Sultanate of Oman

وزارة البيئة والشؤون المناخية
MINISTRY OF ENVIRONMENT AND CLIMATE AFFAIRS

Second National Communication

Submitted to:

United Nations Framework Convention on Climate Change

Submitted by:

Ministry of Environment and Climate Affairs

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FOREWORD

The Sultanate of Oman is taking strong and decisive action to address climate change. In the period since the First National Communication was submitted in October 2013, the Government of the Sultanate of Oman has successfully adopted in October 2019, the National Strategy for Adaptation and Mitigation to Climate Change, 2020-2040.

The development of a comprehensive strategy is a fundamental step in moving forward in the fulfillment of the aspirations of the Paris Agreement of COP-21. The Strategy will establish a framework for designing and implementing preparedness/response measures to reduce the vulnerability of communities, resources, and systems to the adverse impacts of climate change such as increasing temperatures, rising sea levels and intensifying tropical cyclones. On the other hand, the strategy acknowledges that the proper context for mitigation is rooted in the recognition of the need to control a trend of greenhouse gas emissions growth. To slow the growth in national greenhouse gas emissions, the strategy calls for encouraging a low carbon economy, introducing new technologies, and implementing renewable energy projects.

To implement the strategy, partnerships with the international community will be essential to facilitate the flow of technical and financial resources for undertaking the vision embedded in the strategy.

Other significant new climate change measures include the Omani renewable energy plan that aims to secure more than 2,600 MW by 2025. This will reduce approximately 6% of the total GHG emission of 2015.

Oman's Second Communication summarizes the progress we have made to meet our obligations under the United Nations Framework Convention on Climate Change and the Paris Agreement.

The Sultanate of Oman is proud of measures and policies that have been implemented since the First National Communication and remains committed to working constructively nationally and internationally to respond to the global challenge of climate change.

Finally, I would express my highest appreciation to the Global Environmental Facility, to UN Environment Programme, Regional West Asia Office as its implementing agency and Sultan Qaboos University and relevant government entities for their support throughout the preparation process of Oman's Second National Communication.

H.E. Mohammed Bin Salim Bin Said Al Toobi

Minister of Environment and Climate Affairs

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EXECUTIVE SUMMARY

National Circumstances

The Sultanate of Oman is positioned astride the Tropic of Cancer at the southeastern corner of the Arabian Peninsula between latitudes 16°40´N and 26°20´N and between longitudes 51°50´E and 59°50´E. Total land area is about 309,500 km^2 and is characterized by a diverse range of topography including mountain ranges, arid deserts, and fertile plains. Administratively, the country is divided into 11 Governorates and 61 administrative provinces, or Wilayat.

The country has a vast wealth of industrial rocks, minerals, and metals. In addition to oil and natural gas, its natural resources include limestone, dolomite, marble, granite, gabbro, gypsum, wollastonite, guano, olivine, and rock salt. Oman has about 950 million tonnes of gypsum reserves and 500 million tonnes of dolomite deposits.

Oman is a water-stressed country, with less than 1,000 cubic meters in freshwater availability per person per year. Ensuring water supply and demand are in a sustainable equilibrium remains a constant challenge.

The climate in Oman is arid and the large latitudinal extent and complex topography introduce many climatic particularities at local scales. From the intense summer heat of the Rub al Khali desert in the southern Arabian Peninsula to the moderate climate of the Hajar mountains in northern Oman, climatic conditions range from the hyper-arid (< 100 mm of annual rainfall) to the semi-arid (250–500 mm of annual rainfall). These extremes combined with varying temperatures have shaped the distribution and abundance of vegetation.

There have been destructive tropical depressions, tropical cyclonic storms and severe cyclonic storms that have tracked toward Oman over the past decades from the north Indian Ocean and the Arabian Sea. Such storms typically occur during the pre-monsoonal period (May-June) and the post-monsoonal period (October-November).

About 95% of Oman's land area is characterized as a desert or having more than moderate desertification. Land degradation from desertification is most acute in the Al-Batinah, Ash-Sharqiyah and Dhofar governorates. Due to its topographic characteristics and climatic variability from North to South, there is a great plant, animal, marine, and microbiological biodiversity.

Oman has the fifth largest economy in the GCC region, with steady growth at 4.1% per year over 2007-2017. The structure of the economy has changed significantly over the years, thanks in large part to concerted efforts to diversify the economy away from a dependence on oil and gas. Over the 2000-2016 period, non-oil/gas industrial activities increased threefold as a share of GDP while oil and gas decreased by nearly half. Agricultural is a relatively small sector in the overall economy.

