissions of CH_4 and NMVOCs, with 200 kt out of 290 kt of CH_4 being avoidable by 2050, and 90 kt out of 120 kt of NMVOCs.

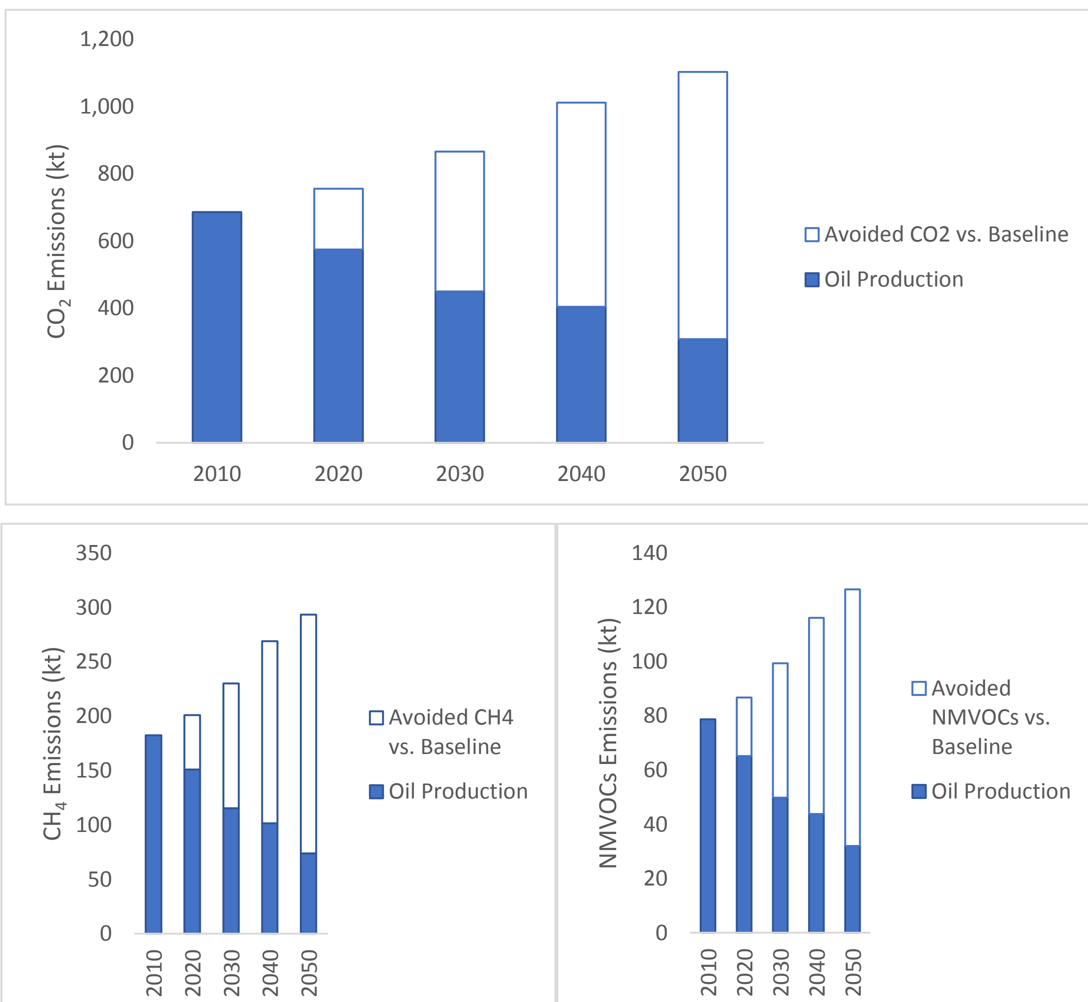

Figure 4-10: Fugitive reduction scenario in oil and gas sector Avoided vs. Baseline, for CO2, CH4, and NMVOCs

Zero Flaring Scenario (ZFS):

ZFS targets flaring within oil production; implementation of the scenario will stop flaring and eliminate the emissions of $PM_{2.5}$ and BC by 2030, as shown in Figure 4-11. In this scenario, 3500 t of $PM_{2.5}$ and 2800 t of BC emissions will avoided, as compared with those in the BAU scenario.

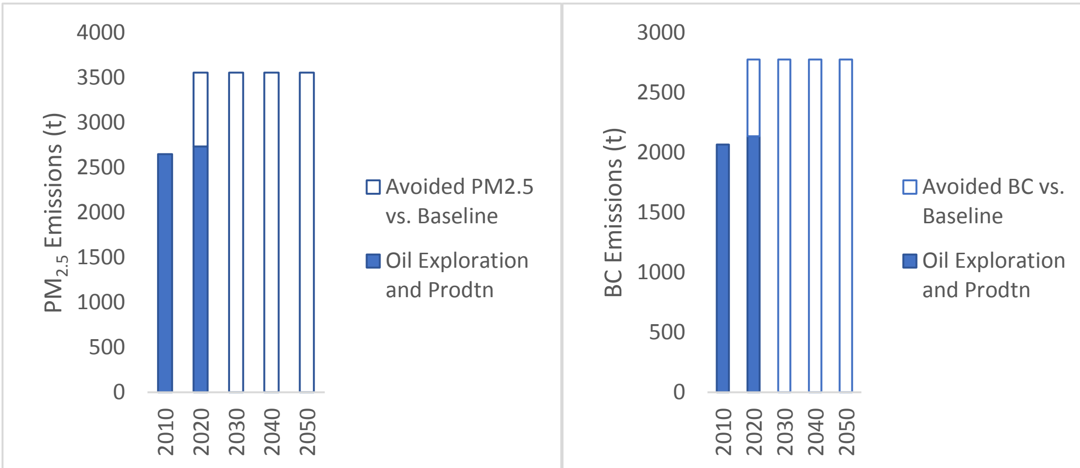

Figure 4-11: Zero flaring scenario in oil and gas sector Avoided vs. Baseline, for $PM_{2.5}$ and BC

Figure 4-12 illustrates the reduction of NMVOCs emission in the oil and gas sector for each scenario: the baseline scenario (BAU), the fugitive reduction scenario (FRS), the zero flaring scenario (ZFS), and the All Measures (AM) scenario for the oil and gas sector. It is clear that the FRS would have a greater effect on the reduction of NMVOCs by 2050 than the ZFS, while the implementation of both scenarios would reduce NMVOCs to almost a half, from 318 kt to 170 kt.

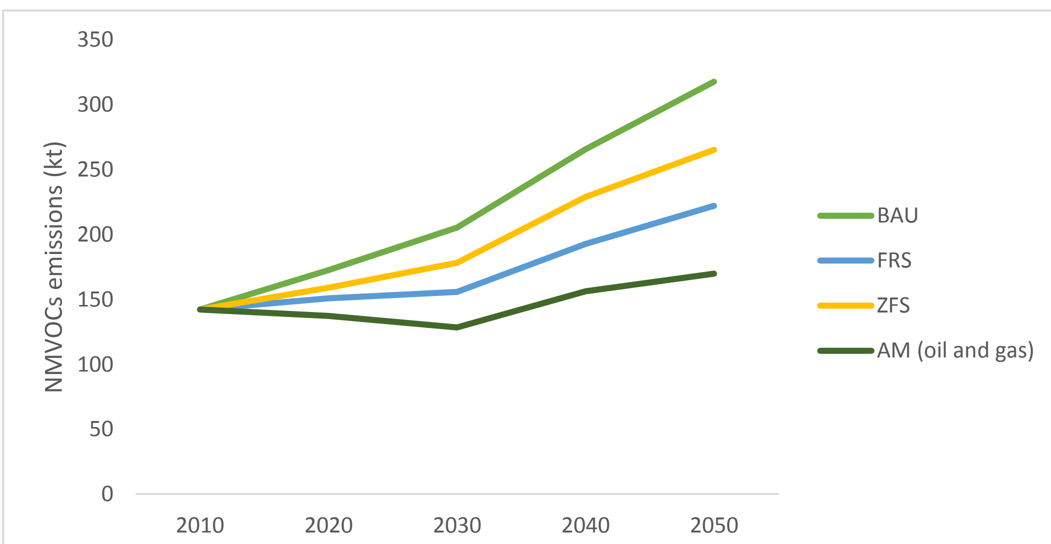

Figure 4-12: Comparison of NMVOCs emissions projection 2010 – 2050 for the fugitive reduction scenario (FRS), zero flaring scenario (ZFS), business as usual scenario (BAU) and the All Measures (AM) scenario for the oil and gas sector

4.3.3 Electricity generation (power) mitigation scenarios:

As demonstrated in Chapter Two, electricity generation made the following contributions to Oman's emissions in 2010: 32% of emission, 24% of CO and 20% of NO_x, with minor contributions of $PM_{2.5}$, NH_3, BC and OC. Figure 4-13 shows emissions for the BAU scenario, with a particularly dramatic rise in CO_2 emissions.

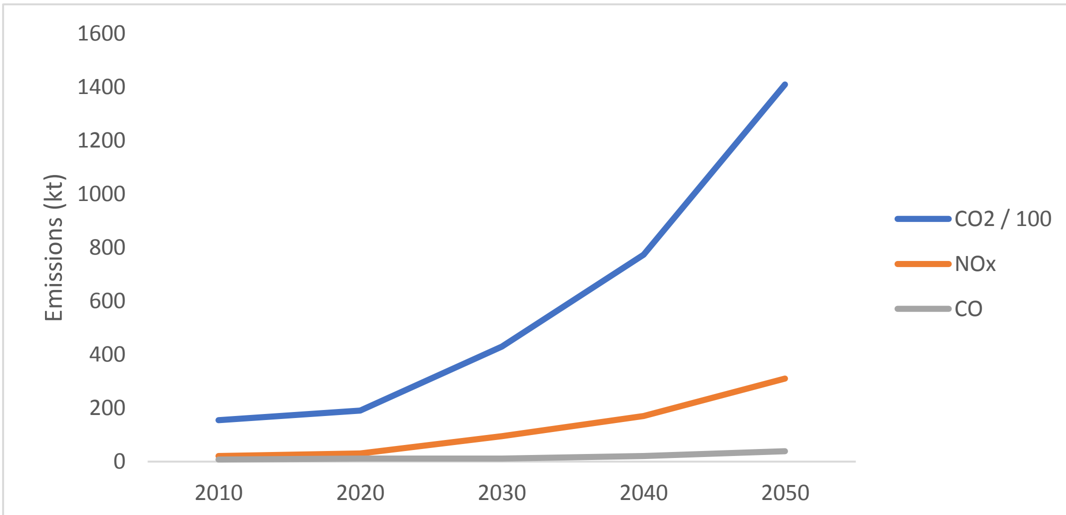

Figure 4-13: The change in electricity generation emissions based on BAU scenario.

This study developed two scenarios to reduce emissions of CO_2, CO, and NO_x in the electricity generation sector, the Renewable Energy Scenario (RES) and the Zero Coal Scenario (ZCS). These were described earlier in Section 4.2.4 and are illustrated in the Figures below.

Renewable Energy Scenario (RES):

RES aims to reduce emissions of CO_2, CO, and NO_x by replacing the natural gas used for generating electricity with solar and wind energy; the success it would achieve in reducing emissions is shown in Figure 4-14.

By 2050, RES will be able to reduce CO_2 emissions from 123 Mt in the BSA to 23 Mt, a reduction of 100 Mt. RES will also avoid over 80% of NOx emissions that would occur in BAU, and half those of CO.

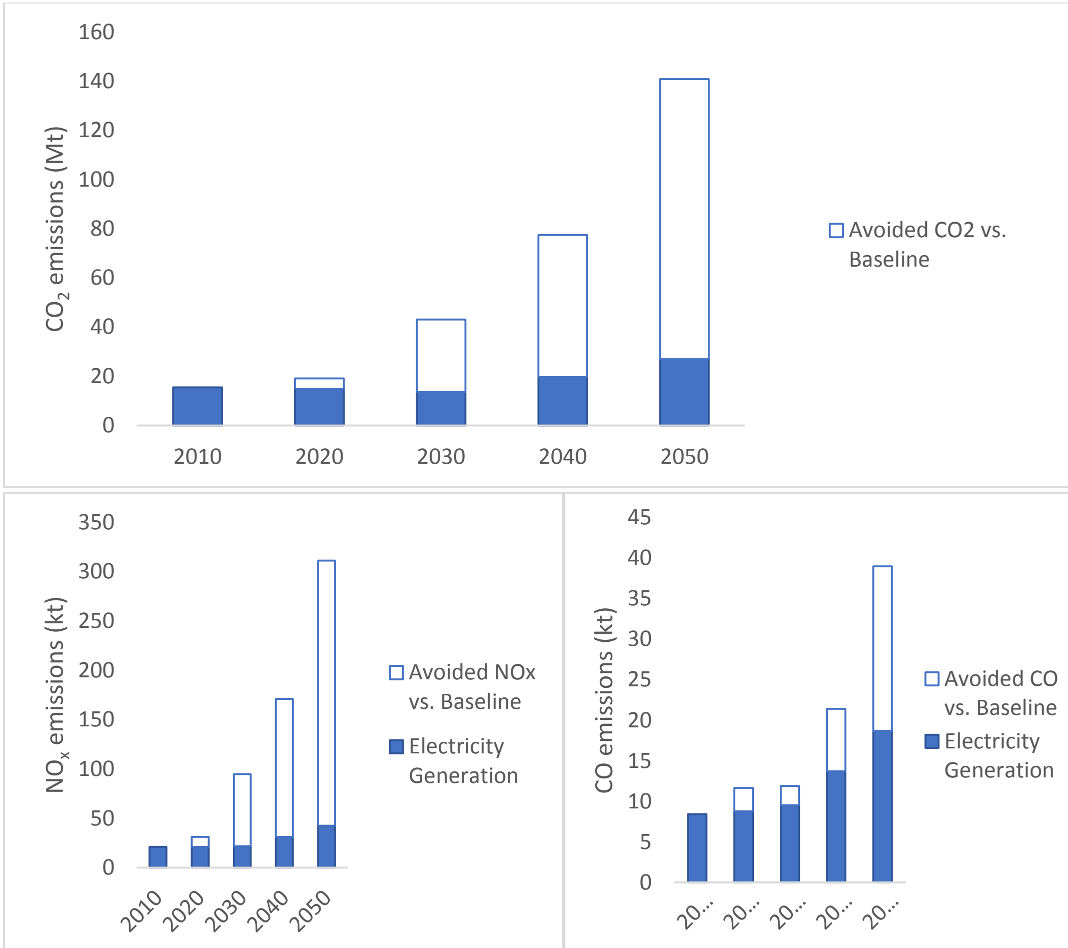

Figure 4-14: Renewable energy scenario in electricity generation, showing avoided emissions for CO_2 and NOx and CO

The CH_4, NMVOCs, and $PM_{2.5}$ emissions would also be reduced, as shown in Figure 4-15.

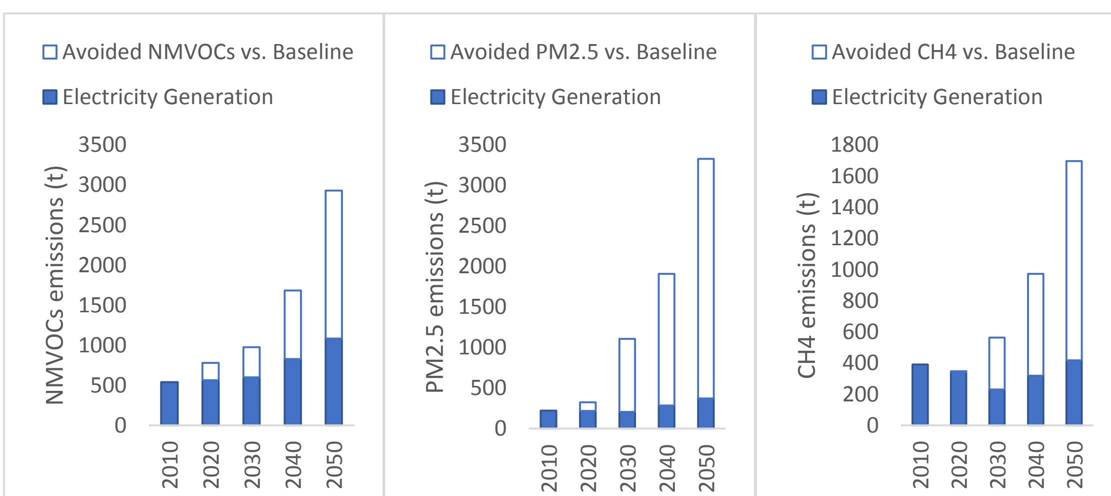

Figure 4-15: Renewable energy scenario in electricity generation, showing avoided emissions for NMVOCs, and $PM_{2.5}$ and CH_4

Zero Coal Scenario (ZCS):

ZCS would obviously have an impact on the CO_2 and NO_x emissions from the electricity generation sector. Figure 4-16 shows that one third of the 2050 CO_2 emissions, or 40Mt, in the BAU scenario could be avoided by the ZCS; it could also reduce NO_x emissions by more than half (146 kt).

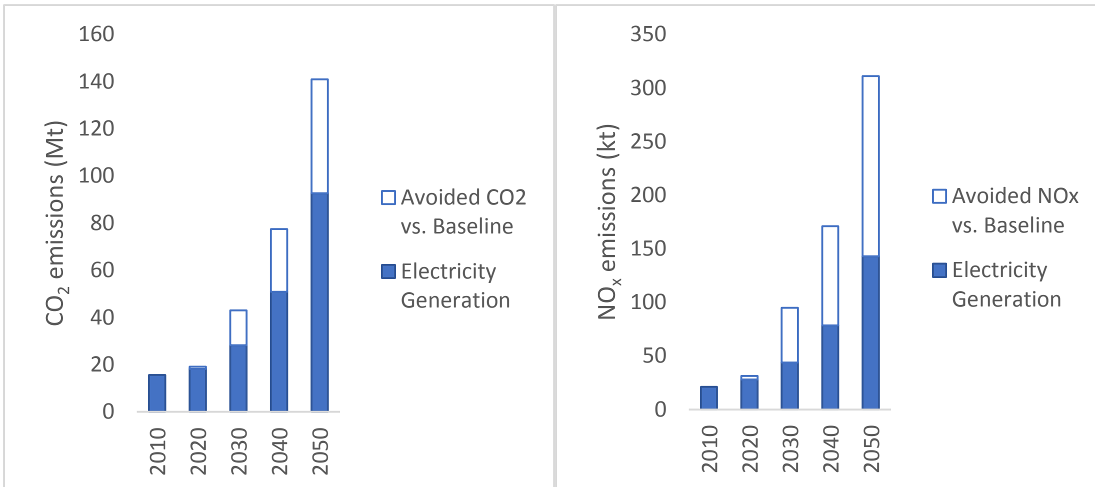

Figure 4-16: Zero coal scenario in electricity generation sector Avoided vs. Baseline, for CO_2 and NO_x

4.3.4 Manufacturing industry mitigation scenario:

The industry sector here includes the manufacturing industry, industrial processes involving minerals and chemicals, and energy industry own use (oil refineries and other energy industry own use). In 2010, this sector contributed to Oman's emissions as follows: 95% of total SO_2 emissions, 49% of NOx emissions, 42% of OC, 41% of CO_2, 37% of BC, 31% of NH_3 emission, 28% of CO emission, and 24% of $PM_{2.5}$. There was only a minor contribution from NMVOCs. The 2010 situation was detailed in Chapter Two, and the projected emissions for the BAU scenario are illustrated in Figure 4-17.

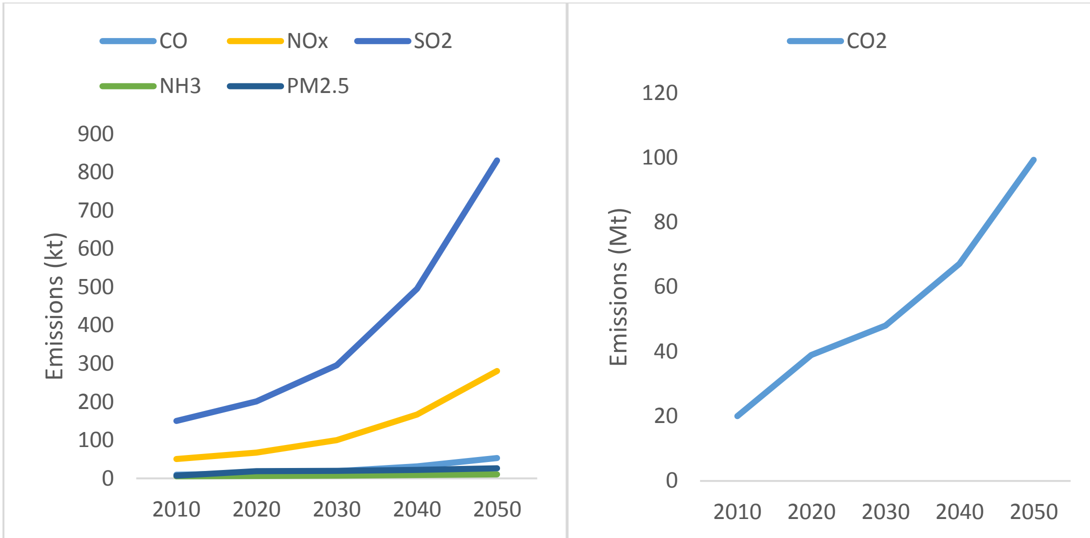

Figure 4-17: The change in industry emissions based on BAU scenario

Two scenarios, mainly to reduce emissions of SO_2, and NO_x, were developed for the manufacturing industry sector. These were the Efficient Industry Scenario (EIS) and the Clean Fuel Scenario (CFS), described earlier in Section 4.2.5 and illustrated in Figures 4-18 and 4-19 below.

Efficient Industry Scenario (EIS):

Figure 4-18 shows that EIS, relative to the BAU, would reduce emissions of CO_2 by 23% (or 3 Mt) by 2030, and by 39% (or 14 Mt) by 2050. Emissions of SO_2 would be reduced by 18% (45 kt) in 2030, and by 39% (275 kt) by 2050.

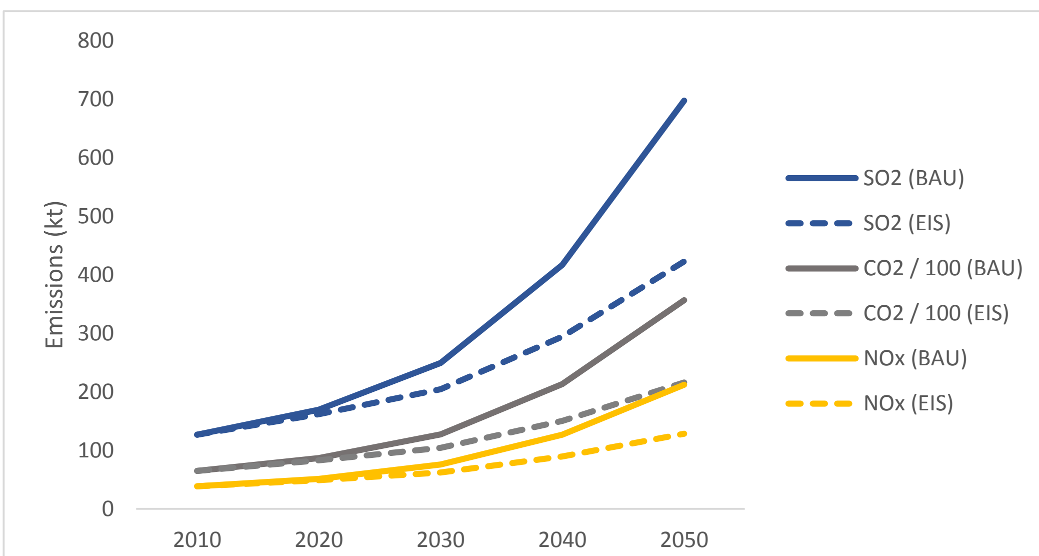

Figure 4-18: Efficient industry scenario (EIS) versus BAU scenario emissions for CO_2, SO_2 and NO_x

Clean Fuel Scenario (CFS):

In this mitigation scenario, the action taken would be primarily preventive, as it would involve the industry sector replacing the high-sulphur heavy fuel oil it currently uses with cleaner fuel. Figure 4-19 shows that in the BAU scenario there would be a sharp increase in the sulphur emissions from the industry sector between 2010 and 2050, resulting from the parallel growth in GDP and industry. Under CFS, however, there would be a significant drop in the SO_2 emissions, with a co-benefit of the reduction of CO_2 and NO_x emissions as well.

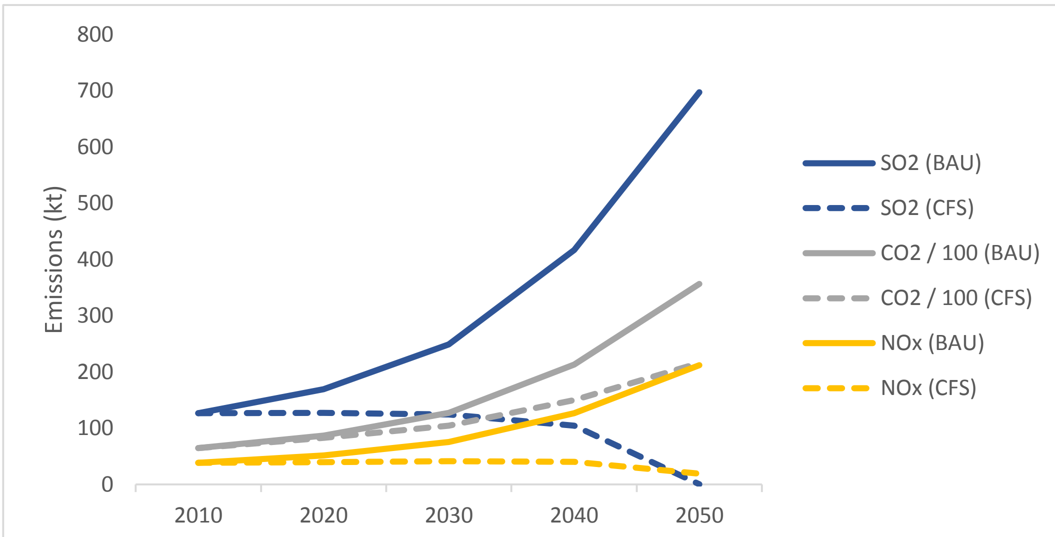

Figure 4-19: Clean fuel scenario (CFS) versus BAU scenario emissions for CO_2, SO_2 and NO_x

4.3.5 Road transport mitigation scenario:

The transport sector includes passenger cars, light commercial vehicles, heavy duty vehicles, urban buses and motorbikes. As demonstrated in Chapter Two, the sector contributed to Oman's 2010 emissions as follows: PM_{10} emission (90%), $PM_{2.5}$ emission (63%), CO emission (39%), NO_x emission (17%), CO_2 (14%), BC emission (5%), and OC (4%). Figure 4-20 shows how these emissions would change in a BAU scenario, with some emissions increasing at a higher rate than others, and some even decreasing. These variations can be explained by the fact that some emissions are more stringently controlled by EURO standards than are others; the more highly controlled are therefore not increasing as fast as the less controlled $PM_{2.5}$ and CO_2.. Indeed, for NO_x and CO, their emissions per vehicle are decreasing. For $MP_{2.5}$,, road dust is also an important factor. Although $MP_{2.5}$ should be mitigated by EURO standards, road dust increases this emission from the transport sector, which is why there is a faster increase in $PM_{2.5}$ than in NO_x and CO.

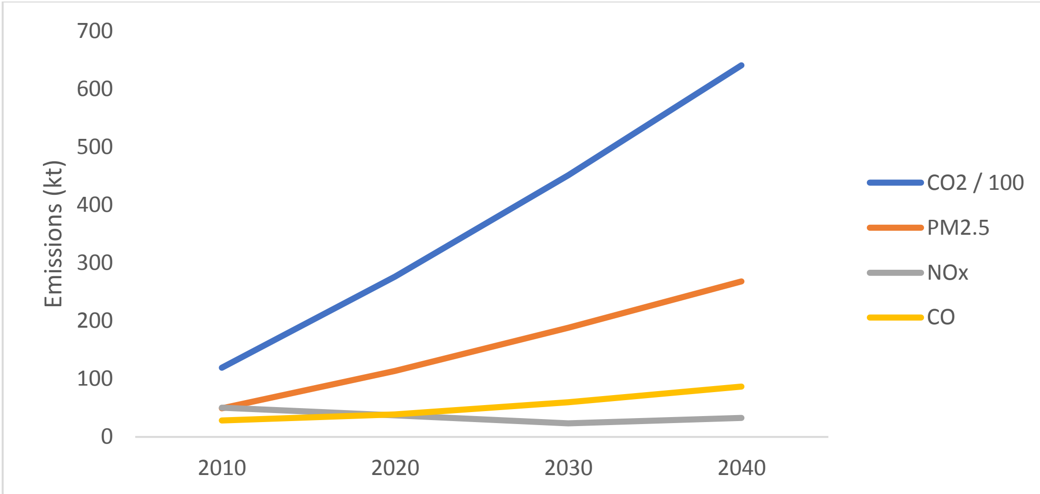

Figure 4-20: The change in transport emissions CO_2, $PM_{2.5}$, NO_x, and CO based on BAU scenario

Three scenarios were developed to tackle emissions from the transport sector: the Electric Vehicle Scenario (EVS), the Public Transport Scenario (PTS) and the Paved Road Scenario (PRS). Each of these scenarios targets a different set of pollutants, as discussed below.

Electric Vehicle Scenario (EVS):

The assumption here is that the penetration of electric vehicles is based on global market trends. Different types of electric vehicles will have different percentage penetration; this was outlined in Section 4.2.6.