Oman's population reached 4.4 million in 2016, with an annual average growth rate of 3.5% over 1993-2016. Most of the population growth took place in urban areas along the Sea of Oman coast in the Muscat and the Al Batinah regions, as well as cities in the Ad Dhahirah, Ad Dakhliyah, and Ash Sharqiyah governorates. The population is well-educated, with a 96% literacy rate.

All public health indicators show positive trends in life expectancy, child neonatal mortality rate, and maternal mortality ratio, consistent with the corresponding rates in other GCC countries. The government currently spends roughly 6.3% of total annual expenditures on health care for citizens.

Oman is a food secure country and is ranked 29th out of 113 countries in the Global Food Security Index. Relative to the size of its economy, Oman invests ambitiously in agricultural research and has promoted public-private partnerships in an effort to enhance food security.

Oman is committed to achieving a high level of regional and international competitiveness in the transport sector. There has been an extensive expansion in transport infrastructure (roads, airports, marine ports) over the past decades.

Greenhouse gas inventory

Table ES-1 presents total GHG emissions and sinks for the year 2000. Total GHG emissions in 2000 were 21,666 Gg CO_2e, which includes 17,196 Gg from energy; 2,865 Gg from IPPU; 806 Gg from waste and 799 Gg from AFOLU. There are no carbon sinks associated with managed green spaces and parks. There are also no emissions of hydrofluorocarbons (HFCs), perfluorinated compounds (PFCs) or sulfur hexafluoride.

Table ES–1: GHG emissions in Oman, 2000 (Gg)

GHG Sources & Sinks	CO_2e	CO_2	CH_4	N_2O
Energy	17,196	10,589	234.8	0.1
Industrial processes and product use	2,865	2,863	0.1	0.0
Agriculture, forestry and other land use	799	27.9	26.6	0.1
Waste	806	0	26.9	0.2
Total National Emissions	**21,666**	**13,481**	**288.4**	**0.4**

Energy-related activities accounted for the dominant portion of GHG emissions in Oman in 2000. Approximately 79% of all GHG emissions are associated with the combustion of fossil fuels or the release of fugitive emissions from oil and gas operations. Industrial processes and product use accounted for about 13.2% of all GHG emissions, followed by the waste sector that accounted for about 3.72% of total emissions. Emissions from agricultural and land use activities are also small, accounting for about 3.70% of total national emissions.

Vulnerability and adaptation

Four RCPs were considered to explore future climate in Oman: RCP8.5, RCP6, RCP4.5, and RCP2.6 relative to the 1950-2000 historical period.

In the best case (RCP 2.6), maximum temperatures are expected to rise by at least 2°C along southern coastal areas. In the worst case (RCP 8.5), maximum temperatures are expected to reach 4°C above historical levels in the interior and north, including Musandam.

By the late-21st Century, average annual rainfall will have changed substantially across Oman. In the best case (RCP 2.6), average annual rainfall is expected to further decrease by up to an additional 10 mm/year in interior areas south of the Al Hajar mountains. In the worst case (RCP 8.5), average annual rainfall decreases in most areas by up to an additional 10 mm/year below mid-21st Century levels. Only in portions of the Dhofar Governorate where average annual rainfall either remains the same as mid-21st-century levels or slightly increase.

Due to climate change, Oman will likely experience adverse impacts on its precious water resources, both surface water, and groundwater. The frequency of destructive flash flooding is already evidenced by an increased frequency of extreme wadi flows while future sea-level rise is projected to impose serious adverse impacts on groundwater quality in some of Oman's most important aquifers.

The impacts of climate change on water resources are due to sea-level rise, temperature, and precipitation variability/extremes. Impacts on groundwater are due to higher evaporation and rates leading to greater water demand for irrigation. Effective adaptation should first develop and implement an integrated water resource management system that accounts for the interdependency of water and other sectors of the economy.

Climate change is projected to lead to changes in the physical and chemical properties of the western Arabian Sea. Such changes are expected to pose important threats to the future sustainability of the annual catch of sardines and yellowfin tuna, two species that are central to the commercial fishing industry of Oman. Effective adaptation should focus on knowledge generation, capacity building, and improved governance and planning.

Climate change poses enormous risks to the future sustainability of Oman's agricultural sector. As agricultural productivity depends entirely on groundwater, rising sea levels will lead to seawater intrusion into aquifers, thereby degrading the quality of water extracted for irrigation. Sea level rise also implies a steady decline in cropland available for cultivation as cultivatable land becomes inundated. Effective adaptation should focus on knowledge generation for managing coastal aquifers, strengthening capacity for assessing the vulnerability of irrigated agricultural production, and improved governance and planning.