Figure 4-21 shows the projection for road transport sector emissions of CO_2, CO, NO_x, and $PM_{2.5}$ from 2010 to 2040 in the BAU scenario. The total emissions in BAU are represented by the combined blue and white parts of each column, while the white part of the columns represents the reduction in emissions (mitigation) that would be achieved by the given years. The results show that EVS would reduce the emissions of CO_2, CO, NO_x, and $PM_{2.5}$ by half by 2040.

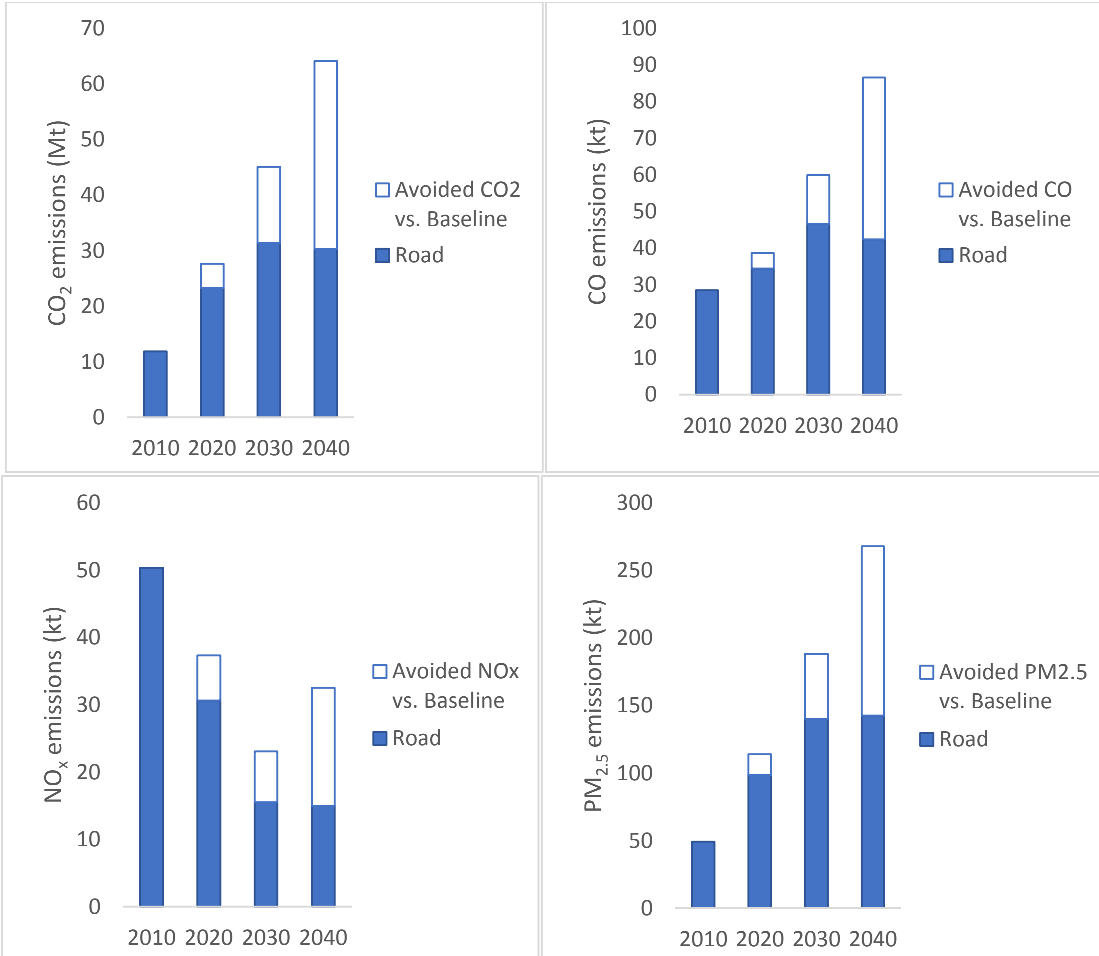

Figure 4-21: Electric vehicles scenario versus BAU scenario emissions for CO_2, CO, NO_x and $PM_{2.5}$

Public Transport Scenario (PTS):

The estimates in this scenario (PTS) are based on the assumption that public transport would become more attractive and that more people would use it, a process described in Section 4.2.6. Although the projection for the number of passenger cars does not change, the projected change is in the distance travelled by those cars, which would decrease from 2020 to 2040 because people would start to rely more on public transport. Figure 4-22 shows that PTS would help to reduce CO_2, $PM_{2.5}$ and NO_x emissions by 5 Mt, 17 kt, and 1 kt respectively, compared with emissions in the BAU scenario.

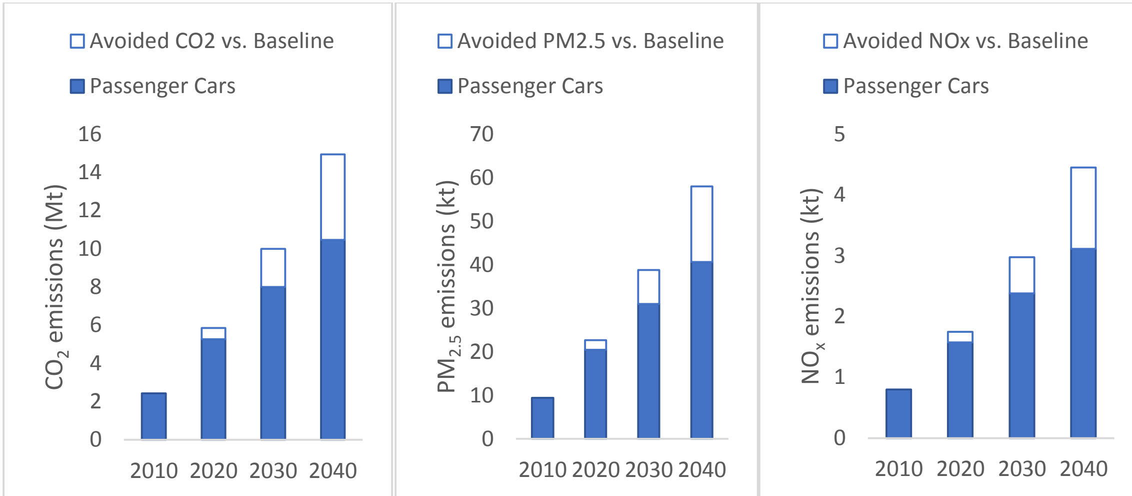

Figure 4-22: Public transport scenario versus BAU scenario emissions for CO_2, $PM_{2.5}$ and NO_x

Paved Road Scenario (PRS):

The PRS scenario envisages that by 2050, 97% of the roads in Oman would be paved. All types of vehicles would therefore travel greater distances on paved roads than they would do in the baseline scenario (BAU), which would decrease the $PM_{2.5}$ emissions caused by road dust. These emissions have a substantial impact on health, and the results of the mitigation will be discussed in Chapter Five. Figure 4-23 shows that when all types of vehicles are travelling greater distances on paved roads, and less on unpaved roads, there is a large reduction in the $PM_{2.5}$ emission from road dust. The results show that, by 2040, PRS would reduce the $PM_{2.5}$ emissions from 268 kt in BAU to only 24 kt, a dramatic reduction.

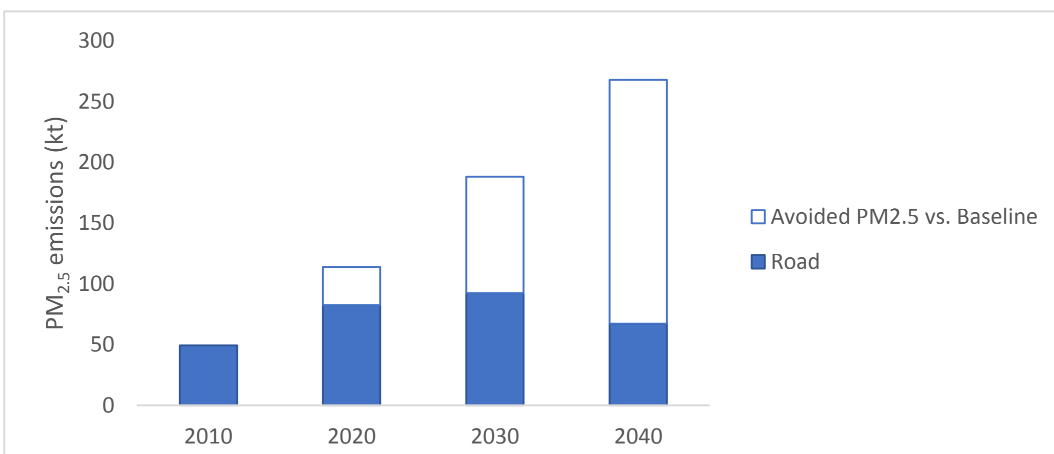

Figure 4-23: Paved road scenario versus BAU scenario emissions for $PM_{2.5}$

Figure 4-24 illustrates the benefits to be gained from the three mitigation scenarios suggested for the transport sector: EVS, PTS, and PRS, when compared with the baseline scenario (BAU). It is clear that the paved road scenario would the most beneficial of the three for $PM_{2.5}$ reduction. The graph also shows the benefit to be gained if all three measures were implemented together, AM.

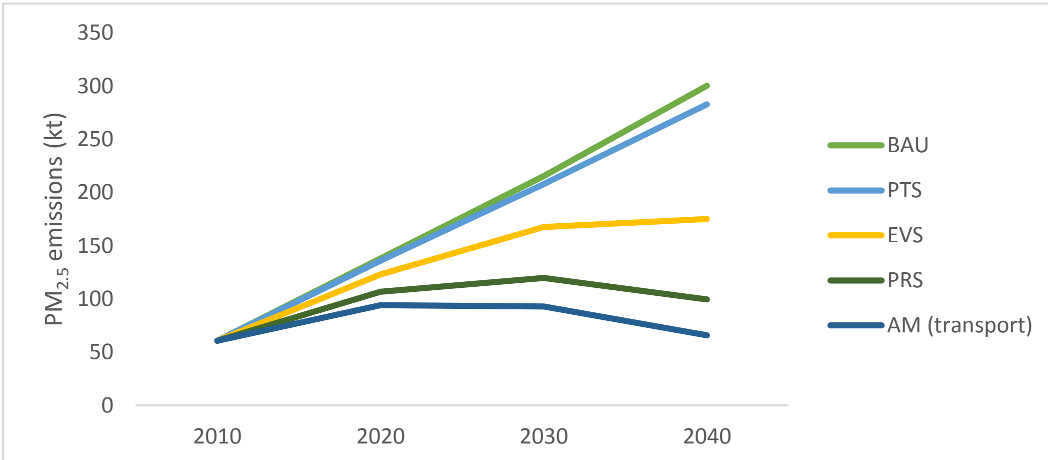

Figure 4-24: Comparison of $PM_{2.5}$ emissions projection 2010 – 2040 for the electric vehicles scenario (EVS), paved road scenario (PRS), public transport scenario (PTS), business as usual scenario (BAU) and the All Measures (AM) scenario for the transport sector

4.3.6 Residential and commercial and public services mitigation scenario:

The results of this study show that, in the BAU scenario, energy demand in the residential sector will increase from 902 ktoe in 2010 to 4,068 ktoe by 2050. The increase in demand in the commercial and public services will be even greater, from 861 ktoe to 8,408 ktoe. Figure 4-25 shows that almost half of this energy is used for air conditioning, while the other half is for lighting, cooking and running other appliances.

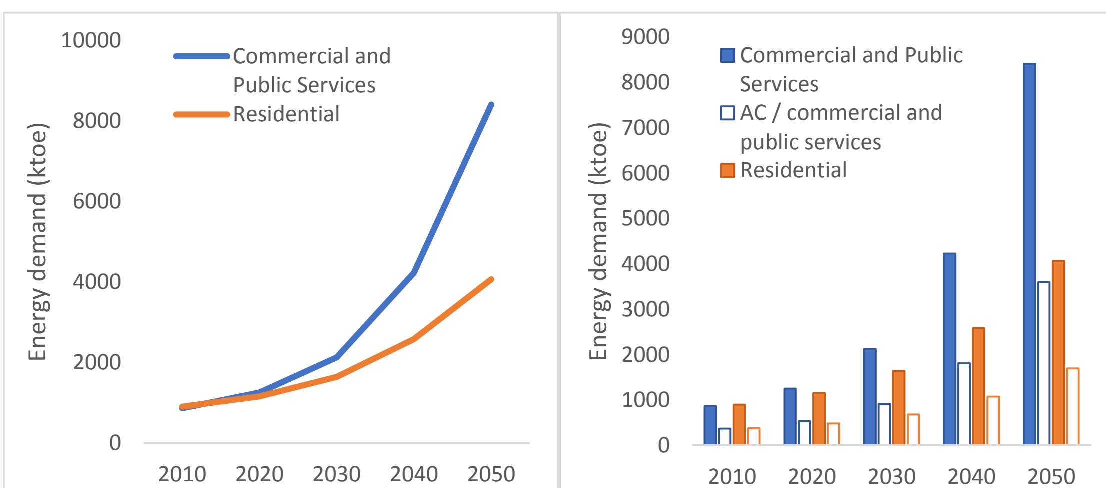

Figure 4-25: BAU scenario of energy demand, thousand tonnes of oil equivalent (ktoe), in residential and commercial and public services sectors and Air conditioning (AC) share for both sectors

These results clearly indicate that the reduction of energy consumption by air conditioning must be the priority within both sectors. Two scenarios were therefore developed to reduce CO_2 emissions in the two sectors: the Commercial Efficient Air Conditioning Scenario (CEACS), and the Residential Efficient Air Conditioning Scenario (REACS). These scenarios were described earlier in Section 4.2.6.

Commercial Efficient Air Conditioning Scenario (CEACS):

Figure 4-26 shows the results. If the CEACS mitigation scenario is implemented, it could avoid more than 18 Mt CO_2 emissions from the commercial and public services sector by 2050.

Residential Efficient Air Conditioning Scenario (REACS):

Figure 4-26 again shows the results. If the REACS mitigation scenario is implemented, it could avoid more than 8 Mt of CO_2 emissions from the residential sector by 2050.

With the implementation of these two mitigation scenarios together, the CEACS and the REACS, efficient air conditioning could achieve a total reduction of almost 27 Mt in CO_2 emissions by 2050.

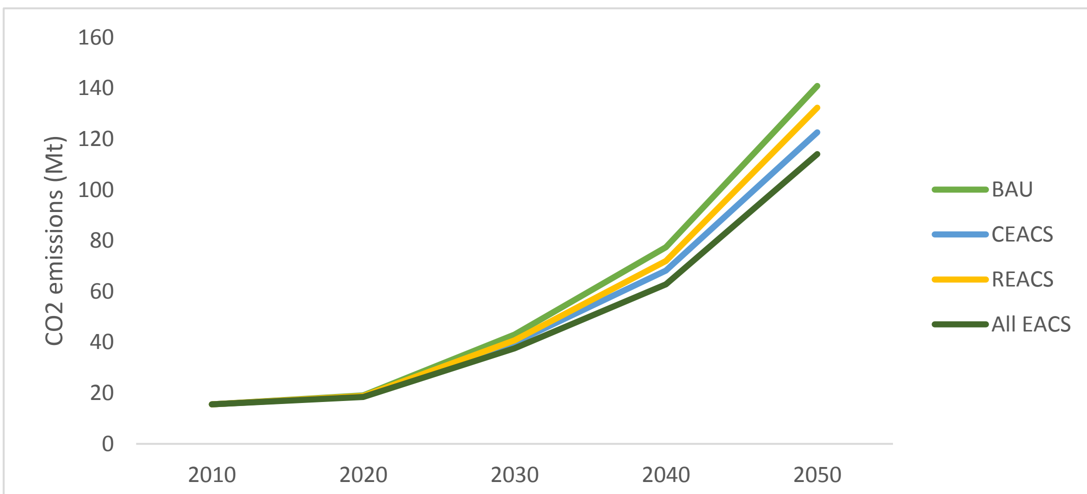

Figure 4-26: Comparison of CO_2 emissions projection 2010 – 2050 for the Business as Usual scenario (BAU), Commercial Efficient Air Conditioning Scenario (CEACS), Residential Efficient Air Conditioning Scenario (REACS), and the All AC Measures (All EACS)

4.3.7 All measures scenario:

As this study shows, the most energy-demanding sector in 2010 is the transport sector, followed by the energy industry's own use in petroleum refining and oil and gas extraction, with the manufacturing industry in the third place. It is also clear from Figure 4.27 that the demand from energy industry own use and from residential and other sectors is set to increase sharply by 2050; this increase can be explained by the projected population growth and by an economic development plan which is focused on the expansion of services and industries. The most demanding sectors in

2050 are projected to be, in descending order: energy industry own use, residential and other sectors (residential, commercial and public services, agriculture and fishing, and non-specified other), the manufacturing industry, and the transport sector. It has been noted that the demand from the agriculture and fishing sectors is exceptionally low (6 kt in 2050) compared with that from other sectors included in the LEAP-IBC categories (7 Mt, commercial and public services; 3.2 Mt, residential; 3 Mt, non-specified other).

However, Figure 4-27 shows that the energy demand situation could be very different if all the mitigation measures suggested were implemented. The energy demands from the different sectors in BAU would be reduced, and one third of the energy, a total of 24 Mtoe, could be saved by 2050.

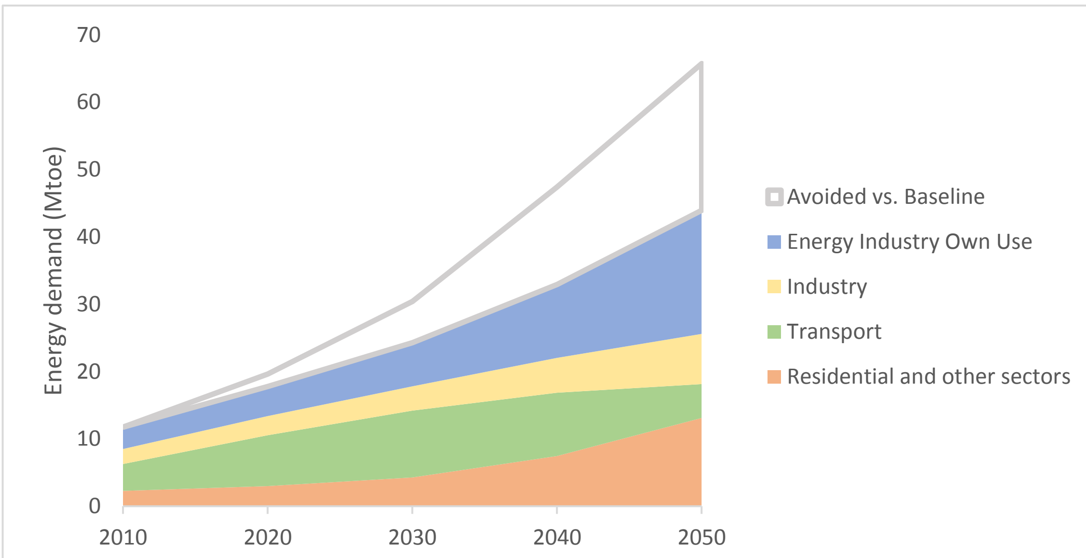

Figure 4-27: Oman historical and future energy demand trends of the BAU scenario versus all measures Avoided (2010-2050)

Projections for CO_2 emissions show that even more dramatic reductions would be possible when compared to the business as usual scenario (BAU). Figure 4-28 shows results for seven different scenarios by 2050. The most effective scenario here is the renewable energy scenario (RES), which will reduce CO_2 emissions by 37% by 2050.

Smaller reductions would be achieved by other scenarios; the efficient industry scenario (EIS) and commercial efficient AC scenario (CEACS) would see similar CO_2 reductions to each other, with the same being true for the electric vehicle scenario (EVS) and zero coal scenario (ZCS). Significantly, then, if all the measures were implemented, CO_2 emissions would drop by a dramatic 60%.

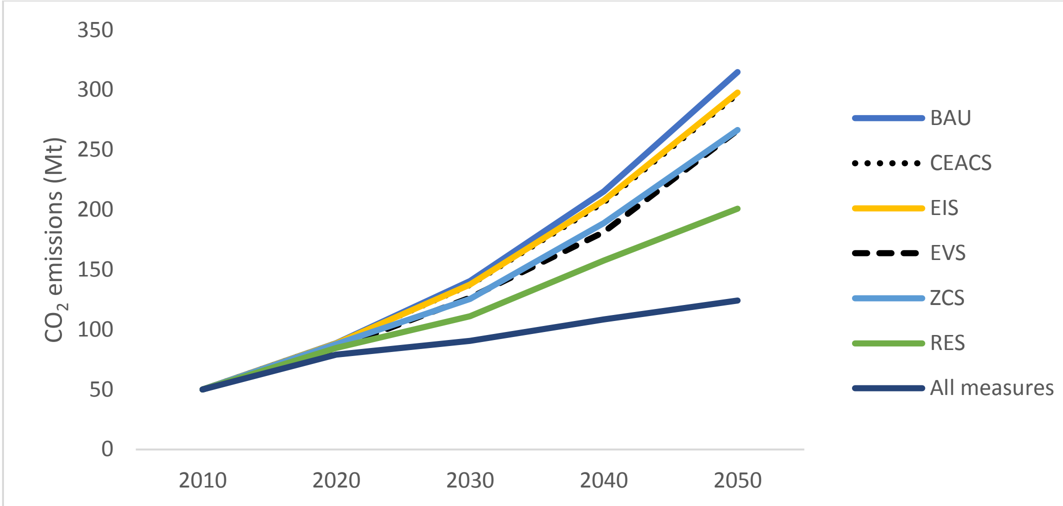

Figure 4-28: CO_2 emissions in the period 2010-2050 under the six mitigation scenarios compared with all measures and the BAU scenarios

Figures 4-29 and 4-30 below summarise and compare the mitigation scenarios and their impacts on pollution reduction. Results from scenarios targeting the oil and gas sector show that FRS, the fugitive reduction scenario, would greatly reduce CH_4 and NMVOCs, while ZFS, the zero flaring scenario, would effectively reduce BC emissions. Results for the transport sector scenarios show that paved road scenario (PRS) and electric vehicle scenario (EVS) would both contribute to the reduction of $PM_{2.5}$ and CO emissions, with the paved road scenario achieving the more remarkable reduction in $PM_{2.5}$ emissions and the electric vehicle scenario achieving a greater reduction in CO. In the power sector, both renewable energy scenario (RES) and zero coal scenario (ZCS) would work very well in reducing NOx emissions, with RES being significantly more effective. In the industry sector, the clean fuel scenario is the most effective in reducing SO_2 and CO emissions.

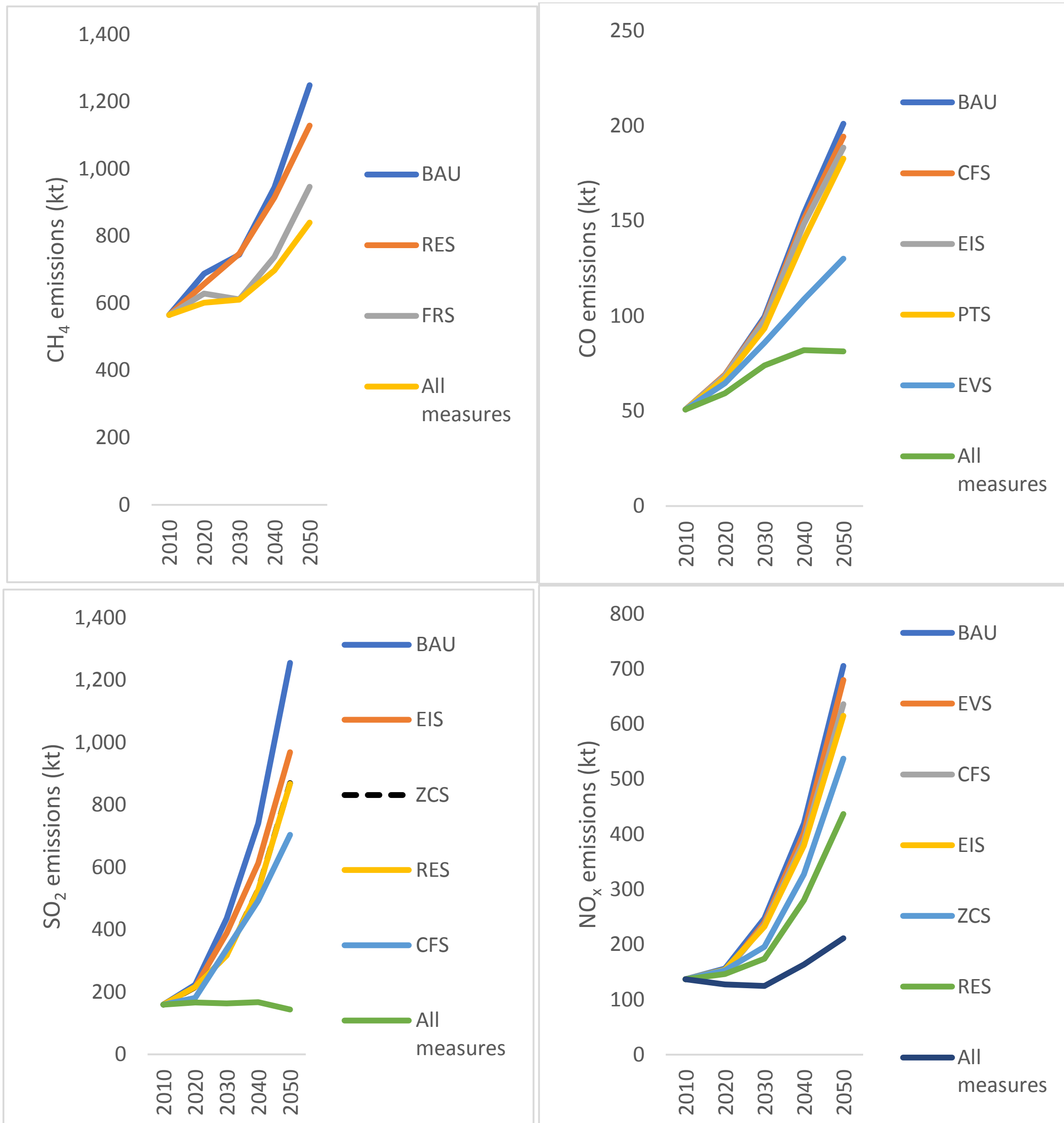

Figure 4-29: CH_4, CO, SO_2, and NO_x emissions in the period 2010-2050 under different mitigation scenarios compared with all measures scenario and the BAU scenario

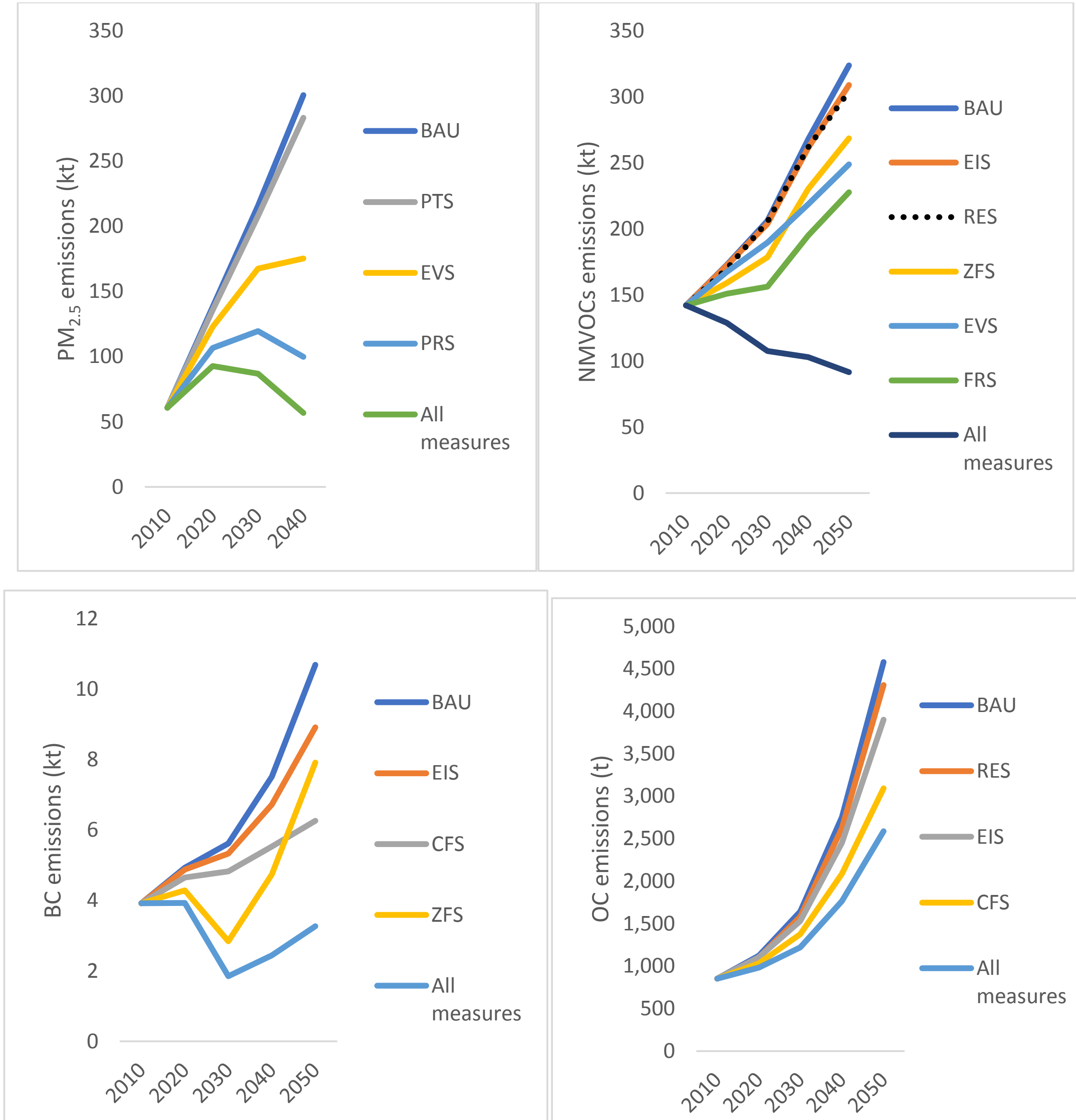

Figure 4-30: $PM_{2.5}$, NMVOCs, BC, and OC emissions in the period 2010-2050 under different mitigation scenarios compared with all measures scenario and the BAU scenario

Oman's NDC clearly states its acceptance of the fact that UNFCCC assistance in finance, capacity building and transfer of technology is conditional on its implementation of the submitted NDC.

The projections of GHG emissions submitted in the NDC are based on forecasts of economic and social growth. In the absence of NDC, GHG is expected to be 90524 Gg in year 2030; however, with mitigation and adaptation strategies, Oman would be able to slightly reduce its growth in projected GHG emissions between 2020 and 2030, which would cut the emissions by 2% to 88714 Gg as depicted in the chart from MECA shown in Figure 4-31 (Ministry of Environment and Climate Affairs, 2015). Given the important role of energy in Oman's GHG emission profile, their mitigation pathways focus exclusively on energy and industrial activities.

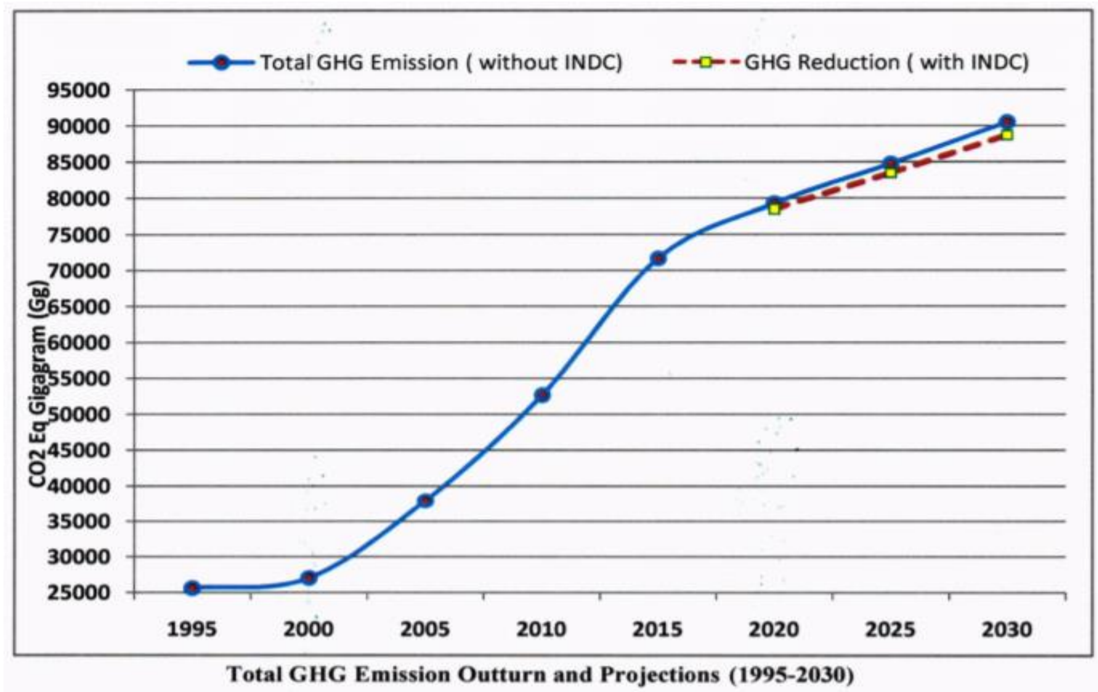

Figure 4-31: Oman GHGs emission projection as business as usual scenario and mitigation scenario, 1994 has been considered for the GHG growth projections

The emissions estimated in the BAU and all measures, AM, scenario of this study are plotted in Figure 4-32. Under the BAU scenario, the total emission of CO_2 and CH_4 in 2030 is 141,000 kt, while the AM mitigation scenario figure of 91,000 kt would achieve a 35% reduction by 2030 and 60% by 2050.

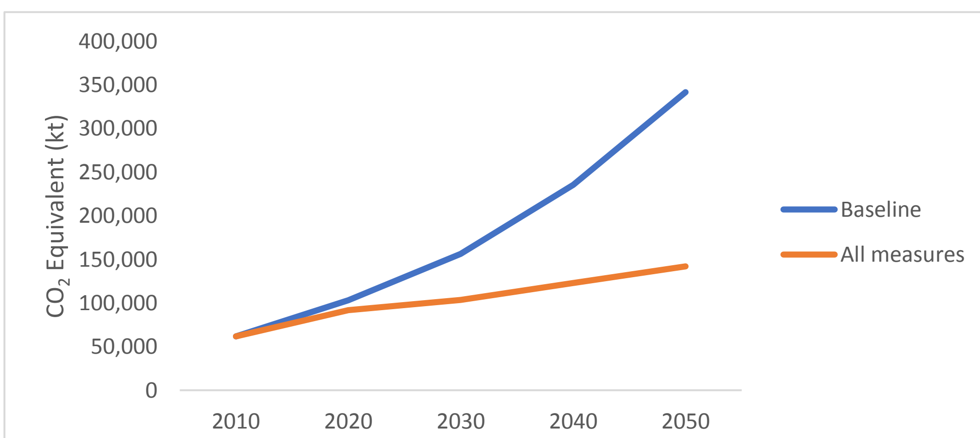

Figure 4-32: Oman CO_2 equivalent projection as BAU scenario and mitigation scenario (all measures) which revealed from this study

Comparing this study with the Oman NDC is difficult because of the lack of information about how the NDC projections were made. However, the estimate of the GHG emissions in this study is likely to be more accurate. This is because the base year for the Oman NDC analysis was 1994, so its growth projections were made from that year, while this study had 2010 as its base year, giving it a much more recent date from which to make projections, as well as the use of historical data from 2010 to 2017.

When a comparison was made between this study and the NDC, it was found that the estimates of emissions for the year 2010, the base year of this study, were relatively similar, despite the base year for NDC being 1994. However, there was a divergence between the NDC and this study for the period between 2010 and 2030. This study has assumed that economic growth will continue based on World Bank GDP growth figures, which would result in an estimate of 160 Mt CO_2 eq in 2030, while the NDC estimate for the same year is only 95 MT CO_2 eq. The reason for this lower estimate is unclear, because the NDC does not explain the growth rate that was used to create the baseline projection.

In the climate change conference of 2019, a new framework was developed for increasing the transparency of countries' climate change commitments; the framework required that more information be included in the NDCs; this would help increase their clarity and transparency, and make it easier to understand them. If Oman follows this framework in future, and explains the assumptions that underlie it, it will be much easier to assess it and compare it with other studies.

4.4 Uncertainty:

Beside the uncertainties related to activity data and emission factors already discussed in Chapter Two, there are other sources of uncertainty related to the future projections considered in this chapter. The major focus in this thesis is on policy, and on the relative differences between the estimated future emissions (and their impacts) in the various mitigation policy scenarios that are being explored. For this reason, the study has not attempted to carry out a formal and comprehensive uncertainty analysis. Also, although there is uncertainty around each individual policy scenario, the relative differences between each scenario are not going to change.

The other sources of uncertainty in the scenarios are as follows:

4.4.1 Extrapolation error:

There is uncertainty in the extrapolation of current trends into the future, and also in using average values; these are both considered as sources of inaccuracy in this study. Technological change and socioeconomic development (GDP, population, etc.) are also sources of uncertainty, and due to lack of some data, available data have been extrapolated from observed tendencies to give the baseline scenario.

4.4.1 Unknown developments:

When constructing baseline emission scenarios to analyse possible future trends, a number of factors can create uncertainty. The emission scenarios are affected by a lack of information on future developments in technology, especially in the long term, with the pathways of technology implementation being significant for most mitigation measures. An incomplete understanding of future developments related to emission factors and of future socio-economic developments are also sources of error and uncertainty.

4.5 Conclusion:

Twelve emission scenarios have been developed and analysed in this study; the BAU scenario and eleven mitigation scenarios.

In the BAU scenario, taken to 2050, all emissions show a remarkable increase with time, with CO_2 emissions increasing most rapidly. Although Oman is attempting to diversify its economy beyond oil resources, the demand for energy will continue to increase with the rise in population and GDP. As a result, the projections made here are expected to change in the near future due to the proposal of a number of projects in the country's development plans. These include the start of operation of the Duqm refinery and petrochemical project, scheduled for 2019, and the coal-fired plant scheduled to start providing energy to the electricity generation power plant by 2024.

The study has explored the strategies outlined in each scenario, with an assessment of the extent to which these mitigation opportunities could reduce emission increases if they were adopted as policy. The findings, by sector, were as follows:

The oil and gas sector has an opportunity to reduce CH_4 by 24% and NMVOCs emissions by 30% by 2050 if It implements the fugitive reduction scenario, taking into account that Oman currently has no policy to control venting from the oil and gas sector. This suggests that Oman should take steps to control fugitive emissions; it should also apply more advanced technology and should set higher standards for monitoring of the processes of oil and gas production.

Although Oman has signed up for the zero flaring initiative, no effective action on this has so far taken place. The chance of eliminating black carbon by banning the practice of flaring is possible if the zero flaring initiative actually becomes a policy. If this is implemented, it would reduce the BC emissions in Oman from 2.8 kt in 2020 to zero by 2030.

For the power sector, both suggested scenarios RES and ZCS would be effective in reducing CO_2 emissions, by 81% and 34% respectively. However, government plans for renewable energy are unambitious compared with the resources of solar and wind energy available. This study shows that if the suggested percentage share of renewable energy is actioned, a major reduction of CO_2 could be achieved. The zero coal scenario is a preventive action scenario that assesses and warns against the government's plan to start producing electricity from coal. It predicts that if the government goes ahead with this plan, CO_2 emissions will increase by 89% on the baseline scenario by 2050. The ZCS, therefore, which means the government cancelling the project, will avoid that 89% increase altogether.

The air conditioning scenarios for residential and commercial and public services would result in a reasonable mitigation of CO_2 emissions, but if a policy combined these two scenarios, their benefit would be much greater. Moreover, if the government plans for energy-efficient regulation of AC were also applied to other appliances, the CO_2 emissions would drop even further. It should be noted that the Sahim initiative already represents remarkable government progress in terms of renewable energy policy; the initiative allows households and businesses to install small-scale grid-connected PV systems, and is described in more detail in Chapter Three (3.8.2),

The other mitigation option that the country should investigate for this sector is sustainable building, which could be achieved by taking such measures as facilitating the penetration of energy-efficient equipment and appliances, introducing tighter building codes, using insulation for both walls and roof, upgrading to LED lights, and improving the air tightness.

The mitigation options suggested for the manufacturing industry sector would achieve positive reductions in CO_2, SO_2 and NO_x emissions. The efficient industry scenario would result in a 39% reduction in each pollutant by 2050, while the SO_2 emission would be reduced to zero by 2050 in the clean fuel scenario. These mitigation scenarios are essential for Oman, since the country's plan for economic diversification is to increase the percentage share of industry at the expense of the oil and gas sector, with the average annual growth of industry expected to be 7.8%. It is important, therefore, that implementation of these scenarios takes place in line with industry growth; if this is not done, air quality, health and climate could all be negatively affected.

The three mitigation scenarios suggested for the transport sector target different pollutants, CO_2, $PM_{2.5}$ and NO_x. All three scenarios successfully and dramatically decrease emissions. The electric vehicle scenario would achieve a 52% reduction in CO_2 by 2040, the public transport scenario would reduce the NO_x emissions by 30% in 2040, and the paved road scenario would decrease $PM_{2.5}$ emissions by 75% in 2040, an excellent achievement. If all three transport scenarios were combined into one policy measure, the emissions of CO_2 would drop by 77% by 2040, from 64 Mt in BAU scenario to 15 Mt in the new policy.

The Oman NDC and the findings of this study can be compared, despite their having different base years of 1994 and 2010 respectively. The comparison shows a similarity in their estimates of emissions for 2010, but a divergence in their estimates for the period from 2010 and 2030. The NDC estimate of CO_2 eq in 2030 is 95 MT, while this study estimates it as 160 MtCO_2 eq for the same year. The more recent baseline year and the historical data used in this study mean that its estimate of GHG emissions must be considered as more accurate.

The study can thus make the following recommendations for achieving additional emission reductions:

- Develop new legislation on climate change which will support the adoption of energy-efficient technologies and Increase energy-efficient projects in industries
- Implement the three mitigation scenarios shown to make the greatest contribution to decreasing the CO_2 emissions of Oman: the renewable energy, electric vehicles and zero coal scenarios.
- The baseline scenario and the suggested mitigation scenarios presented in this chapter provide the basis for an overview of the future of air quality and climate change for Oman. Chapter 6 will use this overview to present strategic pathways and regulatory choices that can serve as a starting point for policy-makers when discussing how best to achieve reductions in air pollution and GHG emission in Oman.
- Policy-makers need to collaborate first nationally and then in the GCC and MENA regions, in the areas of air quality and climate change, so that they can address common challenges and plan for progress.

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5 Estimating Impacts of current and historic atmospheric emissions from Oman

5.1 Introduction:

The aim of Chapter 5 is to provide an updated estimate of the current impacts of major air pollutants on Oman's climate and health, as well as to estimate historic impacts using the Long-range Energy Alternative Planning-Integrated Benefit Calculator (LEAP-IBC) modelling tool. It also aims to understand the contribution of SLCPs, other air pollutants and GHGs from different emission sources.

This chapter will quantify the different impact of emissions through use of the Integrated Benefit Calculator (IBC), which translates emission scenarios from LEAP into impacts, such as avoided premature mortality. It will base its calculations on the up-to-date emission inventory which was developed in Chapter Two using the Long-range Energy Alternative Planning (LEAP) tool, and on the scenarios developed in Chapter Four.

Through the IBC tool, policy-makers can see, for example, how many lives would be saved through an emissions reduction policy; and they can view that impact by age, disease and contributing pollutant. LEAP-IBC can also model how future emission reductions would reduce the rise in global temperature, putting regional action into a global perspective. The chapter will pay special attention to the sectors which are contributing the most to the negative health and climate impacts in Oman; this will be done to encourage policy-makers to implement regulations and introduce incentives for emission reduction, through recommendations which will be discussed in Chapter Six, the conclusion to the study.

This chapter has two main parts: the first describes the method used to develop impacts on health and climate via the LEAP-IBC tool, while the second presents and discusses the results obtained.

Literature

A country-level analysis for Oman by WHO (2015) on the effects of climate change on selected causes of death, revealed that in a high emissions scenario, heat-related deaths in the elderly (65+ years) are projected to increase to around 34 deaths a year per 100,000 by 2080; this compares with an estimated baseline of just over 3 deaths a year per 100,000 between 1961 and 1990. However, the analysis also notes that a rapid reduction in emissions could limit heat-related deaths in the elderly to about 7 deaths a year per 100,000 in 2080 (WHO, 2015).

Another study investigating the effects of climate change and its impact on human health in Oman and other Gulf countries indicates that the region could see increased mortality rates between 2070 and 2099 due to cardiovascular and respiratory illnesses, thermal stress, and increased frequency of infectious vector-borne diseases (Husain and Chaudhary, 2008). The analysis was based on long-term changes in the values of temperature, precipitation and humidity as predicted by global climatic simulation models under different scenarios of GHG emission levels. Monthly data on temperature, precipitation, and humidity were retrieved from IPCC databases. The study used an average of the values for the period 1970 to 2000 as a baseline, and then predicted the changes in humidity, temperature and precipitation for the periods 2020 to 2050 and 2070 to 2099. The next step was the development of empirical models to assess human health risk in the Gulf region, predicting the elevated levels of disease and mortality rates that would occur in the different emission scenarios developed by the IPCC. These models were based on epidemiological studies on various diseases associated with the changes in temperature, humidity and precipitation in hot arid regions. Table 5-1 shows the results of projected all-cause mortality and projected Disability Adjusted Life Years (DALYs)/100,000 population in Oman. It is clear that in 2100, when the population of Oman is projected to reach more than 30 million, there will be more than 277 cases of mortality due to temperature each year (Husain and Chaudhary, 2008). This works out as less than one death in 100,000, which is far lower than the WHO heat-related deaths estimate above (WHO, 2015).

Table 5-1: Oman projected all-cause mortality and projected DALYs/100,000 population from (Husain and Chaudhary, 2008)

2002 Population (`000)	2002 all-cause mortality	2100 extrapolated population est. (`000)	2100 Projected all-cause mortality	Hadley's Projected temp. (ºK) increase	Odd Ratio	Projected temp. adj. all-cause mortality	Excess mortality due to temp.
2,768	301.5	30,548	3327.4	2.62-2.82	1.0834	3604.9	277.5
2002 Population (`000)	**2002 all-cause DALY /100,000**	**2100 extrapolated population est. (`000)**	**2100 Projected all-cause DALY**	**Hadley's Projected temp. (ºK) increase**	**Odd Ratio**	**Projected temp. adj. all-cause DALY**	**Excess DALY due to temp.**
2,768	13,121	30,548	144,805	2.62-2.82	1.0834	156,881	12,076

Ahmed & Choudri (2012) consider Oman to be vulnerable to the likely impacts of climate change, the most significant of which would be increased average temperatures. It is thus vitally important for the country to integrate climate change mitigation and adaptation into its development strategies and policies, especially given that it is in the early stages of economic and industrial development.

5.2 Impact estimation method for Oman:

LEAP-IBC has two integrated components. One is LEAP, which has already been used to create the emissions inventory in Chapter Two and to develop the scenarios in Chapter Four; the second component is IBC, which is used in this chapter to estimate the changes in pollution concentrations and their impacts on climate and health. Taken together, LEAP-IBC converts estimates of future changes in national emissions into two further elements: estimates of changes in $PM_{2.5}$ concentrations and their impacts on human health, namely premature mortality, and, secondly, estimates of impacts on climate, namely temperature change, in four latitudinal bands. The tool is particularly useful for examining the multiple benefits of taking action on both long-lived greenhouse gases (GHGs) and short-lived climate pollutants (SLCPs); also, by comparing alternative policy scenarios, it gives an indication of the benefits of these scenarios in terms of the impacts they would avoid. One element not covered in this study is the impact on crops. There are two reasons for this: first, the ozone calculations in LEAP are carried out using an assumption of a linear relationship between the emissions of precursors and the formation of ozone. However, ozone formation is non-linear, a fact which creates a high level of uncertainty in the impact results and subsequently for scenarios in Oman, because when there is a large change in emissions, the projected concentrations may not be realistic. The second reason is that agricultural production in Oman is wholly dependent on irrigation, meaning that water rather than the availability of arable land and/or suitable soils is the critical constraint. As a result, Oman has little agriculture and is not self-sufficient in food; indeed, most food is imported.

5.2.1 Results of other sources of data used in LEAP-IBC tool:

The first source of data used in LEAP-IBC is the GEOS-Chem Adjoint model (by Daven Henze at the University of Colorado) at a grid resolution of 2 x 2.5 degrees, which is approximately 200 x 250 km at the equator. The GEOS-Chem Adjoint model is a global 3-D chemical transport model (CTM) for atmospheric composition and is driven by meteorological input from the Goddard Earth Observing System (GEOS) of NASA’s Global Modeling and Assimilation Office. It essentially runs the model backwards and creates results that relate the emissions to the concentrations of pollution in a chosen country (Henze *et al.*, 2007). Figure 5-1 shows a sample of the grid boxes of GEOS-Chem.

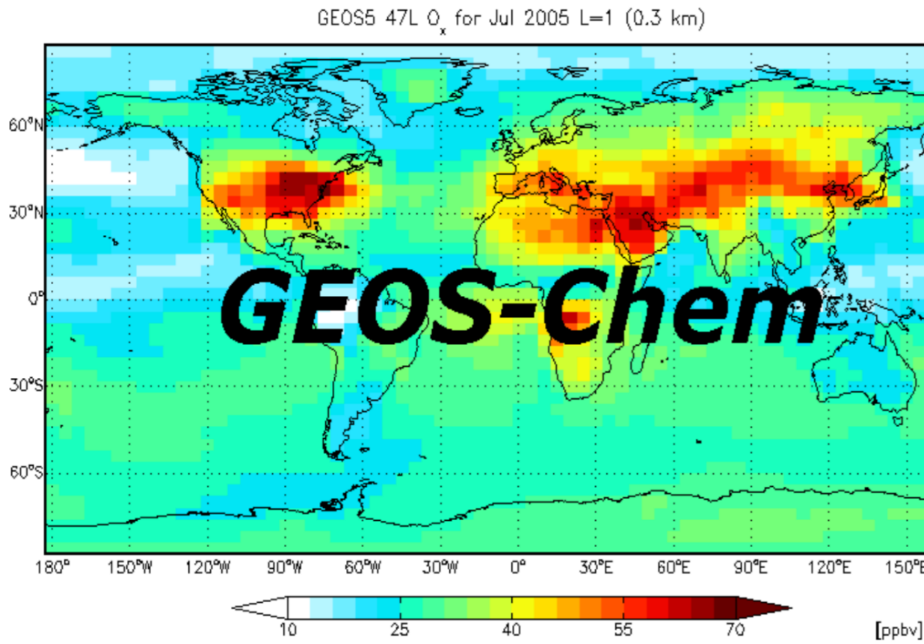


Figure 5-1 The grid boxes of GEOS-Chem

The GEOS-Chem-derived coefficients quantify the sensitivity of $PM_{2.5}$ concentrations in the target country to NO_x, SO_2, NH_3, BC, OC and mineral dust emissions in all grid squares across the world. These sensitivities are calculated for a base set of emissions, for the year 2010. IBC analyses the coefficients to look at the changes in $PM_{2.5}$ concentrations in the target country; these result from changes in emissions in that specific country and also across the world. They are linear coefficients, which means that a change in emissions results in a linear increase/decrease in $PM_{2.5}$ concentrations in the target country. However, the methodology does not account for non-linear changes in target $PM_{2.5}$ concentrations resulting from non-linear chemical reactions in the atmosphere, such as the combination of NO_x, SO_2 and NH_3 to form secondary inorganic aerosols.

The Adjoint model approach traces changes in a model response back to changes in all inputs, as shown on the right side of Figure 5-2. The Adjoint model is receptor-oriented, and suited for a simulation with more input parameters than responses. In this study the intercontinental transport of aerosols was performed with backward model simulations (i.e. adjoint). In order to quantify the impact caused by emissions in various regions using the forward sensitivity analysis, separate simulations must be run for each of the regions. Each of the simulations perturbs the emissions at one particular location, showing how emissions in the particular regions influence air quality at all locations. In contrast, a single adjoint simulation can show how emissions (input data in this study) at each of the locations have an impact on Zone output (the Oman emissions) between 2070 and

2099: this is shown by the concentration change in a particular grid box (which could be a city, region, or part of a country) or in a weighted sum of concentration changes in all grid boxes covering a country.

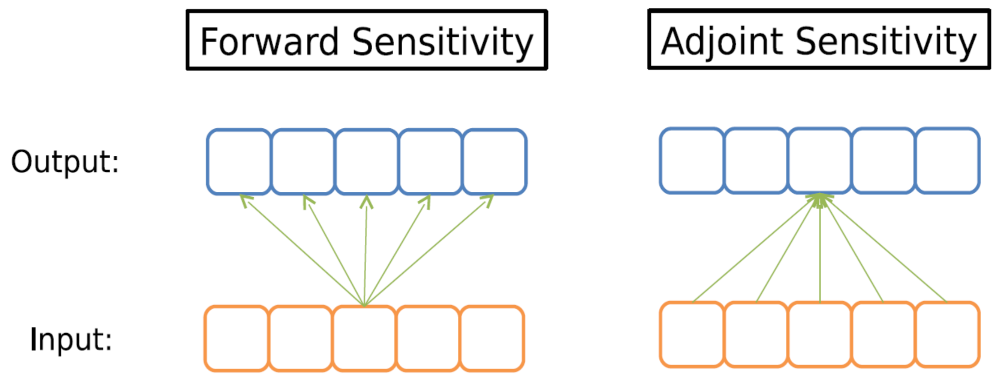


Figure 5-2 Forward and adjoint analyses in GEOS-Chem (Koo, 2011)

The base year (2010) population-weighted $PM_{2.5}$ concentrations for Oman used in IBC was derived from the gridded GEOS-Chem values of $PM_{2.5}$ using a downscaling procedure at 0.1° × 0.1° resolution (Kuylenstierna et al., in preparation). This procedure uses surface $PM_{2.5}$ concentrations from van Donkelaar et al. (2016); these were derived from a combination of satellite and modelled $PM_{2.5}$ data, calibrated to a global network on a ground-based $PM_{2.5}$ measurement. The adjoint coefficients are then used for future years to estimate the change in concentrations for emission scenarios (the emission and the GEOS-chem Adjoint give the change in concentration of $PM_{2.5}$, and this is subtracted from the $PM_{2.5}$ concentration satellite data for 2010).

The concentration-response function (CRF) is relationships which are formulae in LEAP-IBC – derived from epidemiological studies and assume log-linear relationships between $PM_{2.5}$ concentration and Relative Risk (RR).

All sources will be explained in detail in the following sections. Figure 5-3 summarizes the method by which the impacts of different pollutants on climate and health were estimated.

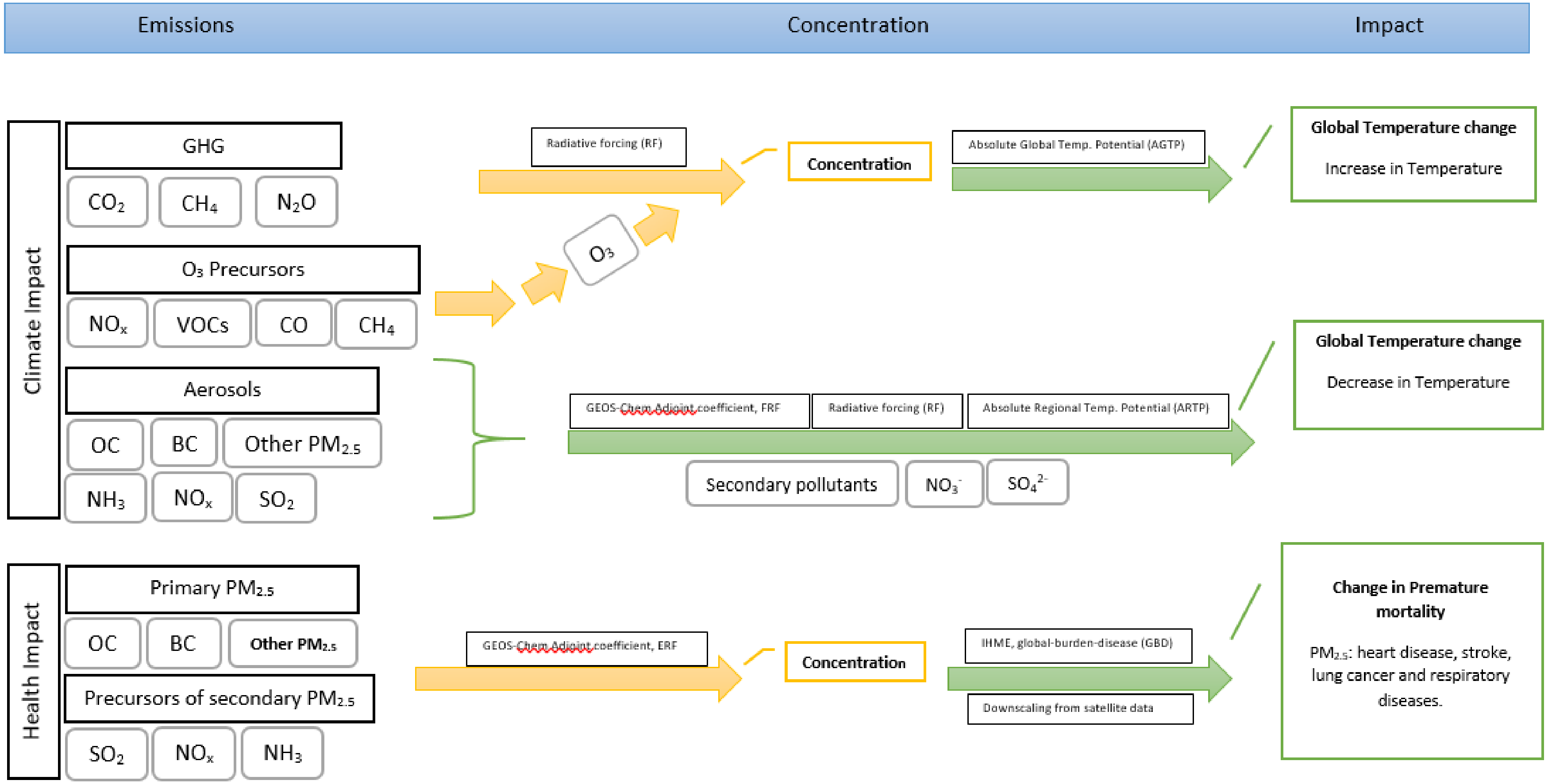


Figure 5-3 : Method of estimating the impacts on climate and health from different pollutants, FRF and ERF is Forcing Response Function and Exposure Response Function respectively

5.2.2 Estimating health impacts:

To estimate the impacts of emissions on health, we need to estimate the extent to which people are exposed to $PM_{2.5}$ from emissions; these estimates were described in Chapter Two. Two parameters are taken into account when estimating $PM_{2.5}$ concentrations: the first is the transport of emissions, since emitted substances do not stay in one place but are moved to different places by winds and by physical processes like convection. The second parameter relates to the chemical reactions in the atmosphere, where pollutants like NO_2 and SO_2 can be oxidised to NO_3 and SO_4, and where NH_3 can be reduced to NH_4. Estimating the impacts of $PM_{2.5}$ emissions on health therefore requires the use of complex atmospheric models that will provide the eventual relationship between the emissions in one place and the concentration of $PM_{2.5}$ in another, and will then link these to concentration-response functions. The next three sections discuss the steps involved in this process.

5.2.2.1 Step 1: How to estimate $PM_{2.5}$ concentrations from emissions:

The coefficients that are used in LEAP-IBC to represent the relationship between emissions and concentrations are calculated by running the atmospheric modelling GEOS-Chem Adjoint model (section 5.2.1), which assumes that the relationship between emissions of the components of $PM_{2.5}$ are linearly related to the concentrations. In other words, in the case of the coefficient calculated for Oman, it takes the emission in any grid in the world and linearly relates it to the concentration of that component in Oman. By doing this calculation for BC, OC, NO_X, SO_x, NH_3 and mineral $PM_{2.5}$ and then adding them all up, we get the average $PM_{2.5}$ concentration estimate for Oman.

5.2.2.2 Step 2: How to estimate exposure to $PM_{2.5}$:

The concentration is weighted by population (i.e. the value for Oman is a population-weighted $PM_{2.5}$ concentration), so the concentration of $PM_{2.5}$ where there are many people is counted more than the concentration where there are fewer people. Thus, the $PM_{2.5}$ concentration in a part of the country where there are no people will not count at all in the population-weighted average, which is the value which then gives an estimate of the average exposure of people in Oman to outdoor $PM_{2.5}$.

For example, if a country is split into four grids as in Figure 5-4, and all the people are living in grid (a), then the population-weighted $PM_{2.5}$ for the whole country will be determined by the concentration of $PM_{2.5}$ in this grid alone, and will ignore the concentration in the other grids, (b), (c), and (d). Similarly, if 50% of the people are living in grid (a) and 50% are living in grid (c), then the model will look at the average of the concentrations in grids (a) and (c).

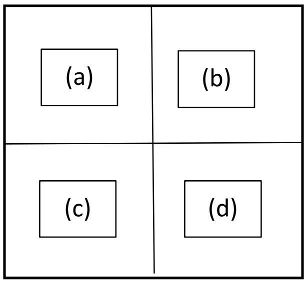


Figure 5-4 How to estimate concentration of PM2.5 weighted by population

In reality populations are usually split over all or almost all the grids (eg. 10% (a), 25% (b), 35% (c), and 30% (d)) and the model will weight according to that split. The grid represents the sensitivity of $PM_{2.5}$ concentrations to emissions in different grids using linear coefficient. However, the large size of grids in GEOS-Chem (250 km by 200 km) means that there is a great deal of uncertainty, as the tool takes a huge area of the country and calculates its estimate as if the exposure was the same throughout that area. Another source of data was therefore used by LEAP-IBC; this is finer in resolution concentration (2.5 km) and links to a population database which comes from satellite data and is at the same resolution. This improves the calculation of the population-weighed $PM_{2.5}$ concentration, as was noted previously in Step 1.

5.2.2.3 Step 3: How to estimate health impacts from $PM_{2.5}$ exposure

In order to estimate the health impacts from $PM_{2.5}$, LEAP-IBC uses the Exposure Response Function (ERF) shown in Figure 5-5; this relates changes in $PM_{2.5}$ concentration to changes in Relative Risk (RR). The relative risk is the probability that a member of an exposed group will develop a disease, relative to the probability that a member of an unexposed group will develop the same disease; it assesses, for example, the risk of chronic cardiovascular and respiratory disease related to the long-term exposure of $PM_{2.5}$.

Figure 5-5 : The relationship between PM2.5 and the health impacts

The GBD study (Cohen et al. 2006) used exposure response functions based on studies carried out in North America and Europe. This study used a different approach, which assumes that the same relationships apply in other regions of the world, including those where $PM_{2.5}$ concentrations are much higher, and where the composition of $PM_{2.5}$ may differ. It also assumes log-linear relationships between $PM_{2.5}$ concentration and RR, following Anenberg et al. (2016), and uses this to calculate the fraction of baseline deaths attributable to a given change in concentration.

The epidemiological studies come from long-term cohort studies. In cohort studies, a large number of people are followed for a long period of time, and people exposed to specific risk factors are compared with people not exposed to them. The occurrence of diseases or deaths in these two groups is observed prospectively. Data from cohort studies allows the estimation of incidence rate and premature mortality rate as descriptive measures of frequency, as well as the estimation of Relative Risk (RR) as a measure of comparative effect. Premature mortality is a measure of unfulfilled life expectancy, and because the deaths of younger people are often preventable, the premature mortality rate is a measure that gives more weight to the deaths of younger people than to those of older people.

Epidemiological studies have documented an association between short- or long-term exposure to various types of airborne particulate matter (PM) and mortality and morbidity (Tsiouri et al., 2014; Mohammadyan and Shabankhani, 2013; Chen and Lippmann 2009; Dockery and Pope 1994; Popeet et al., 2002; Vedal et al. 2003; Anenberg et al., 2016; Vodonos et al., 2018; Schwartz et al. 2002). While most epidemiological research has been conducted in North America and Europe, the evidence available from research in other regions suggests that the associations between air pollutants and their effects on health are relatively consistent around the world. However, some studies indicate a levelling off of risk at the high $PM_{2.5}$ concentrations found in many developing countries, which has led researchers to develop "integrated exposure response" (IER) curves using concentration-response data taken from around the world, among a variety of populations, and across a range of exposure concentrations including high $PM_{2.5}$ concentrations (Burnett et al., 2014). These IER curves were developed by leveraging epidemiological studies of ambient $PM_{2.5}$, typically higher levels of indoor air pollution in developing countries where solid fuel is used for cooking and home heating, and where there are very high particulate exposure levels from cigarette smoking. This IER approach was used by the Global Burden of Disease project (Anenberg et al., 2016).

The Global Burden of Diseases, Injuries, and Risk Factors Study 2010 (the GBD 2010 project) was a major study (Lim et al. 2012) in which Burnett et al. (2014) estimated the population attributable fraction (PAF) from exposure to ambient $PM_{2.5}$. They developed RR functions for each of the 187 countries included in the project; these covered the entire global exposure range for four causes of death in adults: ischemic heart disease (IHD), cerebrovascular disease (stroke), chronic obstructive pulmonary disease (COPD), and lung cancer (LC). They used RR information from epidemiological studies of long-term exposure to particulate matter not only from ambient air pollution, second-hand tobacco smoke, and active smoking but also from studies of household air pollution caused by the use of solid cooking fuel.

They also examined the relationship between $PM_{2.5}$ exposures and another health outcome included in the GBD 2010 project: the incidence of acute lower respiratory infection (ALRI) in infants. Because infants and young children are non-(active)-smokers, the largest $PM_{2.5}$ exposures considered for ALRI are from household air pollution (Burnett et al., 2014).

The study also created an integrated exposure response (IER) model by integrating available RR information from studies of ambient air pollution, second-hand tobacco smoke, household solid cooking fuel, and active smoking. Active smoking exposures were converted to estimated annual $PM_{2.5}$ exposure equivalents using inhaled doses of particle mass. It was then possible to derive population attributable fractions for every country, based on estimated worldwide ambient $PM_{2.5}$ concentrations (Burnett et al., 2014).

The Exposure Response Function (ERF) used in LEAP-IBC is the Integrated Exposure Response (IER) curve from Burnet et al (2014); it is shown in Figure 5-6. The shape of the response curve at different concentration levels (i.e., the slope of the concentration-response factor at different concentrations) indicates the extent to which different air pollutant mixtures pose more or less risk, and the degree to which concentration-response relationships found in one population can be extrapolated to others with different lifestyles, age structures, and medical care (e.g., from a U.S. cohort to other countries). The solid line represents predicted values of Relative Risk from the IER model, the line of dashes represents 95% CIs, the dotted line shows type-specific RRs, and the error bars are 95% CIs for ALRI in infants. The study used separate graphs to represent each of these other diseases: IHD, stroke, COPD, and LC (Burnet et al, 2014).

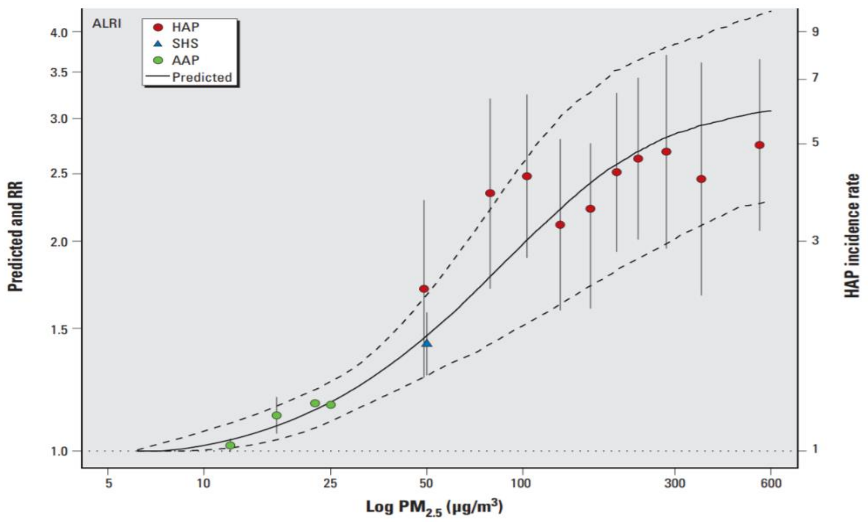


Figure 5-6 the Integrated Exposure Response (IER) curve which describes the relationship between relative risk (RR) and PM2.5 concentration (Ambient air pollution; AAP, Second-hand tobacco Smoke; SHS, household air pollution; HAP), (Burnett et al., 2014)

While considerable epidemiological evidence indicates that outdoor air pollution, principally PM, is a major risk factor for cardiovascular disease (CVD) in developed countries, there is only limited research investigating this association in developing countries, and very little indeed for the Middle East region (NASSE, 2015). This means that a number of limitations must be acknowledged:

- Exposure level estimates are subject to uncertainties concerning the magnitude and spatial distribution of emissions, as well as the chemical and physical processes influencing the impact of emissions on pollutant concentrations. The exposure level can also be correlated to lifestyle, and this might be different from place to place. In Oman, for example, people spend most of their time indoors because of the hot weather and so the actual exposure might be less.
- Risk factors: Oman may have risk factors not widely found in North America and Europe, so that the causes of death may be different. For instance, there is uncertainty about the total dust emissions and burdens and also about what fraction of that dust is possibly anthropogenic. Lelieveld *et al.* (2015) found that emissions from residential energy use such as heating and cooking, prevalent in India and China, have the largest impact on premature mortality globally, whereas in the USA emissions from traffic and power generation are most important, and in Europe, Russia and East Asia agricultural emissions are the largest relative contributor to $PM_{2.5}$. In the Middle East, including Oman, natural sources contribute greatly to mortality; where emissions from power generation have particularly large impacts on $PM_{2.5}$ concentrations, they frequently go unnoticed as they are masked by desert dust.
- The locations of the cohort studies are not representative of Oman. This creates uncertainty because the exposure-response curve has been applied to populations with exposure to different mixes of particle types. The composition of $PM_{2.5}$ might be different in Oman from its composition in North America and Europe. In Oman, for example, the $PM_{2.5}$ contains much more desert dust than the $PM_{2.5}$ in N-America and Europe, where the greater extent of agriculture is likely to result in more NH_3. What this means is that, even if the $PM_{2.5}$ concentration is similar, what we are actually breathing in is quite different. Epidemiological and toxicological studies in the Middle East have found that dust storm events have a significant impact on respiratory admissions, and PM has particularly adverse health effects in cases of asthma and respiratory and cardiovascular diseases (Tsiouri et al, 2014). There is thus more uncertainty regarding the chronic health and mortality impacts associated with exposure to dust in Oman than there is in studies dealing with typical air pollution in industrialized countries, which is where most of the epidemiological cohort studies have been carried out (Lelieveld *et al.*, 2015). Other studies carried out in the Middle East have

allowed comparison with other studies around the world. For example, concentration levels of toxic trace metals observed in Riyadh city during the dust season (Alharbi, 2009) were higher in PM_{10} and comparable in $PM_{2.5}$ with levels found in studies for polluted cities elsewhere. Alolayan et al. (2013) employed source apportionment, back trajectory, and concentration rose analyses to identify sources of ambient $PM_{2.5}$ in Kuwait City and to quantify their contributions to $PM_{2.5}$. They identified five sources contributing to $PM_{2.5}$: soil and sand dust (54%), oil combustion (18%), the petrochemical industry (12%), local traffic (11%), and transported traffic/smelter emissions (5%).

5.2.3 Emission climate impacts:

The climate impact quantified for this study is the average global temperature change. To calculate this in LEAP-IBC, an intermediate variable is used; this is called radiative forcing (RF) which is subsequently related to global temperature change using the Absolute Global Temperature Potential (AGTP) metric. Radiative forcing is the balance (difference) between the incoming and the outgoing energy for the planet.

The sun's visible wavelengths of radiation pass easily through the atmosphere and reach earth. Approximately 51% of this sunlight is absorbed at the earth's surface by the land, water, and vegetation. Some of this energy is re-emitted back from the earth's surface in the form of infrared radiation. Different substances affect the warming of the atmosphere in different ways. Whereas the GHGs absorb IR radiation, BC warms the atmosphere because the black particles directly absorb the energy from visible light. Other aerosols, such as sulphate and OC, reflect sunlight and reflect the energy back out into space, cooling the planet.

Long-lived GHGs mix well with the atmosphere, so that the effect of emissions on the atmospheric concentration and RF is independent of location, source type, and season. In contrast, the impact of Short Lived Climate Forcers (SLCF) on the radiative balance is highly sensitive to the latitudinal and altitudinal location of the precursor emission and the emission source type. Different chemical and meteorological background environments and chemical coupling from co-located emissions affect the production efficiency and lifetime of the SLCF, which influences the resultant perturbation of atmospheric concentration. Thus the SLCF RF depends on local and regional conditions (Unger, 2012).

According to the IPCC (2013), the increase in CO_2 emissions and the resulting increase in the atmospheric concentration of CO_2 has been the most important driver of the increase in radiative forcing (RF) from pre-industrial times to the present day. Air pollutants (CO, NMVOC, NO_X, SO_2 and aerosols) and other greenhouse gases (CH_4, N_2O) have also had an impact on RF.

It can be difficult to assess the RF effects of GHG and air pollutant emissions. This is because RF is not always the direct result of the atmospheric concentration of these air pollutants and GHGs, but is also the result of their indirect interactions in the atmosphere. These indirect effects include both chemical reactions by the air pollutants and GHGs, leading to ozone formation, and also the physical reactions which result in cloud formation and cloud composition.

In spite of these difficulties, quantitative estimates of these indirect effects can be made (IPCC, 2013). Over the past 260 years, emissions of CO_2, CH_4, N_2O, BC, CO, and NMVOC have all resulted in an increase in RF, while emissions of SO_2, OC and mineral dust have contributed to a decrease in RF. The emissions of NO_X and NH_3 have had both a positive and negative effect on RF, but with a negative net impact. Interactions between aerosols and clouds have resulted in a negative RF, but the contribution of individual emitted compounds within mixes of aerosols is unknown.

5.2.3.1 The effect of GHGs on global warming:

Greenhouse gases in the earth's atmosphere absorb the longer wavelengths of outgoing infrared radiation from the earth's surface. These gases then emit the infrared radiation in all directions, both outward toward space and downward toward earth. This process creates a second source of radiation warming the earth's surface – visible radiation from the sun and infrared radiation from the atmosphere – which causes the earth to be warmer than it otherwise would be. This process is known as the natural greenhouse effect and keeps earth's average global temperature at approximately 15°C. If the concentration of greenhouse gases increases, then more infrared radiation will be absorbed and emitted back toward earth's surface, creating an enhanced or amplified greenhouse effect (Figure 5-7).

I. The sun's visible wavelengths of radiation pass easily through the atmosphere and reach Earth. Approximately 51% of this sunlight is absorbed at the earth's surface by the land, water, and vegetation.

II. Some of this energy is emitted from earth's surface back into space in the form of infrared radiation.

III. Much of this infrared radiation does not reach space, however, because it is absorbed by greenhouse gases in the atmosphere, and is then emitted back toward the earth's surface as infrared radiation. This process is known as the greenhouse effect.

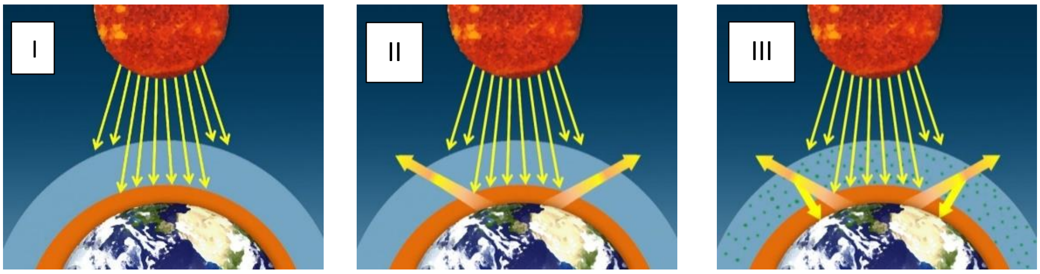


Figure 5-7 GHGs effect[19]

5.2.3.2 Black Carbon (BC) particles effect:

Black Carbon (BC) particles heat the air by absorbing sunlight, warming the atmosphere by emitting that energy through heat (infrared) radiation and conduction to the air around them. This differs from GHGs which allow sunlight to pass through them, but absorb the earth's heat radiation and re-emit it to the air (Figure 5-8). BC is therefore far more effective at absorbing energy than GHGs. When BC particles age in the atmosphere, they become coated by relatively transparent or translucent chemicals, increasing the size of the particles and thus the probability that sunlight will hit them and will then be absorbed by them. These "aged" coated BC particles heat the air more than do newly emitted, uncoated BC particles (Bond, 2007; Jacobson, 2007).

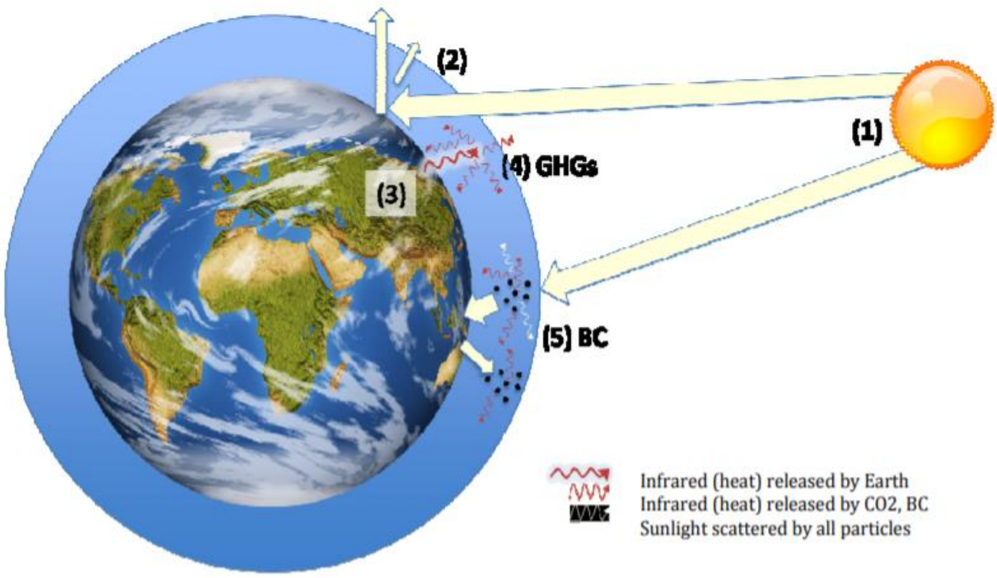


Figure 5-8 : BC effect, (Bachmann, 2009)

One of the most important differences between CO_2 and black carbon (BC) is how long each remains in the atmosphere. The effective atmospheric lifetime of CO_2 emissions is over a century. As a result, CO_2 and other long-lived GHGs are relatively evenly distributed around the globe, reducing some of the uncertainty in estimating their effects. This persistence also means that it would take some time to realize the benefits of a reduction in CO_2 emissions. By contrast, BC and other combustion particles persist in the atmosphere for only a short period, from days to a week, before they are removed by rain, snow, or 'dry' fallout. Even though they can travel hundreds to thousands of miles from source regions in this time, BC and other particles tend to be found in highest concentrations over regions of heavy industry, large populations and high levels of emissions. Concentrations are much lower over oceans and landmasses distant from source regions. This means that the effects of BC on temperature, visibility, and rainfall can be considerably stronger in and near source regions. The short lifespan of BC also means that its effects will diminish very quickly following reductions in emissions.

5.2.3.3 Cooling aerosols:

The warming caused by GHGs and black carbon is partially offset by light scattering from other particles produced by combustion, such as organic carbon (OC), sulphates (from sulphur dioxide), and nitrates (from nitrogen oxides). Incoming sunlight is scattered in all directions by these particles, which reduces the amount of sunlight that reaches earth's surface and thus results in cooling. The amount of black carbon relative to the amount of other particles is a critical factor in assessing the impact of combustion sources on climate. In general, sources with higher black carbon (warming) to organic carbon (cooling) ratios are more likely to result in a net warming (Bond, 2007). The warming and cooling caused by the absorption and scattering of sunlight by airborne particles are considered to be "direct" effects (Forster et al., 2007).

Different pollutants thus affect the energy balance and affect radiative forcing through different processes. Relatively small changes in the amounts of GHGs, BC or cooling aerosols in the earth's atmosphere can greatly alter the balance between incoming and outgoing radiation. Earth then warms or cools in order to restore the radiative balance at the top of the atmosphere (Bachmann, 2009).

5.2.3.4 How do we go from emissions to radiative forcing?

There are two categories of pollutants, the long-lived and the short-lived. These are listed in Table 5-2, and discussed below:

1. Long-lived GHGs (CO_2, N_2O), are named for the length of their atmospheric lifetimes, which can be decades, centuries or even longer. They are globally mixed, which means that any emission of a pollutant results in a global change of concentration of that pollutant. That change of concentration, along with the change in global concentration that it causes, also makes a change in radiative forcing (RF), the change based on the standard relationship as calculated by the IPCC.
2. Short-Lived Climate Pollutants (SLCP) are BC, CH_4, and O_3. Where this type of pollutant is emitted is important, because they only spend days, or at most years, in the

atmosphere. So if BC is emitted near the Himalayas, it can be deposited in the Himalayas and will affect the radiative forcing there, while if it is emitted in South America, for example, that is where it will have an effect.

Table 5-2: Life time of different emissions in the atmosphere (Maione et al., 2016)

Compounds:	CO_2	CH_4	BC	SO_2	NO_x	NH_3	VOCs
Approx. atmospheric residence time:	150 years	8 years	1 week	1 week	1 week	1 week	variable

5.2.3.5 How to convert emissions into climate impact:

A number of factors affect how these pollutants change radiative forcing: how the emission is transported, the chemical reaction that arises and how the final pollutant is deposited. Atmospheric modelling [GEOS-chem adjoint] is used to convert emission estimates into the change in radiative forcing (ΔRF) by means of grids, where each grid represents the sensitivity of radiative forcing to change by emissions from different grids (Figure 5-9 and 5-10).

In order to estimate the change in average global temperature from radiative forcing, LEAP-IBC uses the variable Forcing Response Function (FRF) (Shindell, 2012). The Forcing Response Function (FRF) comes from a global climate model. The model represents radiative forcing, weather patterns and meteorology, as well as the experiments which are run based on the following assumption: if we have this change in RF when we run all of these processes (rainfall, wind patterns, etc.), what is the effect on the average global temperature?

Global Climate Models (GCMs) have evolved from the Atmospheric General Circulation Models (AGCMs) widely used for daily weather prediction. These GCMs also include an Ocean General Circulation Model (OGCM) that simulates the circulation of the oceans. Climate models are based on well-established physical principles and have been shown to reproduce observed features of recent climate and past climate changes. There is considerable confidence that Atmosphere-Ocean General Circulation Models (AOGCMs) provide credible quantitative estimates of future climate change, particularly at continental and larger scales (IPCC, 2007-I, p. 591). In this study, the relationship from the global climate model and the Forcing Response Function is used to estimate the change in average global temperature (Δtemp).

The Absolute Global Temperature Potential (AGTP), which is derived using the forcing response function, provides an estimate of the global mean temperature response to a given emission, based on that emission's global mean RF as a function of time (Shine et al., 2005). The Absolute Regional Temperature Potential (ARTP) is an analogue of AGTP; it provides estimates of regional surface temperature responses to emissions, accounting for the regional radiative forcings (RFs) caused by the emissions (Shindell, 2012).

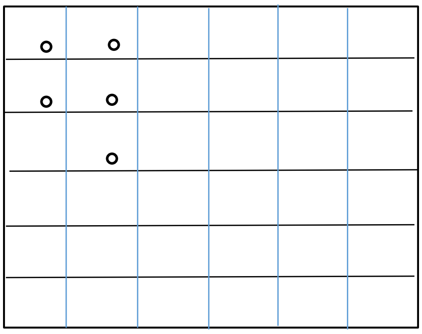
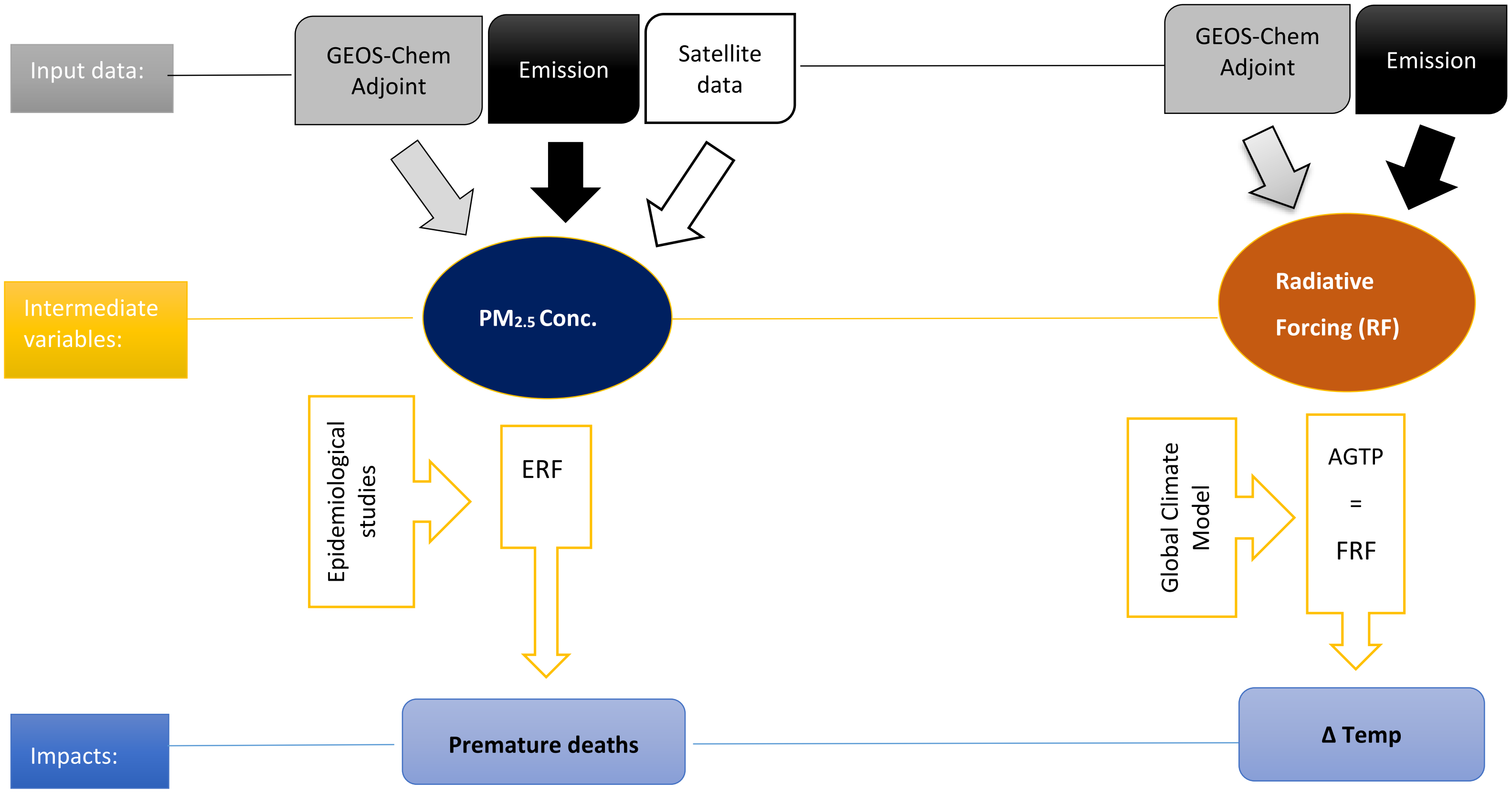


Figure 5-9 Radiative Forcing compared to emissions in different grids

When the impact on climate (RF: ΔTemperature) is being estimated, the grids represent the sensitivity of Radiative Forcing (RF) to changes in emissions in different grids, which gives the change in RF for all the different components.

Figure 5-10 The relationship between radiative forcing and change in temperature.

Figure 5.11 summarises the processes by which LEAP-IBC converts emissions into impacts on health and climate, as discussed in the two previous sections.



ERF: Exposure Response Function, **FRF**: Forcing Response Function, **AGTP**: Average Global Temperature Potential, **Δ AGTP**: change in Average Global Temperature

Figure 5-11 How LEAP convert emission into health and climate impact

5.3 Results and discussion:

In this section of the chapter, the impact assessment of $PM_{2.5}$ on health and climate will be assessed, analysed and compared with similar estimates made in other studies. As explained earlier, the impact of ozone on health and on crops will not be covered in this study.

5.3.1 Components of national anthropogenic $PM_{2.5}$:

Figure 5-12 shows the contribution to $PM_{2.5}$ in Oman from emissions that occur within the country, emissions that occur in other countries, and emissions from natural background, with figures derived from this study and its use of LEAP-IBC. It is clear that the major constituents of total $PM_{2.5}$ come from the natural background, a consequence of Oman's being located in a dry and arid area. Indeed, as can be seen in Figure 5-12, in 2010, the anthropogenic emissions of $PM_{2.5}$ from Oman itself were much smaller than the emissions affecting Oman from the rest of the world.

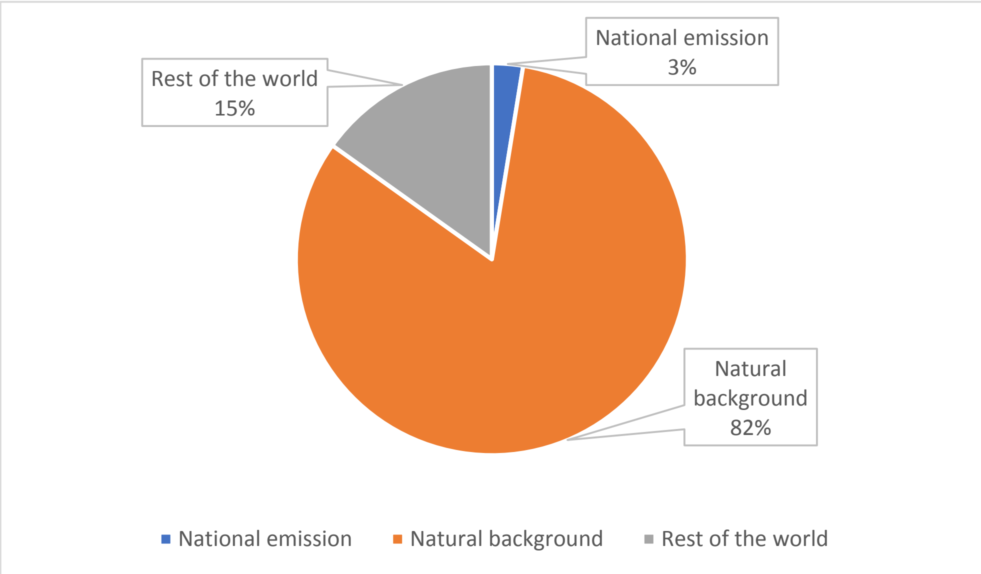


Figure 5-12 National $PM_{2.5}$ concentration compared with $PM_{2.5}$ from rest of the world and natural background in 2010 based on LEAP-IBC (Total $PM_{2.5}$ concentration: 47 µg m^{-3})

Figure 5-13 does not show emissions from the natural background, but compares the national emissions of $PM_{2.5}$ with those from the rest of the world, for the years 2010, 2030 and 2050. Disappointingly, it can be seen that the contribution of national emissions will increase markedly in the future; by 2050 they will be almost on a par with those from the rest of the world. This also shows that in 2010 the non-soil dust emissions in Oman caused $PM_{2.5}$ of below 10 µg m^{-3} as a population-weighted mean, which is within the WHO guideline; in 2030, however, it is projected to exceed this, and in 2050 to be almost double this guideline value.

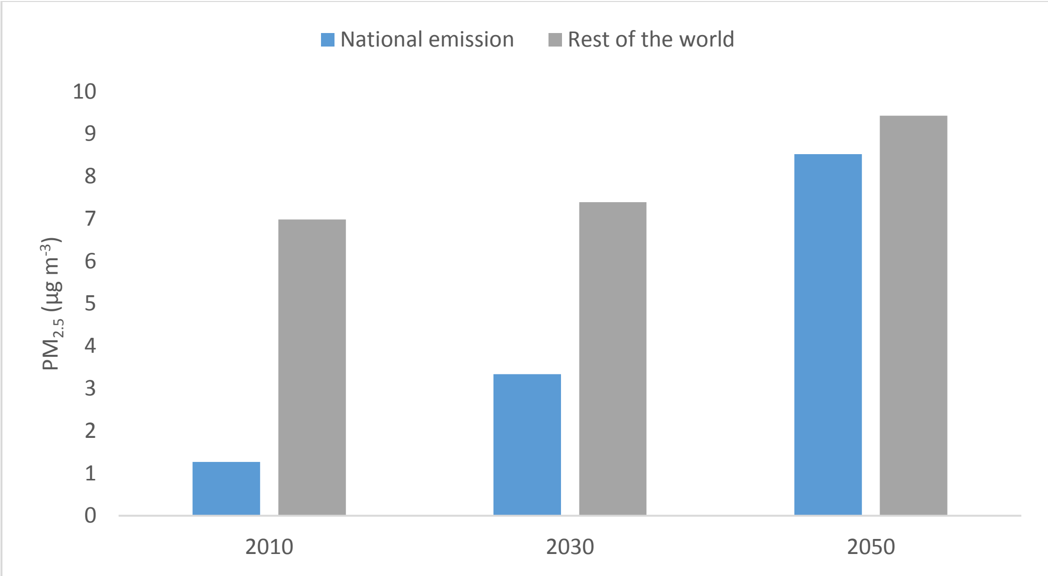


Figure 5-13 $PM_{2.5}$ concentrations projection (2010 – 2030 - 2050) disaggregated into contributions from emissions that occur within Oman, and from anthropogenic emissions from other countries

The left hand side of Figure 5-14 below shows the anthropogenic $PM_{2.5}$ (national and rest of the world). The whole column, that is both blue and white parts, represents these anthropogenic $PM_{2.5}$, in the BAU baseline scenario, with the white part of each column representing the emissions that would be avoided if all measures were implemented. The right hand side of Figure 5-14 represents the total load of $PM_{2.5}$ emissions, including those from the natural background. The figure also breaks the anthropogenic $PM_{2.5}$ into national emissions and those from the rest of the world. Although the emissions from natural background are almost static over time, they have a severely negative effect on Oman's air quality. $PM_{2.5}$ from the rest of the world also plays an important role in Oman's air quality, which means that the sultanate must negotiate and collaborate with neighbouring countries so that they reduce their $PM_{2.5}$ emissions.

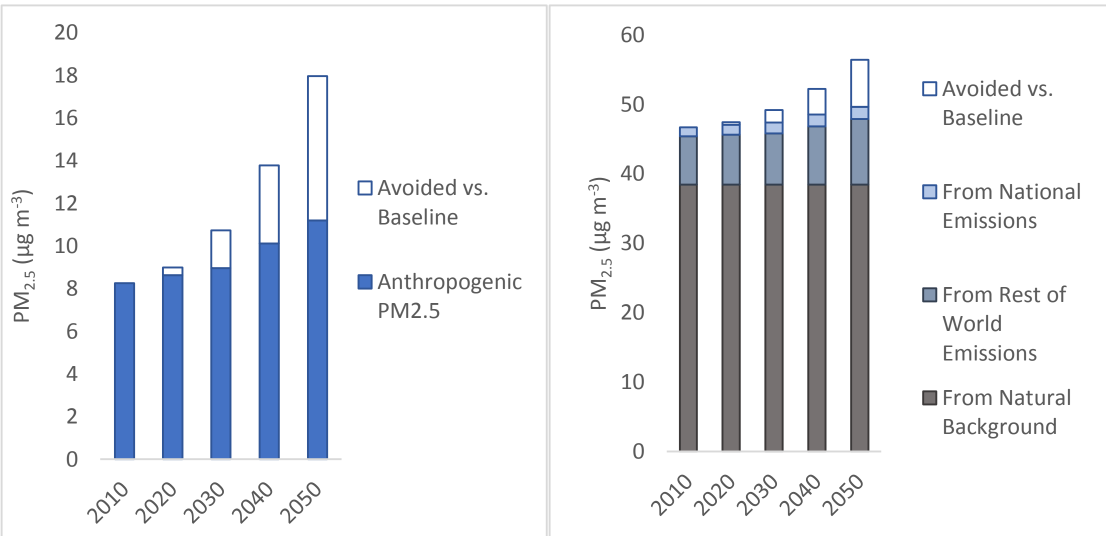


Figure 5-14 All measures avoided anthropogenic $PM_{2.5}$ concentration compared with BAU scenario

Figure 5-15 shows the constituents of anthropogenic $PM_{2.5}$ from national emission as a percentage share, with the left hand figure showing amounts for 2010, and the right hand side showing predictions for 2050. The percentage of components of anthropogenic $PM_{2.5}$ for 2010 are as follows: SO_2 constitutes 49% as $(NH_4)_2SO_4$, with NO_x constituting 21% as NH_4NO_3. Black carbon and organic carbon have only a 3% and 2% share respectively. However, the percentages of constituents are predicted to change in the future, with a notably sharp increase in $(NH_4)_2SO_4$, whose percentage share will rise to 68% by 2050. To the researcher's knowledge, this is the first time that such figures have been presented, and possession of such data will allow us to compare the components of our emissions with those of the rest of the world.

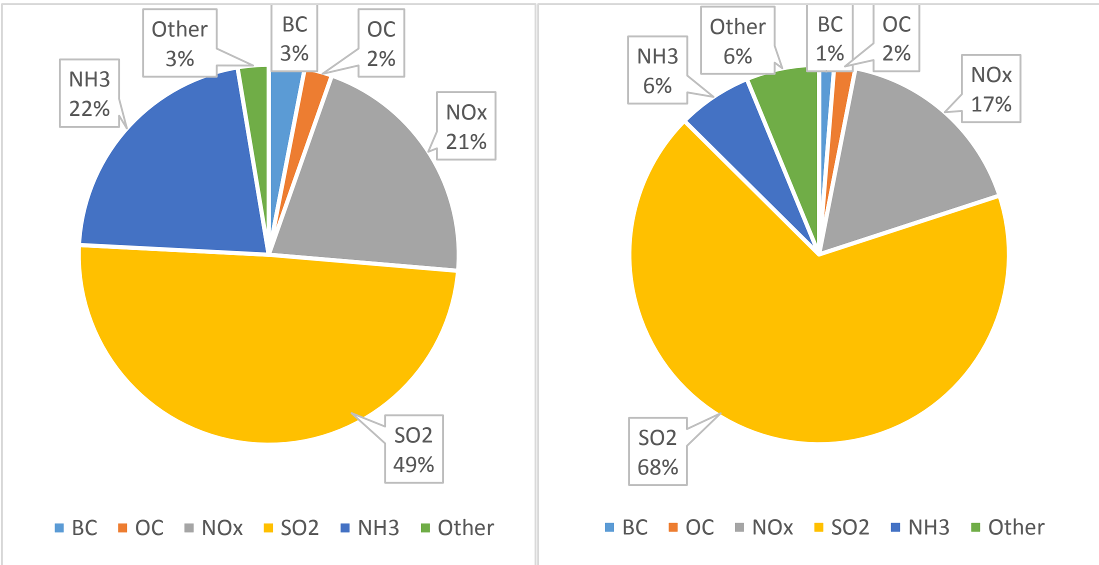


Figure 5-15 Percentage share of pollutants which make up anthropogenic $PM_{2.5}$ in the BAU scenario, (Left-hand side 2010 and Right had side 2050)

5.3.2 Oman premature deaths attributable to $PM_{2.5}$

Particulate matter with diameters smaller than 2.5 µm (referred to as $PM_{2.5}$) is the pollutant with the greatest impact on human health. This study estimates that in 2010 there were approximately 711 cases of premature death from $PM_{2.5}$ associated with anthropogenic and natural emissions; such deaths will rise to 1810 cases in 2030, and will again double to reach more than 4400 cases in 2050. To give a comparison with the 711 premature deaths attributable to $PM_{2.5}$ in 2010, the WHO estimated 405 deaths attributable to household and ambient air pollution in the same year (Chapter 1, Section 1.2.2).

Figure 5-16 provides a breakdown of the information on the premature deaths attributable to $PM_{2.5}$, categorizing them by age group and cause of death. According to estimates in this study, the increase in the number of premature deaths will occur mainly in the elderly, with the >70 age group being most severely impacted. The percentage of deaths for this age category was

52% for 2010, with predictions of 47% for 2030, and 74% for 2050, with the deaths mostly caused by ischaemic heart disease and stroke.

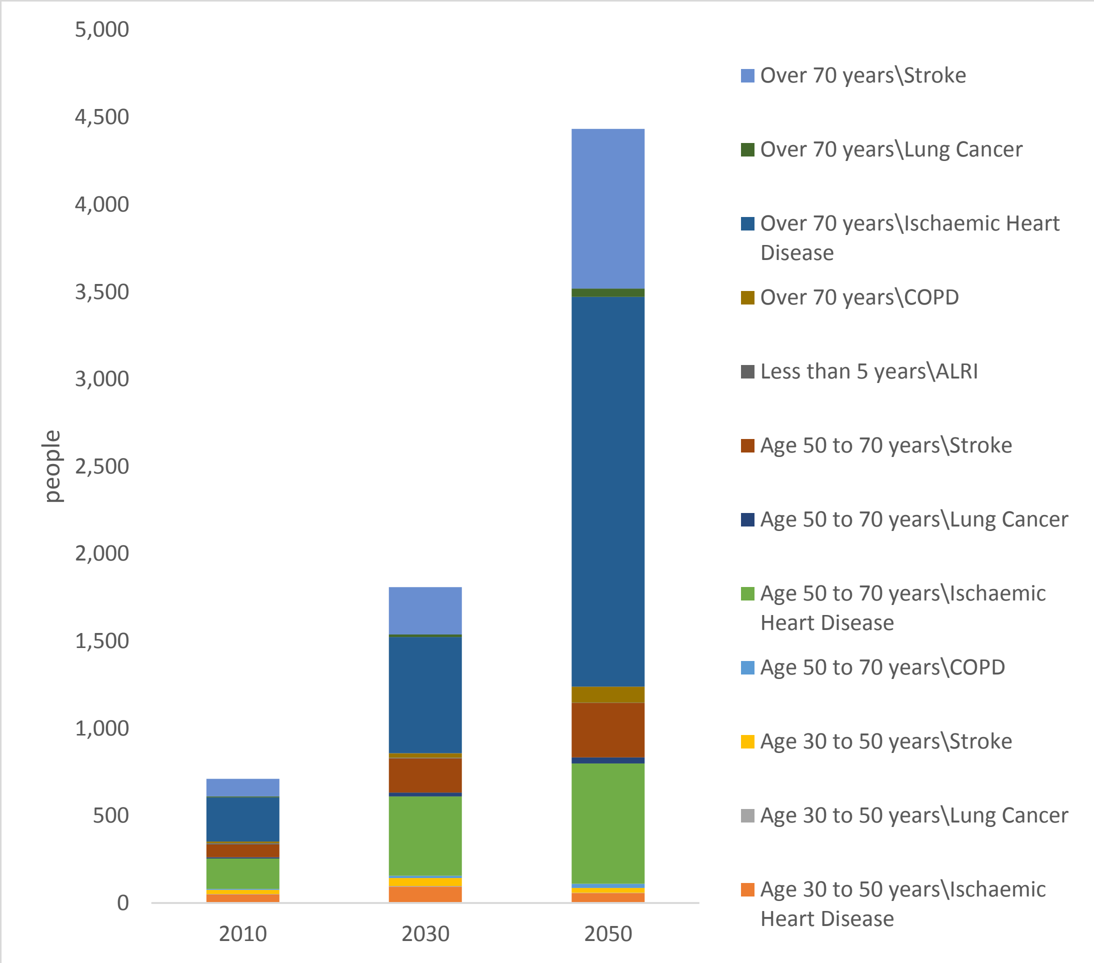


Figure 5-16 Premature deaths in 2010 attributed to $PM_{2.5}$ based on age group and cause of death, and projection for 2030 and 2050 as BAU scenario

This study reveals that out of the 711 premature deaths in 2010 attributed to $PM_{2.5}$ from combined national emissions, emissions from the rest of the world, and from natural background, 138 deaths could be attributed to anthropogenic $PM_{2.5}$, as is shown in the breakdown in Figure 5-17. Most of these deaths can be attributed to SO_2, with NO_x and NH_3 being the next largest contributors. If we are to avoid these premature deaths, it is important to reduce these pollutants.

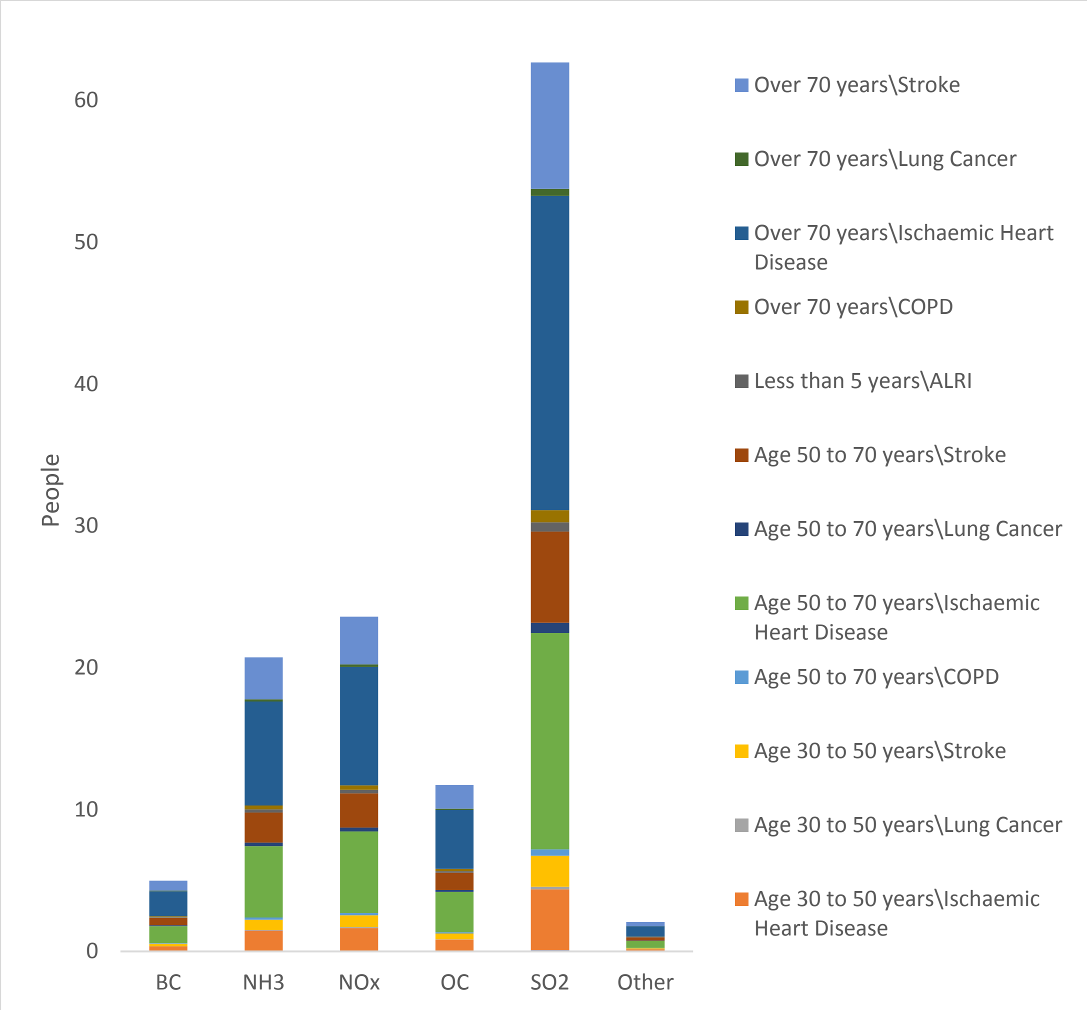


Figure 5-17 Premature deaths caused by national anthropogenic $PM_{2.5}$ emissions for 2010.

Figure 5-18 illustrates how far premature deaths attributable to $PM_{2.5}$ could be reduced if all the measures suggested in Chapter Fourwere implemented. The left hand box, however, shows that the natural background, at 82%, remains the largest constituent of total $PM_{2.5}$. The right hand box shows the total number of deaths due to anthropogenic emissions, with the white parts of the columns showing the premature deaths that could be avoided, with figures of 302, 445, and 654 in 2030, 2040, and 2050 respectively. The figure also clearly shows that 50% of the premature deaths in 2050 could be avoided if all the Chapter Four measures were implemented.

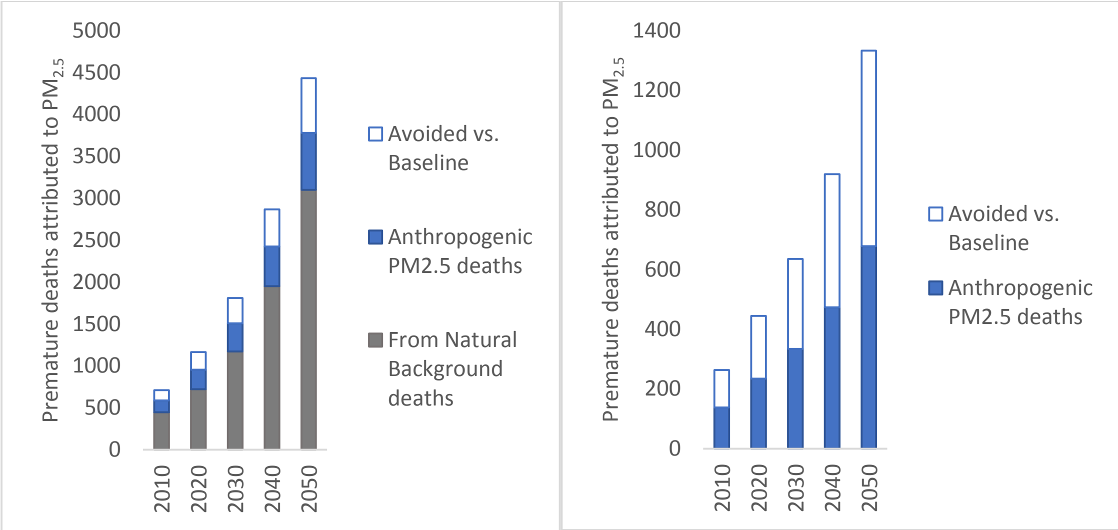


Figure 5-18 All measures Avoided vs. BAU scenario for the premature deaths attributed to $PM_{2.5}$

In Figure 5-19 it is clear that, based on the all measures suggested in this study, all the premature deaths attributable to national $PM_{2.5}$ emissions can be avoided by 2050, although those caused by emissions from the rest of the world, primarily surrounding countries, can only be avoided in future if there is effective regional cooperation.

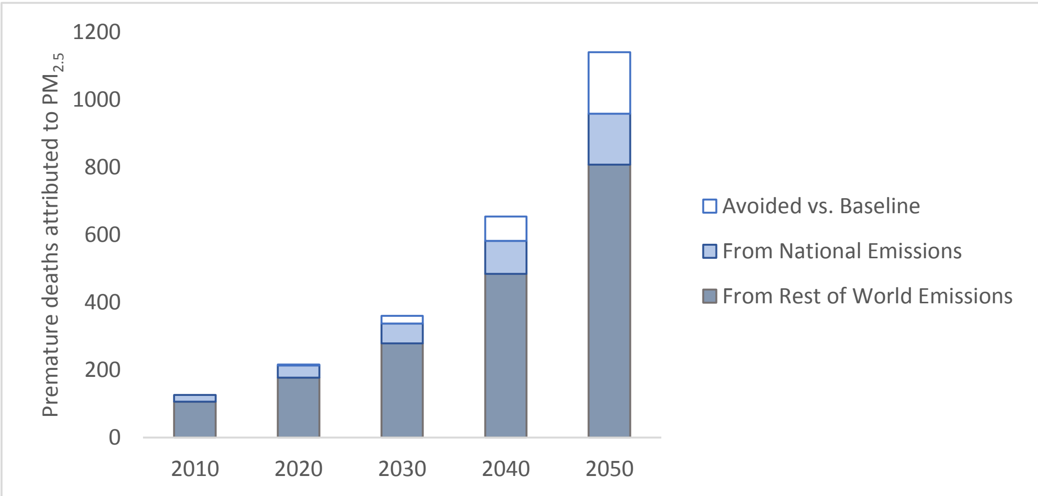


Figure 5-19 All measures Avoided vs. BAU scenario for the premature deaths attributed to $PM_{2.5}$ (national and rest of the world)

5.3.3 Global Temperature Change:

The climate impact of pollutants resulting directly from Oman's emissions, namely the average change in global temperature, is shown in Figure 5-20; those emissions will cause a 0.001°C rise in average global temperature by 2030, and a 0.003 °C rise in 2050.

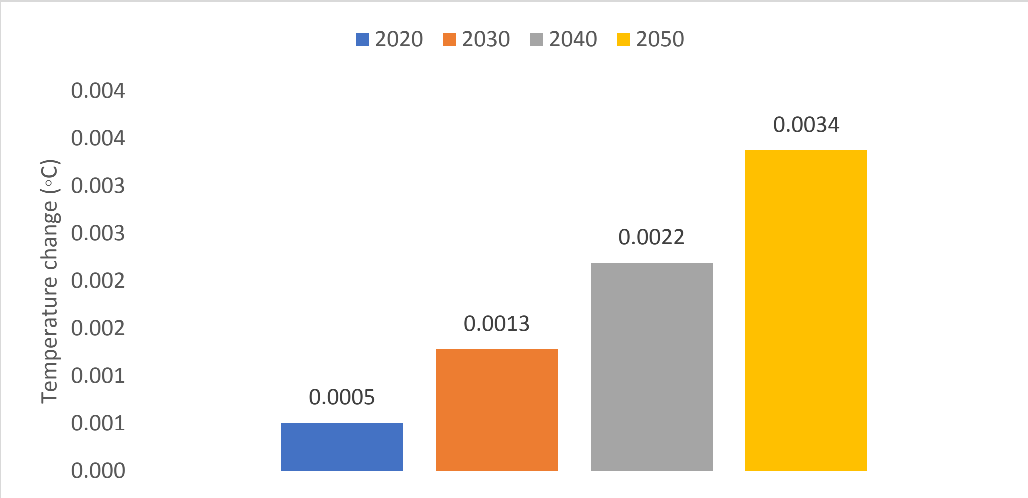


Figure 5-20 Global temperature change due to Oman emissions

The benefit of mitigation scenarios in avoiding global temperature change due to Oman emissions is illustrated in Figure 5-21. According to the graph, the transport mitigation scenario would be the most beneficial scenario to adopt, since it would be capable of avoiding 0.0005 °C by 2050, with the oil and gas scenario and the electricity generation scenario avoiding 0.0003 °C and 0.0002 °C respectively; all these are compared with the baseline BAU scenario. The graph shows a different trend for mitigation measures in the industry sector, which target the reduction of SO_2 emissions. This can be explained by the fact that, as explained in Section 5.2.3, sulphate can be considered as cooling aerosol. Figure 5-22 also clearly demonstrates the difference between SO_2 emissions and others.

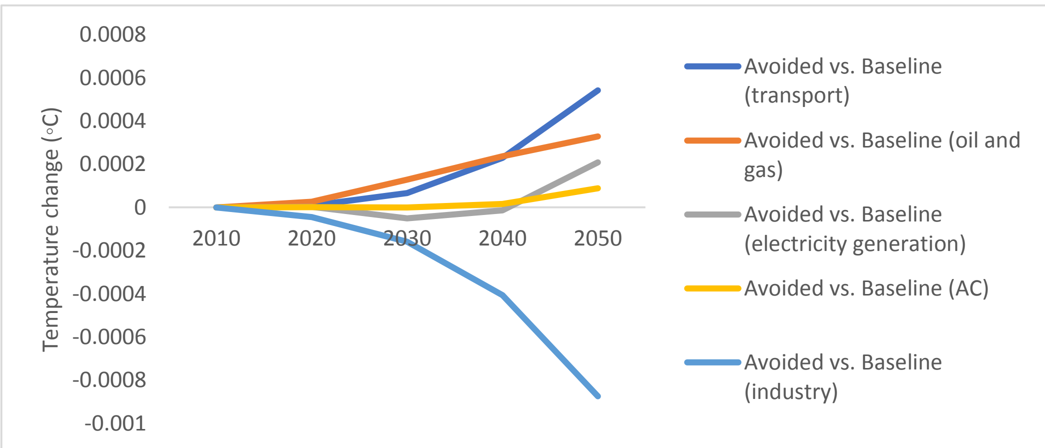


Figure 5-21 Avoided vs. baseline global temperature change projection (2020-2050) for different sector scenarios

Figure 5-22 represents how the individual pollutants in Oman's emissions are increasing or decreasing global temperature. Greenhouse gases basically warm up the climate, while SO_2 and NO_x work in the opposite direction by lowering the temperature.

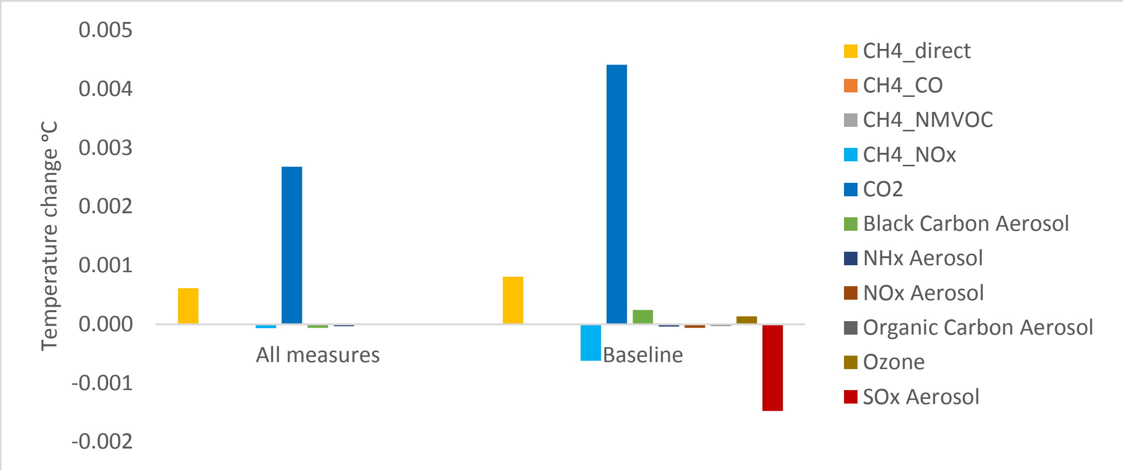


Figure 5-22 Comparison all measures and BAU scenario of the effects of different pollutants in global temperature change due to Oman emissions

The net effect on climate of all the measures suggested in this study is illustrated in Figure 5-23. If Oman were to implement all the measures for emission reduction explained in Chapter Four, the country could avoid a 0.00005°C change in global temperature by 2040, and a 0.0003°C change by 2050, compared to the baseline. It can be seen that between 2025 and 2035, if all measures were implemented, the temperature would go above that for the BAU scenario; this is because removing the cooling aerosols, SO_2, and NO_x, from the atmosphere would impact the temperature faster than removing the warming GHGs. It is expected, but needs more study, that there would be a bigger change beyond 2050. The graph also shows that if only Air Pollution (AP) measures are implemented, without GHG and BC measures, the effect on the climate will be even worse and will increase the temperature above the BAU scenario. This clearly illustrates that it is of vital importance to integrate air pollution and climate policies.

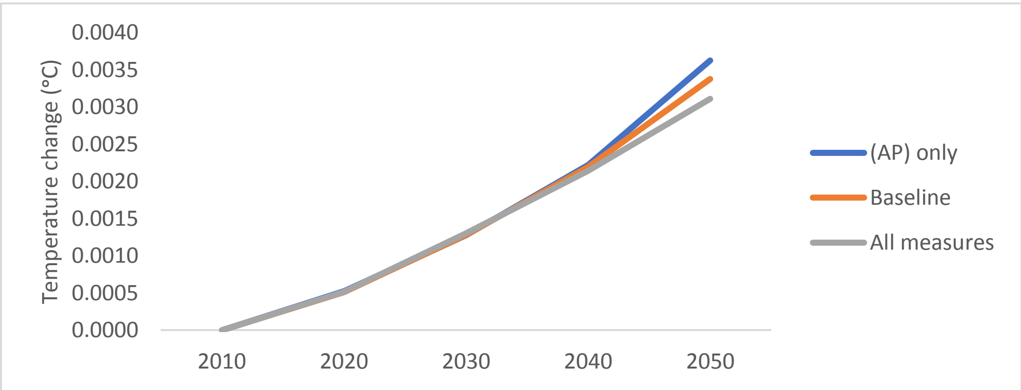


Figure 5-23 Comparison of the effects of baseline (BAU) scenario and all measures scenario in global temperature change due to Oman emissions

5.3.4 Comparing results with other impact estimates:

Chris Malley from the Stockholm Environment Institute (SEI)-York developed a map for Oman and the GCC region which was based on ECLIPSE emissions (ECLIPSE v5a from the IIASA GAINS model) and showed the contribution to national population-weighted $PM_{2.5}$ concentrations from different source sectors and different pollutant emissions in 2010. Based on the ECLIPSE emissions shown in Figure 5-24, the contribution to national population-weighted $PM_{2.5}$ concentrations from different source sectors and different pollutant emissions in Oman for 2010 can be summarized as follows:

It shows clearly that shipping contributes 12.59% to the $PM_{2.5}$ concentrations, mainly through SO_2 (32%) and NO_x (28%). This applies for the other sectors:

- ✓ 22% of $PM_{2.5}$ in Oman comes from the energy industry sector, and this is mainly from SO_2, NO_x and BC emissions.
- ✓ 22% of $PM_{2.5}$ in Oman comes from the transport sector, and this is mainly from OC, BC and NO_x emissions.
- ✓ 18% of $PM_{2.5}$ in Oman comes from the manufacturing industry sector, and this is mainly from SO_2, NO_x, and NH_3 emissions.
- ✓ 15% of $PM_{2.5}$ in Oman comes from the agriculture sector, and this is mainly from NH_3 emissions.
- ✓ 12.59% of the $PM_{2.5}$ in Oman comes from shipping, and this is mainly from SO_2 (32%) and NO_x (28%) emissions

The colour indicates the size of the contribution (in $\mu g/m^3$) to $PM_{2.5}$ concentrations in Oman from emission of that particular pollutant (e.g. SO_2, NO_x, NH_3 …etc.) from that sector. Therefore, the same colour grid has the same effect. Basically, the redder the grid square, the larger the contribution from emissions of that pollutant from that source sector.

There are many similarities between the percentage contribution of pollutants to $PM_{2.5}$ shown in this figure and the results estimated by this study in Chapter Two. This not only makes this figure relevant to Oman but also gives added validity to the mitigation options explored in Chapter Four.

When discussing this figure, several points must be made. Firstly, the pollutants included here are only those contributing to anthropogenic $PM_{2.5}$, which means dust is excluded. Secondly, the figure overestimates the percentage contribution of ammonia from agriculture to $PM_{2.5}$,; this might be because the agricultural sector in Oman is much smaller than that in most other countries, so the high contribution estimated by ECLIPSE might be related to use of an estimate coefficient irrelevant to Oman.

Third, justification of these results requires an exploration of wind patterns in Oman and the region, as some of the pollutants emitted come from neighbouring countries. For example, in 2010, the major contributor (21.86%) to $PM_{2.5}$ in Oman was the energy sector, and its main emission was SO_2. However, much of these SO_2 emissions come from the UAE, Qatar, Bahrain, Kuwait, and KSA.

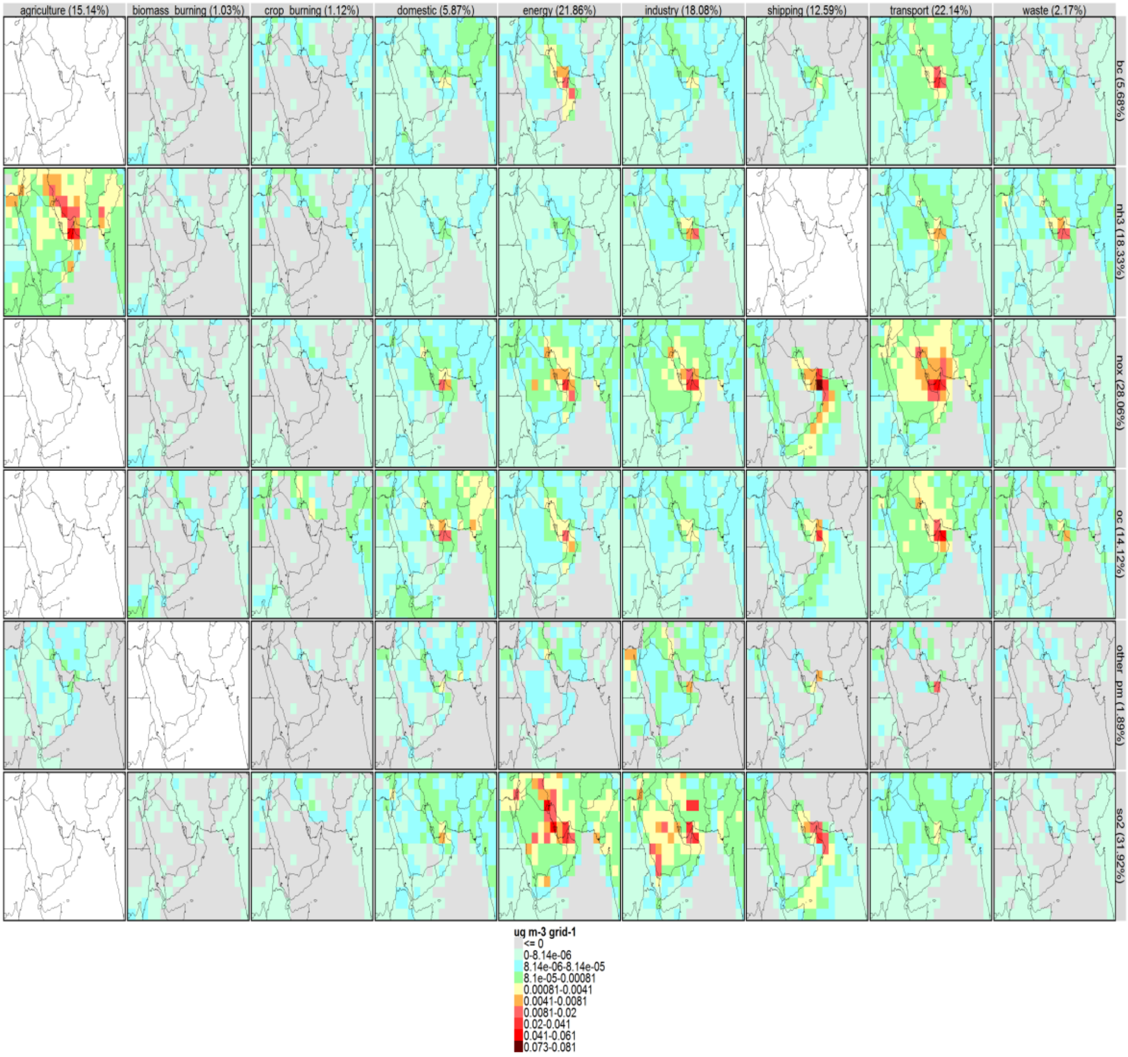


Figure 5-24 The contribution to national population-weighted PM2.5 concentrations from different source sectors and different pollutant emissions in Oman for 2010

Appendix A5 shows a graph of wind patterns in Oman, with the annual and seasonal means (DJF winter, MA Spring, MJ early summer, JAS late summer and ON Autumn).

- Annual: the prevailing winds are S/SW especially over the south, middle and east of Oman.
- Winter: The NE trade winds (NE monsoon) affect the east, middle and south of Oman, while the rest of the country gets NW winds.
- Spring: S, SW, SE winds prevail, except for north-west Oman which gets NW winds.
- Early summer: Typical summer winds, where the SW monsoon winds affect areas from South Al Sharqia to Dhofar, while the rest of the country gets dry NW winds.
- Late summer: Similar to early summer but with more intense winds. There is also some SE wind penetration over the Sea of Oman.
- Autumn: The start of the NE monsoon winds prevails for most of these two months.

5.4 Uncertainty:

Beside the limitations outlined in the section dealing with methodology for estimating impacts on health and climate, there are other general limitations:

The assessment of the impact of air pollution on health and climate combines information from different sources and on many topics, including estimated pollutant concentration, exposure, demographics, aerosol radiative forcing and the relationship between ambient concentrations and health outcomes. Each of the information sources used carries with it some degree of uncertainty, which influences the precision of and confidence in the health and climate impact results. These uncertainties propagate as the impact assessment moves through each stage. In addition, projecting future demographic changes is subject to uncertainties regarding population aging and migration, as well as the epidemiological transition from infectious diseases to chronic diseases, which are more affected by exposure to air pollution.

5.5 Conclusion:

From the discussion in this chapter, it can be concluded that $PM_{2.5}$ concentration in Oman is currently within the WHO limit; however, this concentration is projected to increase four times by 2050 if no measures are taken to reduce $PM_{2.5}$ emissions.

It has been revealed for the first time that the largest constituents of national $PM_{2.5}$ are SO_2, NO_x, and NH_3. If Oman implements all the measures suggested in Chapter 4, the country would be able to avoid all premature deaths attributed to national $PM_{2.5}$ by 2050. However, even more can be done if it initiates and carries out extra measures that particularly target SO_2, NO_x, and NH_3.

For Oman to improve its air quality and avoid the premature deaths that can be attributed to emissions from the rest of the world, it needs to take further steps towards regional collaboration so that $PM_{2.5}$ emissions from neighbouring countries can also be reduced. In addition, further studies are clearly needed into emissions from the natural background.

This chapter has also shown that temperature change is a complex issue, and cannot be looked at in isolation. Targeting the cooling aerosols (SO_2, and NO_x) alone will create a short-term increase in temperature, while reducing the emissions of warming greenhouse gases CO_2 and CH_4 will only impact the global temperature in the long term. This brings us to the importance of the integration of air quality policy and climate policy, which will be further addressed in Chapter Six.

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6 Opportunities for Oman to mitigate atmospheric emissions

6.1 Introduction:

In this thesis I set out to investigate the problems associated with air pollution and climate change, to investigate the potential for integrated control of these problems and to look at the importance within this of control strategies for Short-Lived Climate Pollutants. Chapter Two identified the major sources of emissions causing air pollution and climate change in Oman; with Chapter Three exploring current policy and its implementation in Oman and the GCC countries. Chapter Four examined the best measures to mitigate these emissions, with Chapter Five assessing their implications for the health of Oman's population and for climate change. This final chapter demonstrates how Oman could make further progress to limit emissions; the suggestions are based on the Chapter Three analysis of the existing legislative framework, and investigate the suitability of that framework for implementing the measures that would be required for progress The chapter also attempts to use the findings of this study to develop a framework through which Oman could achieve emission reductions; it also seeks to outline the difference this could make to people's health and well-being, and to show how Oman can play its part in the global effort against climate change.

Chapter Six, then, proposes ways that Oman could use already available opportunities to mitigate its atmospheric emissions, suggests convenient options open to the country, and discusses the significant impacts on air quality, health and environment that these could bring. It also makes recommendations to the planning authorities for actions they could consider and implement in the future.

This chapter will revisit the hypothesis set at the beginning of this study and will examine whether it has been proved or disproved. It will conclude by identifying other opportunities for future research that will contribute to the improvement of air quality of Oman and will promote participation in the climate change discussion.

The three questions raised in this chapter, then, are:

- First: Are air quality and climate change important for Oman?
- Second: Is it possible for Oman to implement measures that will significantly reduce the impact of both Air Pollution (AP) & Climate Change (CC) in both the near- and the long-term?
- And third: What changes are required to make this happen?

6.2 Air quality in Oman:

Air quality and its impact on health are as important for Oman as for the rest of the world, where people globally are very concerned about these issues. Table 6-1 presents estimates of the total emissions affecting air quality in Oman in 2010, along with the source of those emissions; it also gives the 2050 projection for those emissions, based on the BAU scenario.

Table 6-1: Total emissions (kt) in Oman and their main sources

Pollutants	main sources	Total emissions (2010)	Total emissions (2050)
SO_2	Manufacturing industry	160	1,255
NMVOCs	Oil and gas industry	142	324
NO_x	Transport, Manufacturing industry, and Electricity generation	137	705
$PM_{2.5}$	Road transport	61	309
CO	Road transport	51	201
NH_3	Agriculture	18	34
OC	Residential, and Industry	0.9	5

$PM_{2.5}$ leads to premature mortality and many other non-fatal health impacts. The increases projected for SO_2, NO_X, BC, OC, $PM_{2.5}$ (i.e. BC, OC but also other primary emissions) and NH_3 will all increase $PM_{2.5}$ concentrations. Although in 2010 the composition of $PM_{2.5}$ in Oman was mainly as dust, mostly of natural origin, and was also affected by emissions from the rest of the world, the amount of anthropogenic emissions of national origins is projected to increase by 85% by 2050, as was shown in in Chapter Five. However, if all the measures suggested in Chapter Four were implemented, 89% of the $PM_{2.5}$ concentrations resulting from Oman's own emissions could be avoided by 2050. In 2010, the concentrations of $PM_{2.5}$ were well above the WHO guideline value of 10 µg m^{-3}. The soil dust component already exceeds this guideline figure, but anthropogenic emissions are making the impacts worse, and it is this challenge that governments in the region could effectively address.

This study has outlined the main sources of the emissions that contribute to national $PM_{2.5}$ pollution in Oman:

1. Transport (responsible for 81% of the $PM_{2.5}$ emissions in Oman)
2. Industrial process emissions (responsible for 10% of the $PM_{2.5}$ emission Oman)
3. Oil and gas industry (responsible for 5% of the $PM_{2.5}$ emission in Oman)

$PM_{2.5}$ emissions from the transport sector are set to increase to 86% in 2050, even taking into account the ambitious BAU scenario for road transport, which would bring engine standards in line with the most up to date EURO engines. This is because the increase is related to emissions of road dust from unpaved roads.

Natural dust makes up the highest percentage of $PM_{2.5}$ and although the reduction of this source of $PM_{2.5}$ might be difficult, it is certainly possible to reduce the anthropogenic part of it. This source could be related to land degradation caused by overgrazing and other practices and will be affected by climate change, which will further dry out the soil and thus exacerbate the problem. At the national level, this needs to be addressed through more research throughout the GCC region to find out the potential for reducing emissions, as well as awareness-raising to highlight the issues; action must also be taken on practices like overgrazing. Regional communication also needs to be enhanced so that unified actions can be taken under the umbrella of the GCC cooperation mechanisms.

The levels of $PM_{2.5}$ pollutions are already having a serious impact on health in Oman, with the scenarios in this study projecting that this will only increase in the future. The number of premature deaths attributable to $PM_{2.5}$ was estimated at 711 for 2010; this could rise to more than 4000 in 2050. This increase, however, would not only be caused by the increase in emissions and thus in higher $PM_{2.5}$ concentrations; most of the increase can be attributed to population growth (from 2.8 M in 2010 to 7.0 M in 2050), and to the fact that the population would include a higher number of older people.

Whatever the reason, air pollution impacts on health are set to increase significantly, with premature deaths likely to increase nearly six times by 2050, and those parts of the problem that can be addressed by government need careful consideration. The results above suggest a clear need for an updated air pollution policy addressing the specific issues related to Oman, as well as for further action across the GCC region.

6.3 Climate change in Oman:

Climate change is extremely important for Oman, and many sources of air pollution are also sources of greenhouse gases and SLCPs. The effects of climate change have already been experienced in Oman and the GCC region in numerous ways, such as the increased frequency of severe heat waves, increased sand storms, changing rainfall patterns, and cyclones which have become more frequent and more violent. A recent report by Germanwatch (based on data for 1998–2017) ranked Oman as the 29th most vulnerable country in the world in terms of the Global Climate Risk Index[19].

Table 6-2 shows the emissions of major greenhouse gases and black carbon in Oman for 2010, along with the main sources of these emissions and the projected increase in emissions by 2050 in the BAU scenario.

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[19]David Eckstein, Marie-Lena Hutfils and Maik Winges, 2018

Table 6-2: CO_2, CH_4 and BC emissions (kt) in Oman and their main sources under the BAU scenario

pollutants	main sources	Total emissions (2010)	Total emissions (2050)
CO_2	Electricity generation, Road transport, and Manufacturing industry	50,000	314,867
CH_4	Oil and gas industry	565	1,249
BC	Manufacturing industry, Oil and gas industry, Residential, and Road transport	4	11

Oman's GHG emissions come mainly from the energy sector (both power generation and the oil and gas sector), as well as from road transport and from manufacturing industries. As shown earlier in the study, the main sources of CO_2 emission in Oman are these:

1. Electricity generation (31%)
2. Road transport (23%)
3. Energy industry own use (16 %)
4. Industry (14%)

According to the BAU scenario developed in this thesis, there will be a massive increase in total CO_2 emissions by 2050 if action is not taken now. This is particularly true for electricity generation, which will rise from 31% of the total in 2010 to 45% in 2050. However, these increases are not inevitable. According to the analysis in this study, if Oman implemented all the measures proposed in Chapter Four, it could reduce its emissions of CO_2 by 60% in 2050.

This potential reduction in CO_2 emissions and other GHGs and SLCPs, as well as the reduction in emissions leading to cooling aerosols, would reduce the net impact of Oman's emissions on the global temperature by 8% by 2050 compared with the BAU scenario, and the improvement could be even greater with further efforts to reduce CO_2 and other warming pollutants.

An ambitious climate-change mitigation policy has become particularly important for Oman at this point, as the country has initiated a heavy industrialisation programme aimed at increasing the share of industry in its GDP and thus helping to diversify the economy away from oil and gas. The industries are mostly situated on the coast of the Arabian Peninsula, the area most vulnerable to cyclones, which are likely to increase in frequency and severity as a result of climate change. This means that these industries, and thus the economy as a whole, are themselves greatly at risk, making it vital for Oman to move forward and engage seriously in the global climate debate.

6.4 Integrated air quality and climate policy:

Although Oman is currently more interested in its economic development than in air pollution or climate change, it is still possible for the country to develop without damaging the climate or human health. Oman faces a number of choices about the ways that it is going to develop, and this study identifies ways in which it can develop economically while still reducing GHG emissions and providing better air quality in and for the future.

One challenge confirmed by this study is the fact that the most important measures to improve air quality and human health will do so at the expense of the climate. This is because the main pollutants to reduce $PM_{2.5}$ are SO_2 and NO_x, but both of these give rise to cooling aerosols. If their emission levels are reduced, more warming will occur. This implies that if Oman is to help win the battle against climate change, it will need to focus far more on reducing the warming substances. Given that climate change also affects human health, it is vital to integrate the approach to air pollution and climate change in as many ways as possible if the sultanate is to develop a wealthy but cleaner future, and reduce emissions to the benefit of both national health and the global climate.

The following section proposes and discusses Air Quality (AQ) and Climate Change (CC) policies which could be integrated to bring both national and global benefits.

6.4.1 CO_2 affecting long-term climate change:

The renewable energy scenario (RES) aims to replace natural gas for generating electricity with solar energy (50% by 2050) and wind energy (20% by 2050); this would lead to a reduction of 100 Mt CO_2 by 2050. In addition, 86% of the NO_x emission in BAU would be avoided by 2050, and half the CO emissions.

The zero coal scenario (ZCS) is a scenario that looks into the possibility of abandoning the government of its plan for having a 7% of the country's electricity generation from coal by 2024. The implementation of the ZCS would avoid 30% of CO_2 emissions by 2050 (40 Mt) compared with the BAU, and would lead to a reduction of more than half of NO_x emissions by 2050, avoiding 168 kt.

Implementing these two policy scenarios would achieve 140 Mt reduction of CO_2 by 2050, with an added benefit for air quality (from SO_2 and NO_x emission reductions) as well.

These policies now come under the Ministry of Oil and Gas (MOG), and the proposed update of the policy implies the evolution of a more ambitious strategy with a higher percentage share of renewables in the power sector. The coal plant being planned by the MOG should be replaced by renewables, and no further steps should be taken towards building it.

6.4.2 SLCPs (BC and CH_4) affecting near-term climate change:

Implementation of the zero flaring scenario (ZFS) would not only reduce but actually eliminate all the BC emissions from the oil and gas sector in Oman; they would go from 2.8 kt in 2020 to zero by 2030. It is definitely possible to eliminate black carbon by banning the flaring practice, and this can be done if the zero flaring initiative to which Oman signed up becomes a fully implemented policy. All that is needed is a time frame for the ban to be approved by the Ministry of Oil and Gas (MOG), and for the Ministry of Environment and Climate Affairs (MECA) to actively begin monitoring and inspection.

The fugitive reduction scenario (FRS) works on the assumption that oil and gas production will continue to 2050 without any decline in the amount of drilling, processing, transportation, and distribution it carries out. However, if the industry achieves a 50% reduction in fugitive emissions by 2030, and a 75% reduction by 2050, then it will reduce CH_4 emission by 200 kt by 2050. However, this FRS will only be achieved successfully if, and only if, MECA makes it a serious part of their policy, and improves their procedures for inspection of the oil and gas industry.

The renewable energy scenario (RES) discussed earlier would be able to achieve a 75% reduction in CH_4 emissions from the electricity generation sector by 2050, since renewable energy would replace natural gas and it is the generation of gas which leads to fugitive emissions of methane.

6.4.3 Pollutants affecting $PM_{2.5}$ (SO_2, NO_x, NH_3, BC, OC dust)

In Oman, the premature deaths attributed to $PM_{2.5}$ are mostly caused by emissions of SO_2, NO_x and NH_3. The efficient industry scenario (EIS), which proposes increasing the efficiency of the industry sector, will be capable of reducing 39% of SO_2 emissions and 40% of NO_x emissions by 2050. This type of policy would come under the Ministry of Commerce and Industry (MOCI); the ministry needs to take steps to include an industry efficiency initiative within plans for each industrial sector.

The clean fuel scenario (CFS) aims to move away from using heavy fuel oil (HFO) in the cement and lime-producing industries and to replace it with cleaner fuel, so that by 2050, the use of HFO will be at 0%, with natural gas and electricity at 50% each. This would serve as a preventive action and would result in a significant drop in SO_2 emissions, with a zero emission target being reached by 2050. The same policy scenario will also serve to reduce NO_x emissions by 91% by 2050. This policy requires collaboration between both MOG and MOCI.

The zero coal scenario (ZCS) and the renewable energy scenario (RES) will not only have advantages for climate regulation, but ZCS will also be able to reduce NO_x emissions by half by 2050, and RES will substantially decrease the NO_x emissions by the same date.

The transport policy scenarios also play a very important role in the reduction of NO_x, and CO, and of $PM_{2.5}$ in general. The electric vehicle scenario (EVS) which advocates the penetration of electric vehicles into the market, will reduce CO, NO_x, and $PM_{2.5}$ emissions to half by 2040, while the public transport scenario (PTS) will achieve 33% NO_x emissions reduction and 29% $PM_{2.5}$ emissions reduction by 2040. In Oman, dust emissions from vehicles travelling on unpaved roads are a much greater source of PM emissions than the relatively small amount of exhaust emission of primary $PM_{2.5}$ (mainly black carbon). The paved road scenario (PRS) is thus a very important scenario, and could result in a 75% reduction in $PM_{2.5}$ emissions by 2040.

In terms of policy framework, the electric vehicle scenario (EVS) will be partly driven by international trends, since most vehicle production companies are in the process of moving towards electric cars. For Oman, what is most important is that they, with other GCC countries, lead the movement to change to electric vehicles. This will involve collaboration both nationally (between MOCI, MOG and the Royal Oman Police), and regionally (between MOCI and the GCC). The responsibility for implementing the public transport scenario (PTS) will fall to the Ministry of Transport and Communications (MOTC), which must ensure that the shift towards more public transport is compatible with the ministry's strategic plans. Indeed, if the political will is strong enough, plans can be even more ambitious than those suggested here. The last few years have seen a number of awareness-raising activities taking place, as well as major investment in a public transport system that is providing more access to and greater flexibility in options for traveling around both cities and the country as a whole.

However, further progress is still needed to compensate for population growth, and the institutional framework must be restructured if it is to cope with the fast economic and population growth that is taking place. The adoption and implementation of the paved road scenario (PRS) would be the responsibility of two entities, with the main roads coming under the Ministry of Transport and Communication (MOTC) and the rural governorate roads being the responsibility of the regional municipalities. In terms of readiness, the MOTC already has a clear plan in place to pave more roads, and has made it a priority, while the regional municipalities tend to provide paved roads mainly when driven by plans for the distribution of residential houses.

6.5 Developing the policy:

Chapter Three of the study has shown that the overall legislative framework in Oman has adequate potential to implement the scenarios that were identified in Chapter Four and discussed in the earlier sections of this chapter. However, although the overarching framework might exist, a good deal of new policy and associated legislation would need to be developed and put in place. Based on the estimated relative effects of air pollutants and GHGs on climate and mortality which obtained from the developed scenarios in this study, two summary graphs are illustrated in Figures 6.1 and 6.2 of the avoided premature deaths and the avoided temperature change of different scenarios vs. baseline scenario (2010-2050). Table 6.3 shows the scenarios abbreviations and for more details, chapter Four have introduced them sufficiently.

Table 6-3 Scenarios abbreviations:

FRS	Fugitive Reduction Scenario	CFS	Clean Fuel Scenario
ZFS	Zero Flaring Scenario	EVS	Electric Vehicle scenario
RES	Renewable Energy Scenario	PTS	Public Transport Scenario
ZCS	Zero Coal Scenario	PRS	Paved Road Scenario
EIS	Efficient Industry Scenario	ACS	Air Conditioning Scenario

It is clear from Figure 6.1 that the three best scenarios in terms of reducing premature deaths by 2050 are the clean fuel scenario (74 avoided deaths), the renewable energy scenario (63 avoided deaths) and the zero coal scenario (57 avoided deaths). The least important scenarios are the fugitive reduction scenario and the public transport scenario.

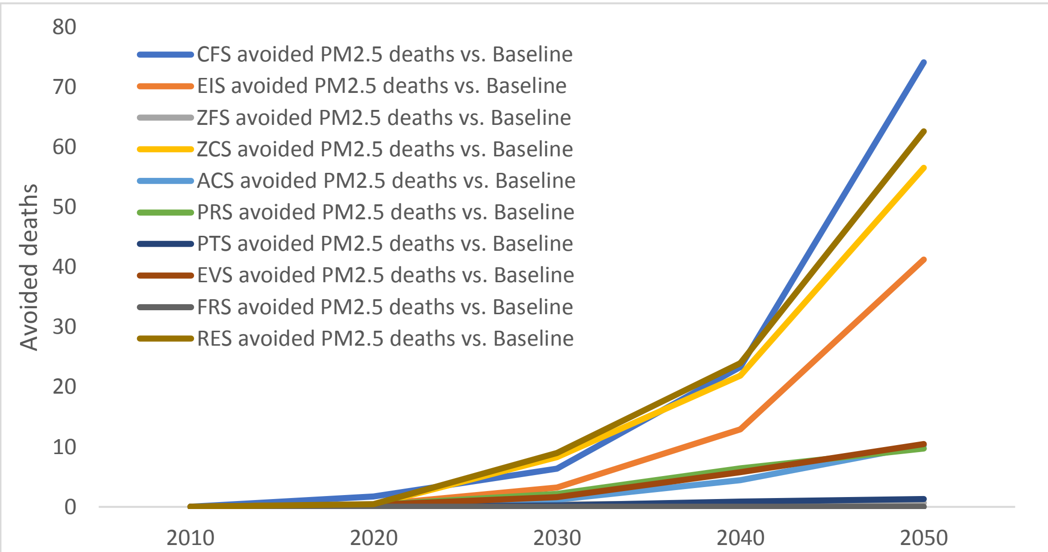


Figure 6-1 Avoided deaths of different scenarios vs. baseline scenario (2010-2050)

In Figure 6.2, the change in the global temperature were compared for the different scenarios. The more effective scenario which will be able to avoid more global temperature change was found to be the electric vehicle scenario.

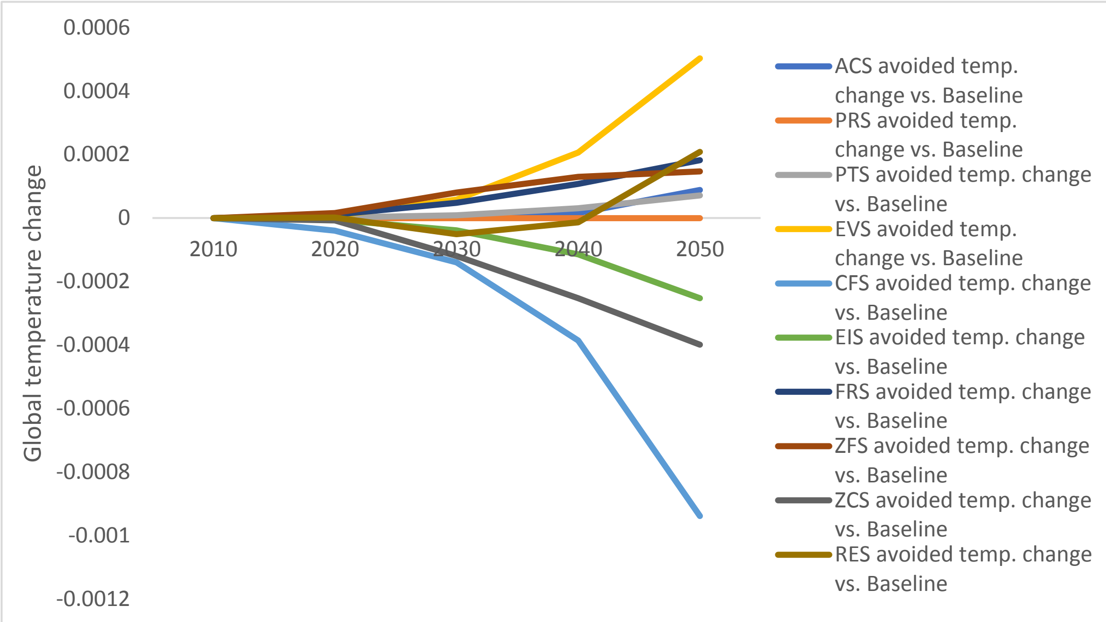


Figure 6-2 Global temperature change of different scenarios vs. baseline scenario (2010-2050).

To maximize the environmental (avoided temperature change) and health (avoided premature deaths) benefits (the so-called 'low hanging fruit'), a plot of the avoided change in temperature from each scenario against the avoided mortality (ΔT vs deaths) for 2020-2050 has been summarized in the following graphs of the different scenarios (Figures 6.3 and 6.4).

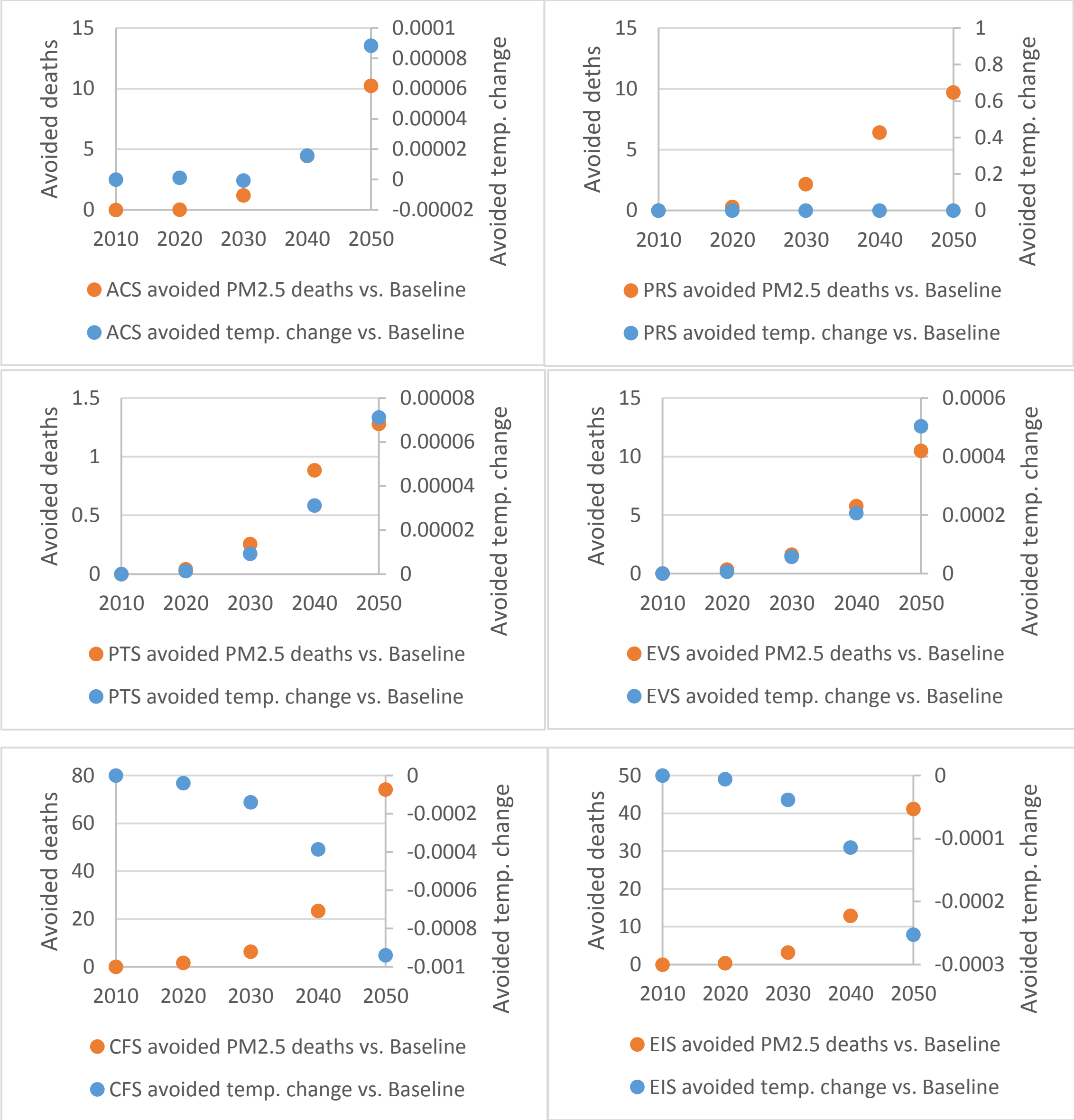


Figure 6-3 The avoided change in global temperature against the avoided premature mortality (ΔT vs. deaths) for 2020-2050 for the different scenarios from right to left: Air Conditioning Scenario (ACS), Paved Road Scenario (PRS), Public Transport Scenario (PTS), Electric vehicle scenario (EVS), Clean Fuel Scenario (CFS), and Efficient Industry Scenario (EIS).

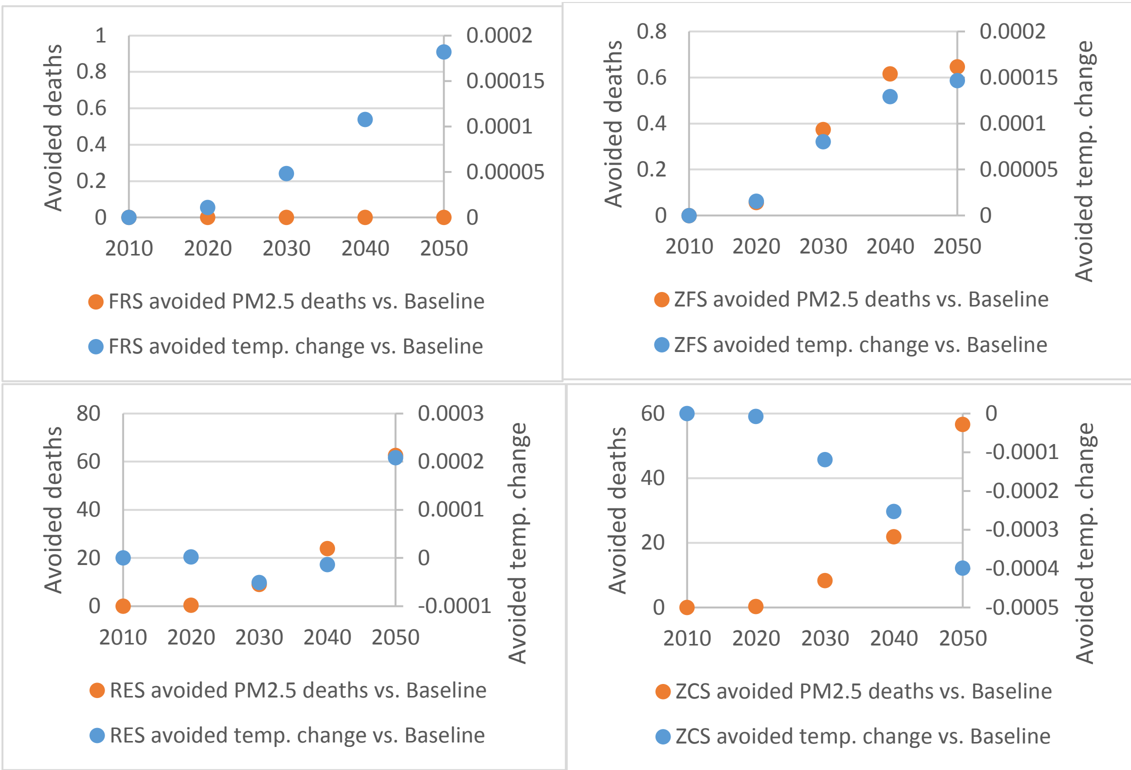


Figure 6-4 The avoided change in global temperature against the avoided premature mortality (ΔT vs. deaths) for 2020-2050 for the different scenarios from right to left: Fugitive Reduction Scenario (FRS), Zero Flaring Scenario (ZFS), Renewable Energy Scenario (RES), and Zero Coal Scenario (ZCS).

The scenarios which would benefit climate more than air quality and vice versa are discussed in the following as demonstrated in Figure 6.3 and 6.4:

1) Air Conditioning Scenario (ACS): It is clear that reducing electricity demand for air conditioning in households and commercial and public sectors will avoid temperature increase because of the reduction of CO_2 and slight reduction in premature deaths.
2) Paved Road Scenario (PRS): Paving more roads will avoid deaths due to the reduction in the anthropogenic $PM_{2.5}$ but it makes no much difference to global warming.
3) Public Transport Scenario (PTS): Will avoid both deaths and global warming.
4) Electric Vehicle scenario (EVS): Will avoid both premature deaths and global warming
5) Clean Fuel Scenario (CFS): Although it will reduce deaths, it will lead to increased global warming because SO_2 is taken out from the atmosphere.
6) Efficient Industry Scenario (EIS): Will reduce deaths but increases global warming – I guess because SO_2 is taken out. However, in the long term, after 2100, CO_2 reduction from this scenario should reduce warming.
7) Fugitive Reduction Scenario (FRS): Reducing methane will reduce global warming, but that does not affect $PM_{2.5}$ and so no change in premature deaths.
8) Zero Flaring Scenario (ZFS): Will reduce BC and $PM_{2.5}$ and so will reduce premature deaths and global warming as well.

9) Renewable Energy Scenario (RES): Will reduce premature deaths and global warming due to the reduction of CO_2 and air quality pollutants.
10) Zero Coal Scenario (ZCS): Will reduces death due to reducing SO_2. However, CO_2 does not take over to lead to benefit for climate because of the government plan which is included in the baseline of generating electricity from coal by 7% in 2024, and 50% in 2030.

Table 6.4 gives an overview of how different scenarios will affect the future by 2050 in terms of the avoided deaths and avoided temperature change globally. This will allow prioritization of the most effective actions that is recommended and could be pursued by Oman government in order to maximize the benefit of human health and warming.

Table 6-4 the effect of different developed scenarios on national deaths and global temperature by 2050.

Scenario		Avoided premature deaths	Avoided global temp. change (°C)
FRS	Fugitive Reduction Scenario	0	**≈ 0.0002**
ZFS	Zero Flaring Scenario	1	**0.00015**
RES	Renewable Energy Scenario	**> 60**	**> 0.0002**
ZCS	Zero Coal Scenario	**> 55**	Negligible
EIS	Efficient Industry Scenario	**> 40**	Negligible
CFS	Clean Fuel Scenario	**> 70**	Negligible
EVS	Electric Vehicle scenario	10	**0.0005**
PTS	Public Transport Scenario	1	Negligible
PRS	Paved Road Scenario	10	Negligible
ACS	Air Conditioning Scenario	10	Negligible

From the above Figures 6.3 and 6.4 and Table 6.4, The best scenarios in terms of avoided deaths in 2050 are as follow:

Clean Fuel Scenario (CFS) > 70, Renewable Energy Scenario (RES) > 60, Zero Coal Scenario (ZVS) > 55, Efficient Industry Scenario (EIS) > 40

Whereas, the best scenarios in terms of avoided temperature change in 2050 are as follow:

Electric Vehicle scenario (EVS) (0.0005 °C), Renewable Energy Scenario (RES) (> 0.0002 °C), Fugitive Reduction Scenario (FRS) (≈ 0.0002 °C), Zero Flaring Scenario (ZFS) (0.00015 °C)

The Renewable Energy Scenario (RES) beat all other scenarios in reducing both premature deaths and temperature change by 2050, taking into consideration the CO_2 reduction (avoided global temperature change) might take longer than 2050 for some other scenarios to see the benefit, such as Zero Coal Scenario (ZCS), Efficient Industry Scenario (EIS), and Clean Fuel Scenario (CFS).

A combination of both existing and new legislation will be required if Oman is to take effective action to achieve the emission reductions of which it is capable, along with their benefits to health and climate. The existing legislation that can be used includes:

- Royal Decree No. 114/2001, the 'Law on the Conservation of the Environment and Combating of Pollution'
- Ministerial decision 118/2004, law on 'Air pollution from stationary sources'
- Ministerial decision 41/2017, 'Ambient Air Quality' law
- Royal Decree 8/2011, 'Oil and Gas Law'
- Royal Decree 28/1993, the 'Traffic Law'

However, there is as yet no legislation in place that can address the following issues:

- The policy for the energy sector (oil and gas and electricity generation) needs to specify the percentage share for renewable energy in the power sector. Regulations must also be developed to enforce the zero flaring goal as well as to reduce fugitive emissions of methane. Another issue requiring regulation is the venting of methane in the oil and gas sector; thus far it has not been covered by laws relating to the activities of the Ministry of Oil and Gas (MOG) nor by any law relating to the Ministry of Environment and Climate Affairs (MECA). The government therefore needs to use appropriate technologies to facilitate emission control programs for the industrial and private sectors; these must be more consistently applied and rigorously enforced than happens at present, if effective control is to be achieved.
- Road transport is the second largest contributor to CO_2 emissions, and this is an area there is a good deal of room for emission reduction. Shifting the finance from subsidising fuel to improving the public transport infrastructure will substantially reduce road transport emissions. Another positive measure is the increased penetration of electric vehicles, but for this to happen, decisions need to be taken at both national and regional

levels. Current procedure for the annual inspections of vehicles also needs to be revised, and the rigorous testing of vehicle emissions must be included.

- Policy for the industry sector also needs revision. This will involve a decision for manufacturing industries to shift to cleaner fuels, and other decisions aimed at bringing about an improvement in industrial efficiency.

An increase in the political will to address the problems is a key factor if Oman is to make the required changes to existing legislation and is to develop the new legislation needed to implement the measures described. Interviews with key members of government and other stakeholders showed that at present there is a very little understanding of either the issue of air pollution or of climate change. Most policy makers do not link the recent increases in the frequency of heat waves with climate change, nor do they consider the issue of air pollution as a priority. The NGOs are not active on these issues and the media is silent. The air pollution legislative and regulatory systems that do exist are based on international environmental standards set by organisations such as the World Bank and the US EPA, and there is currently no evidence of national interest in building on or improving these standards to make them more representative of the country’s situation and what should be its urgent concerns.

There are a number of barriers to overcome before the scenarios can be put into place. First of all, although Oman is rich in the sunlight and wind resources that would facilitate the production of renewable energy, it is also a country rich in fossil fuels. As a result, it is reluctant to give up oil production until renewables have taken a steady place in the energy markets, despite the fact that the oil and gas sector is the main source of **cli**mate-change-related emissions in the country. Although the oil and gas sector may on the one hand desire to achieve a significant reduction in its emissions, the sector is also powerful and ambitious, and might face challenges in the political will needed to make the required changes. Procedure for dealing with the air quality and emissions data collected from the fixed and mobile monitoring stations constitutes another challenge, as the data will have to be effectively analysed and employed if it is to support policy makers in setting out new policy and reduction plans.

This study has a number of recommendations for the action needed to increase the attention given to air quality and climate change in the country, and to show the importance of integrating them at policy level. The recommendations are:

- Raising awareness within the policy makers, public, media, and judiciary.
- Involving more stakeholders in the policy development process.
- Encouraging research at national and regional levels in the fields of climate change and air pollution, and their health impacts.

- Taking steps to strengthen Oman's voice in regional and international communications.

6.6 Future work:

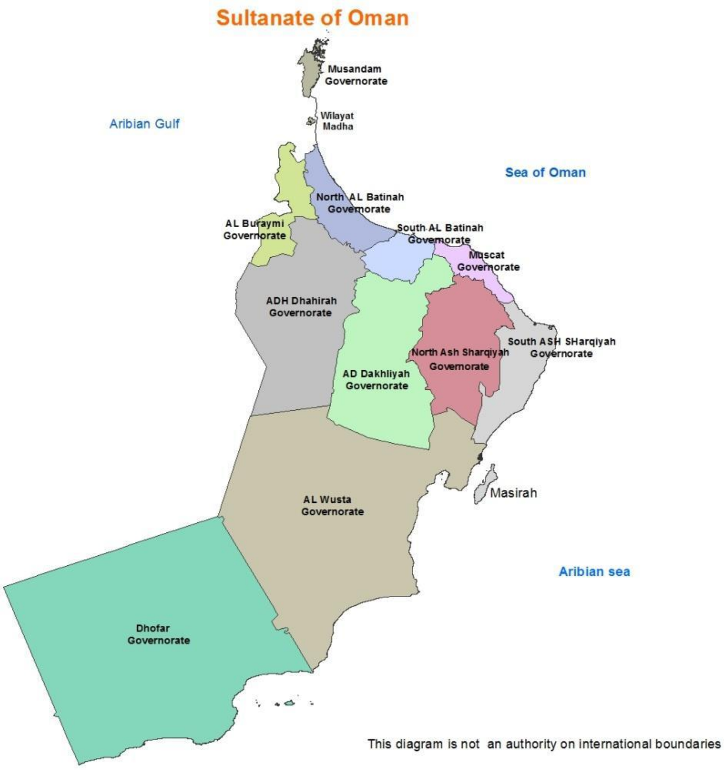
A lot of $PM_{2.5}$ is natural soil dust which is responsible for a percentage of premature deaths, and nothing can be done to avoid that. However, part of this natural dust is from anthropogenic sources due to land degradation. As yet there is no solid information about how much soil dust is from anthropogenic sources, but they are known to play a part. This is not just a problem for Oman; it is a regional problem which needs further work in collaboration with the GCC and other neighbouring countries. Natural dust is a part of life in Oman, but behavioural change can mitigate its impact; people should learn to stay indoors particularly during sand storm episodes, and the country could implement an early warning system to alert people so they can avoid exposure to heightened soil dust days.

Sand storms are another big issue to Oman, and we need more studies investigating the implications of climate change for sand storms in the region in general; we also need more research on how much anthropogenic activities affect the natural dust, so that those activities may be avoided as far as possible. The health risks posed by sand storms should also be studied and evaluated, with an emphasis on those aged 50-70, who make up the most vulnerable age group. This age group will become increasingly dominant in the future, and if nothing is done, the number of premature deaths will increase.

Another area needing to be investigated in future work is the occurrence of cyclones and an evaluation of their risk to Oman, especially to the industrial and economic ports. It is important for there to be investment in the modelling and support of research studies in this area.

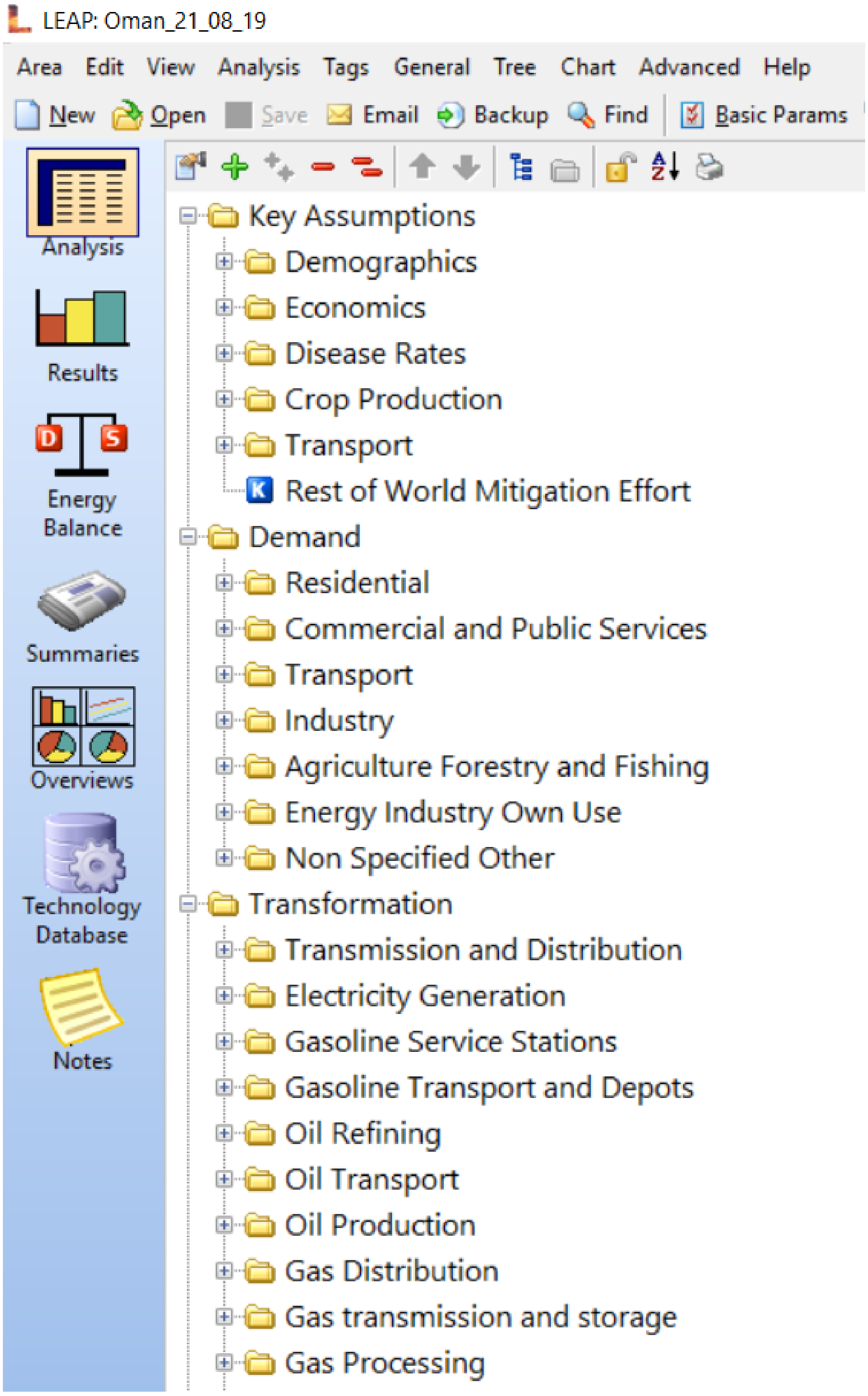
For all this to happen, it is essential to create the political will, to raise awareness, to involve the public in the policy-making process, and to ensure greater transparency.

Appendix (A1): Diagrammatic Presentation of Sultanate of Oman

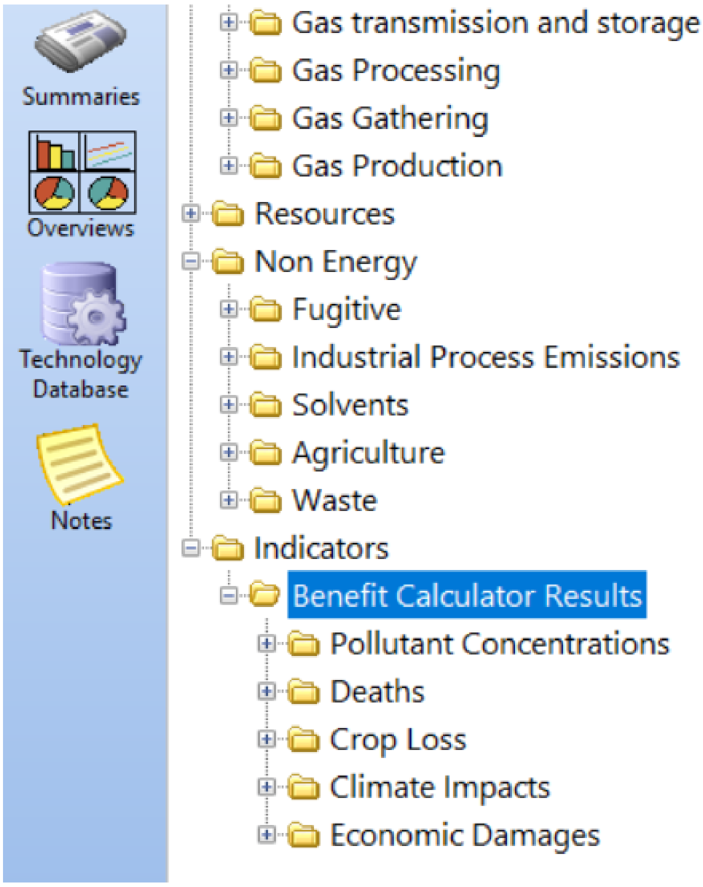


Source: Oman health vision 2050

Appendix (A2): Branches within LEAP-IBC tree source of emissions.

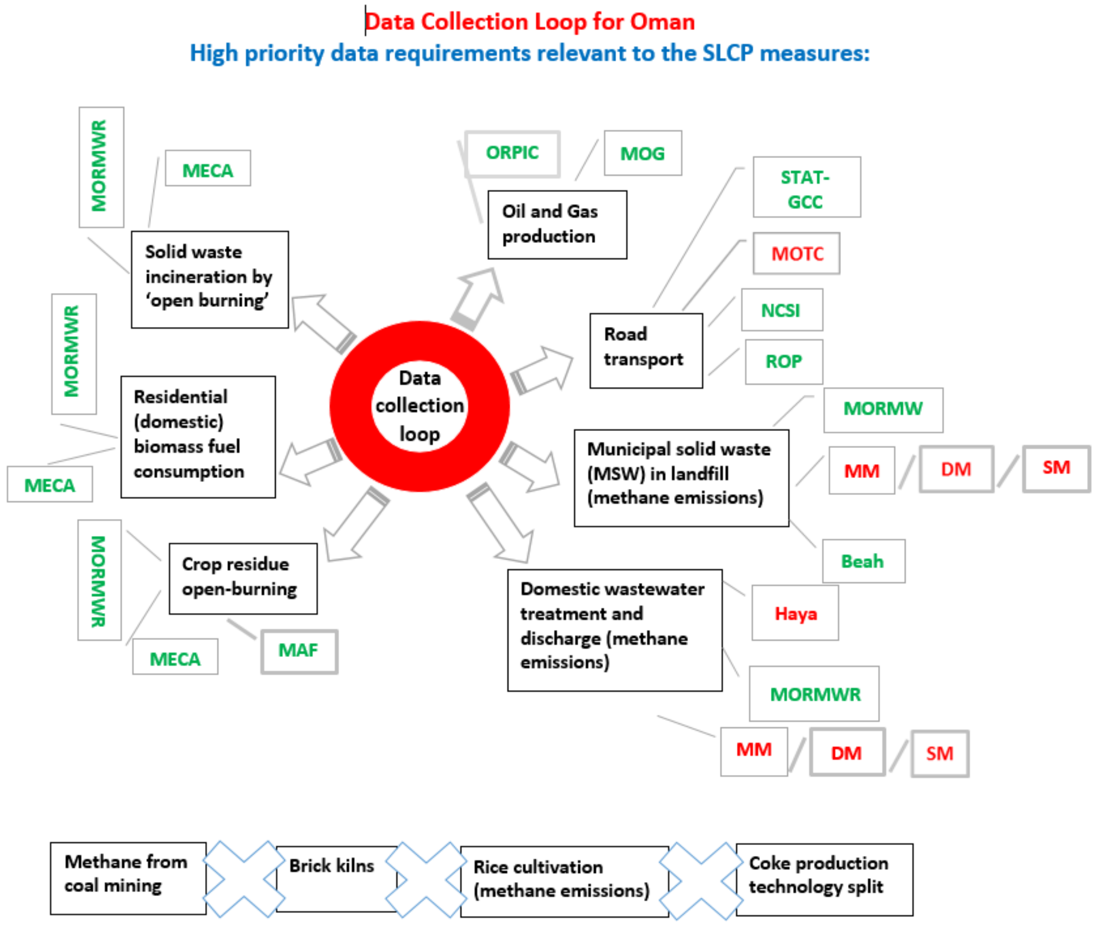


Cont. Appendix (A2):



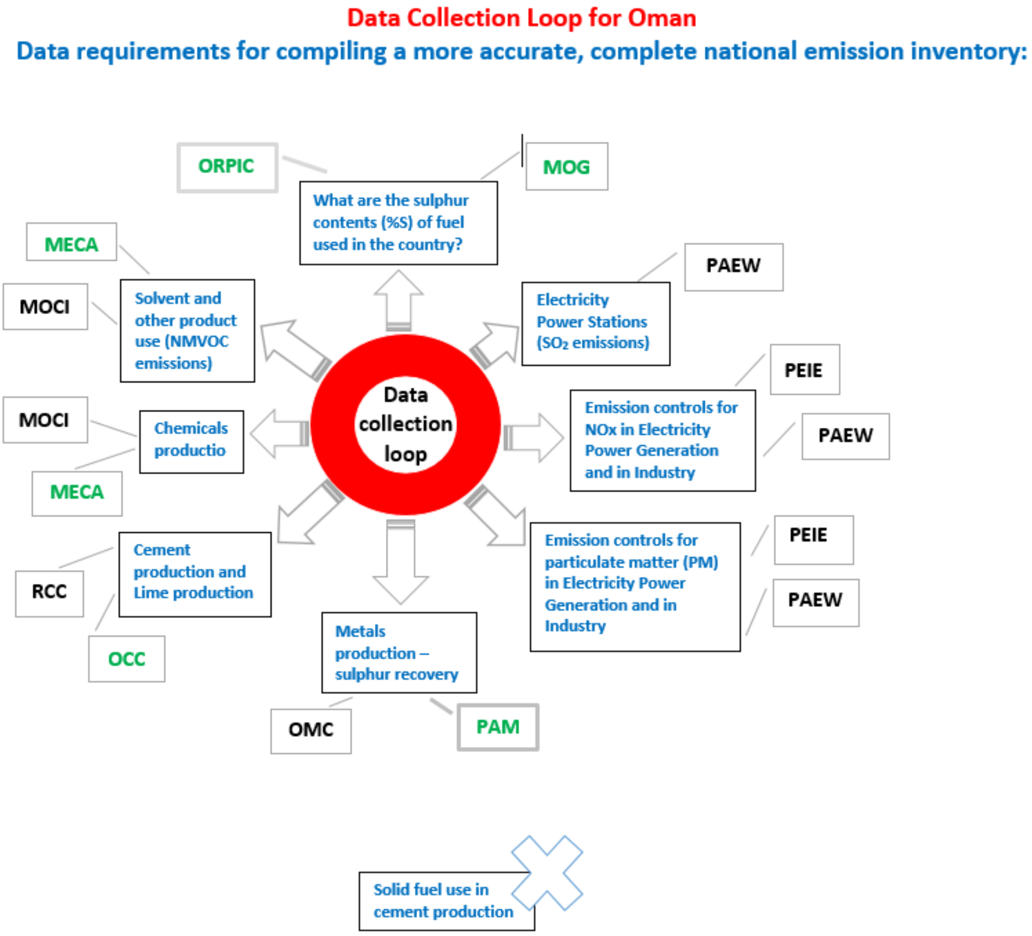
Appendix (B2): Data Collection Loop for Oman

High priority data requirements relevant to the SLCP measures

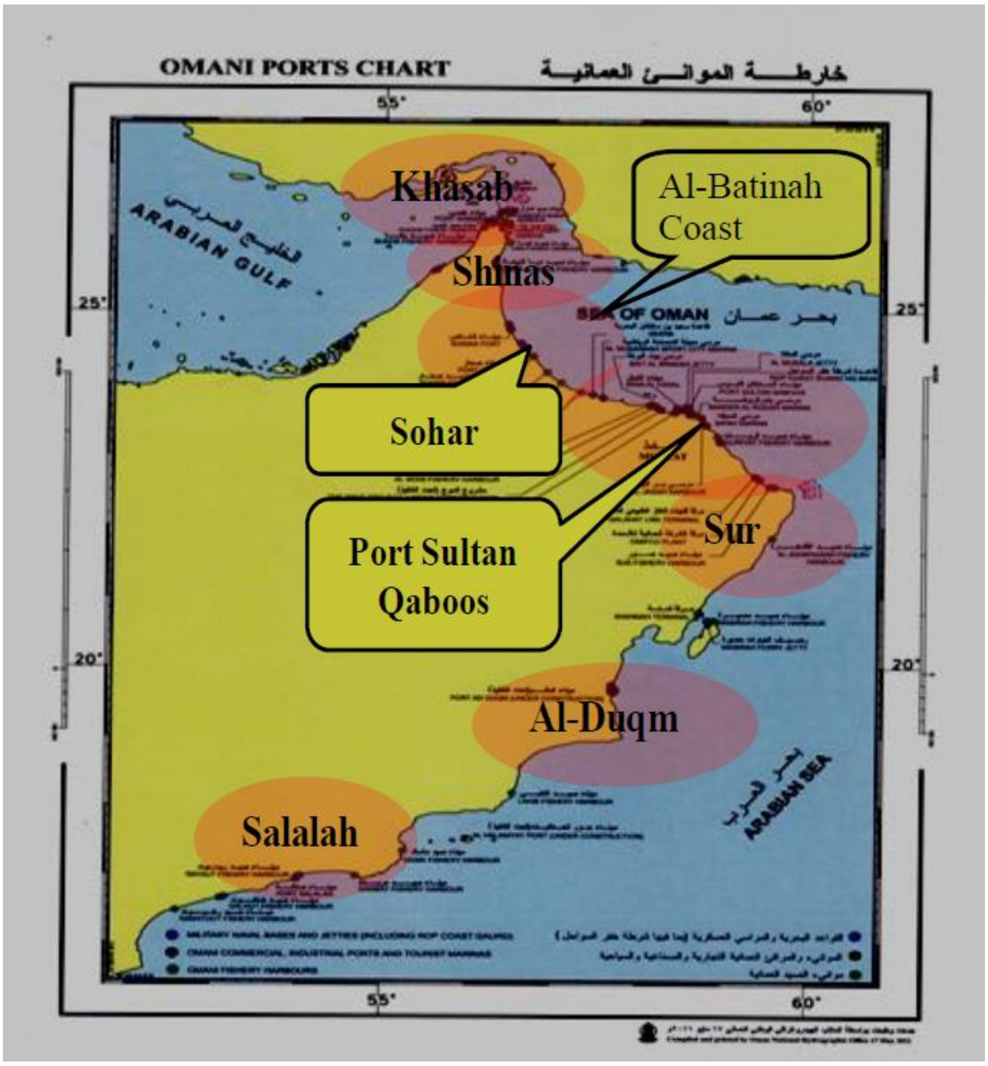


Appendix (C2): Data Collection Loop for Oman

Data requirements for compiling a more accurate, complete national emission inventory



Appendix (D2): Oman's Commercial and Industrial Ports 2011



Source: Oman's National Hydrographic Office, 2011

Appendix (E2): ORPIC plants production of fuels and petrochemicals, for end use or for further downstream processing.

Source: (ORPIC, 2017)

Appendix (F2): Al Amerat landfill (Photo taken by the researcher).

Appendix (A3): list of laws and regulations in the Sultanate of Oman – related to the environment, waste, permitting, climate affairs, on sustainability, etc.

No.	Title	Description	Category	Authority	comments
1	RD 34/74	The Marine Pollution Control Law	Marine Pollution		These decrees are considered the cornerstones of the institutional environment in the Sultanate.
2	RD 68/79	Establishment of the Board of Environmental Protection and Pollution Control	Institutional development		
3	RD 114/2001	Law on Conservation of the Environment and Prevention of Pollution	Environment Pollution	MECA	
4	RD 26/81	Sanctioning the Convention on the Prevention of Marine Pollution by Dumping of Wastes and other matter	Marine pollution	MECA	
5	RD 40/81	Sanctioning the UN Industrial Development Organization Charter	Industrial development	MECA	
6	RD 67/89	Authentication of UN Convention on the Law of the Sea Law	Maritime law	MECA	
7	RD 119/94	Authentication of Basel Convention on the Control of Trans boundary Movements of Hazardous Wastes and their Disposal	Hazardous waste	MECA	need to be checked
8	RD 119/94	Authentication of the UN Framework Convention on Climate Change (UNFCCC)	Climate Change	MECA	
9	RD 73/98	Accession to Vienna Convention on Ozone Layer protection and the Montreal Protocol on Ozone depleting substances	Ozone	MECA	
10	RD 107/2004	Ratification of the Kyoto Protocol on Climate Change	Climate Change	MECA	

11	MD 20-2016	Issuing a Board for Managing Climate Affairs	GHG	MECA	
12	MD 118/2004	Air pollution from stationary sources	Emission standards	MECA	
13	MD 200/2000	Crushers Quarries & Transport of Sand	Dust emissions	MECA	
14	MD 107/2013	Issuing Regulations for the Protection of the Ozone Layer	Ozone	MECA	
15	MD 67/2015	Amendment of MD 107/2013	Ozone	MECA	
16	MD 17/1993	Management of Solid non-hazardous waste	non-hazardous waste	MECA	
17	MD 18/1993	Management of hazardous waste	hazardous waste	MECA	
18	MD 145/1993	Regulation for waste water re-uses and discharge	waste water	MECA	
19	RD 27-2003	Mining Law	Mining		I should check who’s responsibility
20	Guideline No. 22	Regarding Environmental Conditions for Refineries	refineries	MECA	
21	MD 187-2001	Organizing the Issuance of Environmental Approval	Environmental Approval of new establishment	MECA	
22	MD 68-2004	Modification of MD 187-2001	Environmental Approval of new establishment	MECA	

Appendix (B3): Oman air quality and environmental regulations.

Provided separately

Appendix (C3): GCC Air Quality Policies: (documents provided by UNEP)

Provided separately

Appendix (D3): GCC countries National Determined contribution (NDC)

Provided separately

Appendix (E3): Method of interviews

Interview Strategy

Research project: Investigating the Benefits of Short-Lived Climate Pollutant Strategies in Oman and other Gulf countries

Aim of the Interview:

To answer the following research question:

Are the current policies which regulate the activities related to air pollution and GHG emissions effective for the current situation?

This project is the first investigation in Oman of Short Lived Climate Pollutants (SLCPs) as a group of pollutants affecting Oman and other Gulf Cooperation Council (GCC) countries. It will focus on investigating the implications of an SLCP strategy in the GCC region and see how it could best reduce SLCP pollution and its impact on health, climate, and the economy. The implementation of policies in Oman is the main way by which air pollution is controlled. The policy part of the project seeks to develop a comprehensive overview of the policies in Oman which impact on the emission of GHGs and air pollutants; these include climate policies, and regulations concerning air pollution, land planning, and transport. This overview will help to determine the impact of policies on the quality of the environment. By The project will evaluate the successes and failures of existing policies, and then attempt to identify areas for improvement in the future.

The aim of these interviews is to obtain an overview of all the policies, regulations, legislation and guidelines that govern issues related to the impact of various sectors on the environment. The interviews will look particularly at those policies, laws and guidelines relevant to GHG and air pollutant emissions in Oman, and will also seek to analyse policy-making processes and describe the development of environment policies in the country. They will also investigate the implementation and enforcement of those policies, what different stakeholders see as the drawbacks of implementing them. They will also seek to discover how effective the policies are and whether stakeholders see the situation in Oman as representative of that in the GCC countries as a whole.

The interviews will cover as an overall theme "The Policies of air pollution and climate in Oman", with a number of topics being addressed during the interviews, as follows:

- The current legislation covering air pollution and climate change (GHG emissions).
- Processes of policy-making for the areas of air pollution and climate change.
- The implementation, enforcement and evaluation of policies.
- The 2040 vision for environment policies and the renewable energy sector in Oman.

Method followed:

The project drew upon a mix of primary and secondary data sources including government documents, legislation and statistics. The researcher also conducted semi-structured interviews with key stakeholders.

The researcher used the information gathered in the interviews to develop a summary of the policies governing air pollution and climate in Oman and an outline of how the regulations are implemented. Any case studies or stories given in the interviews and related to those policies, were also collected.

4. The approach used in the semi-structured interview was an interpretive route that developed a clear question that the researcher wishes to address. The broad question was organised around a set of predetermined open-ended questions, with other questions emerging from the dialogue with interviewees. Interviews were scheduled in advance at a designated time and location outside of everyday events and lasted between 30 minutes and an hour.
5. A triangulated interview approach was carried out by interviewing a range of different levels and types of people involved in the policy-making process, including:

- ✓ Policy-makers
- ✓ Decision-makers
- ✓ Environmentalists
- ✓ Business professionals
- ✓ Leaders of industries
- ✓ NGO representatives
- ✓ Media representatives
- ✓ Legal representatives

Selecting Interviewees:

Based on LEAP-IBC emission inventory analysis we were able to identify the sectors which contribute most to the $PM_{2.5}$ emissions and ambient concentrations in Oman, both now and in the future (2050). They are the transport and the manufacturing and construction sectors.

The map developed by Chris Malley for Oman and the region showed the contribution to national population-weighted $PM_{2.5}$ concentrations from different source sectors and different pollutant emissions, revealing that the main sectors contributing to $PM_{2.5}$ are:

- Road Transport - 22%,
- Energy Industry - 22%
- Manufacturing and Construction Industry - 18%
- Agriculture - 15%
- Shipping - 13%

On the basis of this information, the researcher decided to interview the following types of people: policy-makers, decision-makers and specialists in the oil and gas industries and in the road transport and manufacturing/construction sectors, since these areas are responsible for 75% of $PM_{2.5}$ contribution. The following table shows the different organizations from which people were interviewed, based on the major sectors selected. Although agriculture contributes 15% of $PM_{2.5}$ emissions, none of its representatives were interviewed, because a good deal of the agricultural pollutants affecting the country are emitted by neighbouring countries rather than by Oman itself.

The interviewees were chosen based on the following classifications: decision-makers, policy-makers, environmentalists, business people, journalists, and judges.

Each individual interviewee gave the answers to the set of questions listed below according to the classification field they represented.

Major sectors contributing to $PM_{2.5}$ emission in Oman.

Sectors / Interviewees	Oil & Gas	Road Transport + Shipping	Manufacturing and Construction
Decision-Makers	MOG: 1st priority: Minister of MOG. 2nd priority: Under Secretary MOG.	MOTC (Road): 1st priority: Minister of MOTC. 2nd priority: Under Secretary of MOTC. ROP (Vehicles): 1st priority: DG of Traffic of ROP.	MOCI: 1st priority: Minister of MOCI. 2nd priority: Under Secretary of MOCI.
Industry representatives	1st priority: (HSE) of PDO, Mohammed Al-Salmani. 2nd priority: HSE of OXY	-	1st priority: Chairman of OCCI, H.E Said Saleh Said Al Kayoumi 2nd priority: Deputy Chairman of OCCI
Renewable Energy Industry	Nafath Renewable Energy Chief Executive Officer, Abdullah Alsaidi Continental Shelf of Solar Technology, General Manger, Majid Alalawi		
NGOs	Environment Society of Oman 1st priority: Board Member: Mr. Ahmed Al Rashdi, 2nd priority: PR Officer: Ms. Dana Al Sarhani,		
Media	Muscat Daily 1st priority: Journalist, 2nd priority: Reporter Times of Oman 1st priority: Journalist, 2nd priority: Reporter		
Court	Public Prosecution Office 1st priority: Attorney General Hussein al-Hilali 2nd priority: Deputy President of the Court Saleh al-Rashidi		
Policy-Makers	Supreme Council for Planning 1st priority: Deputy Secretary General, Talal Alrahbi 2nd priority: Directorate General of Planning, Hilal Alzadjali Parliament (Shura Council) Legislative committee 1st priority: Mohamed Alzadjali, 2nd priority: Khalid Alsadi Health and Environment committee 1st priority: Ali Alqutaity 2nd priority: Ahmed Alhadrami		

Abbreviations:

MOG: Ministry of Oil and Gas**, MOCI:** Ministry of Commerce and Industry, **ROP**: Royal Oman Police, **ORPIC**: Oil Refineries and Petroleum Industries Company, **PAEW**: Public Authority for Electricity and Water, **PEIE**: Public Establishment For Industrial Estates, **OPWR**: Oman Power and Water Recruitment, **MOTC:** Ministry of Transport and Communication, **PDO:** Petroleum Development of Oman, **OXY:** Occidental of Oman Inc. **OCCI:** Oman Chamber of Commerce and Industry. **HSE**: Health Safety & Environment, **DG:** Directorate General, **PR:** Public Relationship.

Processes for recording interview data:

Audiotape recordings were made for recording the interviews for documentation and later analysis, with note used to highlight the more interesting points emphasised by the interviewee. In order to ensure reliable recordings, the researcher practised with the tape-recorder prior to using it for the interview, and had extra batteries and a back-up recorder on hand during the actual recording.

Informed consent:

The interviewees were all informed about the aim and objectives of the project, with the researcher reading out the consent form at the beginning of the interviews and meetings. The consent form clearly stated how the data and answers to questions gained in the interview would be used. Interviewees were also informed that they could withdraw their participation at any time prior to the publication of any research, without giving a reason for such withdrawal. At the beginning of each interview, the participant was asked whether they were happy to be recorded; if they agreed, they were asked to sign the consent form. If the interviewee did not agree to being recorded, they could still take part in the study, but the researcher would take notes detailing their responses.

Confidentiality, security and retention of research data:

The answers of each interviewee's answers were coded and only the researcher had access to this codes; access was kept to a minimum. The only data gathered was that necessary for answering the research questions. After the interviews, the recordings were carefully guarded, and were erased after transcription had been verified or once analysis was complete. Interviewees were asked whether the researcher might quote them and whether she could attribute data or information to them or their organisation.

Flexibility:

The interviewee was offered the choice of having the interview in either Arabic or English. In any case where the interviewee asked to be sent the interview questions by email, a good reason had to be given before this was agreed.

Transcribing data:

After transcribing the tape-recorded interviews into text, the researcher listened to the audiotape while reading the transcriptions; this was done to ensure accuracy of interpretation. When there was any difficulty in capturing the spoken word in text form because of sentence structure, use of quotations, omissions, mistaking of words or phrases, or any other source of doubt, the researcher then made the judgment call.

Using software programs to assist with data management and analysis:

Software programs do not analyse data, but can be a tremendous aid in the process of data management and analysis. Atlas ti, Folio Views and NVivo are computer-assisted qualitative data analysis software which can save time, make procedures more systematic, reinforce completeness and permit flexibility in the process of revision of analysis.

Manual Analysis of data:

Another way of analysing the data was to do it manually, by coding, ranking and classifying the answers. The following are examples of environment indicators which could be used for determining whether policies are effective:

- Whether air quality was better or worse ten years ago
- Whether there had been any stories about air quality or climate change in newspapers or magazines?
- Questionnaire
- Whether there had been any legal cases concerning environmental issues, and if so, how many.

Questions for the Oil and Gas sector:

(1) Decision-makers

1. What is the process in Oman for developing and implementing environment policies to regulate the oil and gas industry?
2. What policies in Oman currently govern the way that the oil and gas industry affects air pollution and climate change?
3. Do you think they are sufficient to keep air quality within acceptable safety limits? If not, what other legislation is needed?
4. Are these policies revised systematically? How often is this done?
5. Are these policies implemented effectively? If not, what do you see as the reason/s behind this ineffective implementation?
6. Are these policies properly evaluated? If so, how and by whom?
7. Do you think Oman's air pollution policy can be considered as representative of the policies in the GCC countries as a whole?
8. From your perspective, are the relevant policies effectively enforced?
9. What changes have there been since 2010 to the legislation and policies related to how air pollution and climate change are affected by the oil and gas industry in Oman?
10. Are there any other relevant laws in the pipeline?
11. What forces in Oman drive the legislation about air pollution and climate change?

12. How do you see the oil and gas sector 20 to 30 years from now?

(2) Industries:

1. Do you follow any guidelines or regulations in all the processes carried out in your company? If yes, what are these regulations?
2. Does your company have any plans to introduce more advanced environment-friendly technology? If yes, please give examples.
3. Do you think there have been any developments in the air pollution and climate change policies as they affect the oil and gas sector in Oman?
4. How do you usually deal with fugitive emissions? Have you improved or are you in the process of improving your monitoring system to address and minimize leakages?
5. How do you deal with the water (brine) you produce?
6. Can you describe any experience or incident related to an air pollution issue in your company? If so, how did you address the issue?

Questions for the Transport sector:

(1) Decision makers:

1. What is the process in Oman for developing and implementing environment policies to regulate the transport sector?
2. What policies in Oman currently govern the way that the transport sector affects air pollution and climate change?
3. Do you think they are sufficient to keep air quality within acceptable safety limits? If not, what other legislation is needed?
4. Are these policies revised systematically? How often is this done?
5. Are these policies implemented effectively? If not, what do you see as the reason/s behind this ineffective implementation?
6. Are these policies properly evaluated? If so, how and by whom?
7. Do you think Oman's air pollution policy can be considered as representative of the policies in the GCC countries as a whole?
8. From your perspective, are the relevant policies effectively enforced?
9. What changes have there been since 2010 to the legislation and policies related to how air pollution and climate change are affected by the transport sector in Oman?
10. Are there any other relevant laws in the pipeline?
11. What forces in Oman drive the legislation about air pollution and climate change?
12. How do you see the transport sector 20 to 30 years from now?

Questions for the Manufacturing and Construction sector:

(1) Decision makers

1. What is the process in Oman for developing and implementing environment policies to regulate the manufacturing and construction sector?
2. What policies in Oman currently govern the way that the manufacturing and construction sector affects air pollution and climate change?
3. Do you think they are sufficient to keep air quality within acceptable safety limits? If not, what other legislation is needed?
4. Are these policies revised systematically? How often is this done?
5. Are these policies implemented effectively? If not, what do you see as the reason/s behind this ineffective implementation?
6. Are these policies properly evaluated? If so, how and by whom?
7. Do you think Oman's air pollution policy can be considered as representative of the policies in the GCC countries as a whole?
8. From your perspective, are the relevant policies effectively enforced?
9. What changes have there been since 2010 to the legislation and policies related to how air pollution and climate change are affected by the manufacturing and construction sector in Oman?
10. Are there any other relevant laws in the pipeline?
11. What forces in Oman drive the legislation about air pollution and climate change?
12. How do you see the manufacturing and construction sector 20 to 30 years from now?

(2) Industries:

1. Do industries in Oman follow any guidelines or regulations for the processes carried out in their companies? If yes, what are these regulations?
2. Are there any plans for industries in Oman to introduce more advanced environment-friendly technology? If yes, please give examples.
3. Do you think there have been any developments in the air pollution and climate change policies as they affect the manufacturing and construction sector in Oman?

Questions for policy makers dealing with multiple sectors

(1) Policy makers:

1. What is the process in Oman for developing and implementing environment policies to regulate the oil and gas, transport and manufacturing and construction sectors?
2. What policies in Oman currently govern the way that the oil and gas, transport and manufacturing and construction sectors affect air pollution and climate change?
3. Do you think they are sufficient to keep air quality within acceptable safety limits? If not, what other legislation is needed?
4. Are these policies revised systematically? How often is this done?
5. Are these policies implemented effectively? If not, what do you see as the reason/s behind this ineffective implementation?
6. Are these policies properly evaluated? If so, how and by whom?
7. Do you think Oman's air pollution policy can be considered as representative of the policies in the GCC countries as a whole?
8. From your perspective, are the relevant policies effectively enforced?
9. What changes have there been since 2010 to the legislation and policies related to how air pollution and climate change?
10. Are there any other relevant laws in the pipeline?
11. What forces in Oman drive the legislation about air pollution and climate change?

Questions for NGO & Environmentalists:

1. What is the process in Oman for developing and implementing environment policies?
2. What policies in Oman currently govern air pollution and climate change?
3. Do you think they are sufficient to keep air quality within acceptable safety limits? If not, what other legislation is needed?
4. Are these policies revised systematically? How often is this done?
5. Are these policies implemented effectively? If not, what do you see as the reason/s behind this ineffective implementation?
6. Are these policies properly evaluated? If so, how and by whom?
7. Do you think Oman's air pollution policy can be considered as representative of the policies in the GCC countries as a whole?
8. From your perspective, are the relevant policies effectively enforced?
9. What changes have there been since 2010 to the legislation and policies related to air pollution and climate change?

10. Do you see any gaps in the environmental policy? If so, what are they?

11. Are there any other relevant laws in the pipeline?

12. What forces in Oman drive the legislation about air pollution and climate change?

13. Can you tell a story or describe an experience or incident that shows how a law or policy can make Oman's environment cleaner and safer?

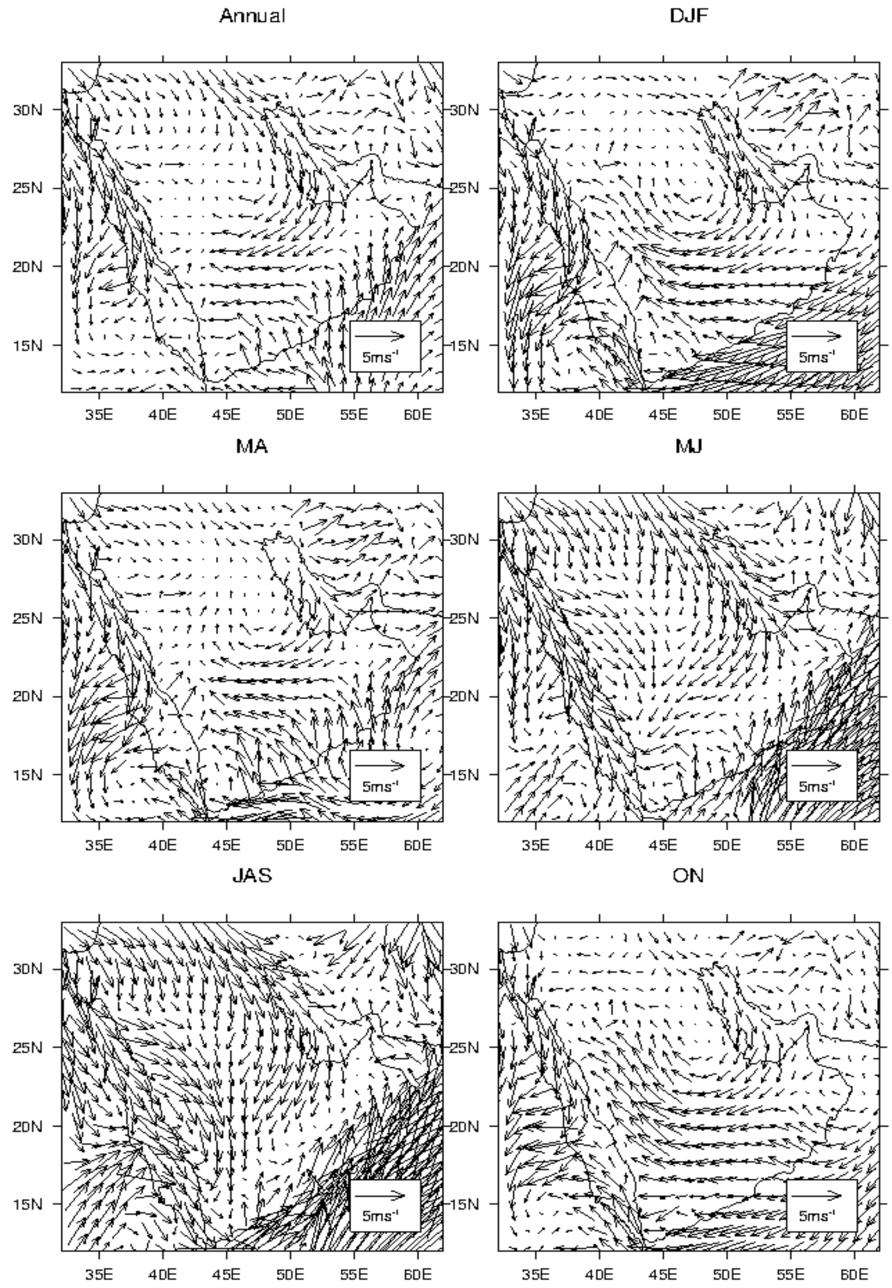
Questions for Businessman (Renewable Energy)

1. What is the current situation regarding renewable energy in Oman? And what do you predict for the future?
2. What are the benefits of renewable energy for the economy?
3. What are the obstacles and challenges to the adoption of more renewable energy strategies in Oman?
4. What are changes to the law are needed to enable greater use of sustainable energy and thus benefit the environment?
5. From your perspective, what have been the main achievements in the renewable energy sector since 2010?

Questions for Judiciary and Media

1. Have there been any cases/stories in the courts or the media related to any environmental policies or legislation? Have the courts handed down any punishment for the breaking of any environmental legislation?

Appendix (A5): The annual and seasonal means of Oman wind patterns (DJF winter, MA Spring, MJ early summer, JAS late summer and ON Autumn).



<u>Source: Oman meteorology, Dr. said Alsarmy, DJF (December, January and February)</u>