There are substantial amounts of urban infrastructure are vulnerable to climate change impacts associated with sea-level rise and tropical cyclones. In addition, flash flooding magnitude and frequency could increase in the future from heavy rainfall events. Among other measures, effective adaptation should focus on updating hazard maps, establishing coastal setback lines, and evaluating risks to existing coastal infrastructure.

Finally, climate change is expected to exacerbate today's health problems – deaths from extreme weather events, cardiovascular and respiratory diseases and infectious diseases – whilst undermining Oman's social protection systems. Among other measures, effective adaptation should focus on raising public awareness on the detrimental effects of climate change on human health, expanding knowledge on the science of climate change and its effects on human health, and developing preparedness and response strategies at the institutional level.

Greenhouse gas mitigation

Oman understands the need to transition to a low carbon future that reflects new thinking, new frameworks, and new methods. The transition will also need to find practical ways to promote clean energy initiatives, facilitate access to new low-carbon technologies, and develop long-term partnerships to exploit sustainable energy opportunities. Through such actions, Oman seeks to reflect its solidarity with the international community, as well as its long-term commitment to promote greenhouse gas mitigation in a carbon-constrained world.

An analysis of the potential of energy efficiency measures (improved energy management, labeling systems, building codes) shows that such measures can lead to significant savings. A scenario analysis framework was applied for the period 2010 to 2035. The results indicate electricity savings of about 15 TWh or roughly 25% of electricity consumption by the end of the period. The GHG reduction benefits from these electricity savings are considerable, resulting in a reduction of approximately 23 million tonnes by 2035, or 21% less than what national emissions would have otherwise been in 2035.

Going forward, there are four “streams” to focus on sustained GHG emissions reductions.

- The energy supply stream will focus on incorporating more renewable energy for meeting electricity demand.
- The energy demand stream will focus on cutting fossil fuel subsidies, developing awareness programmes, and centralizing energy planning.
- The research & development stream will focus on fostering better ties between academia and industry, establishing research clusters, and retaining a higher number of Ph.D. students to study and work in Oman.
- The water-food-energy nexus stream will focus on a systems approach to managing these resources. It will involve establishing an executive authority that focuses on water, energy, and food, evaluating renewable-based desalination, and enforcing building codes to promote efficiency.

Other information

The government of the Sultanate of Oman has adopted in October 2019 a comprehensive National Strategy for Adaptation and Mitigation to Climate Change, 2020-2040 to address areas that are central to Oman's development aspirations against the backdrop of a changing climate. The key areas addressed in the strategy are briefly outlined in the bullets below.

- *Regional climatic change:* There are current gaps in knowledge about the range of potential climatic change in the region;
- *Vulnerability of key sectors and systems:* A number of needs - financial, technological, and research-oriented - have emerged from the various vulnerability assessment; and
- *Growth in GHG emissions:* Oman faces both constraints and options in transitioning to green growth development pathways.

Several commitments and actions have already been carried out. First, in Paris in 2015, Oman committed to the goal of reducing GHG emissions by 2% by 2030 from they would otherwise be in that year. Second, twelve renewable energy projects are being implemented to demonstrate Oman’s commitment to the global effort to reduce emissions. Combined, these projects will account for at least 2.6 GW of new electric generating capacity. The focus on renewable energy is in direct response to the prominence of energy-based GHG emissions in the national inventory. By increasing the role of renewable energy technologies in meeting the national demand for energy, Oman is transitioning to a green growth energy pathway.

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LIST OF ACRONYMS

°C	degree Celsius
AFOLU	agriculture, forestry and other land use
ASYAD	Oman Global Logistics Group
b/d	barrels per day
bcf	billion cubic feet
CFSR	Climate Forecast System Reanalysis
CH_4	Methane
CMIP5	Coupled Model Intercomparison Project Phase 5
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
COP	Conference of the Parties
CPI	crop production index
CPUE	catch per unit effort
CSP	Concentrating solar power
CVI	Coastal Vulnerability Index
DEM	Digital Elevation Model
DWD	deep-water disposal
EEZ	Exclusive Economic Zone
EMS	Energy management system
FAO	Food and Agriculture Organization of the United Nations
GCC	Gulf Cooperation Council
GCF	Green Climate Fund
GDP	Gross Domestic Product
GECF	Gas Exporting Countries Forum
GFDL	Geophysical Fluid Dynamics Laboratory model
GFSI	Global Food Security Index
Gg	gigagrams (10^9 grams)
GHG	Greenhouse gas
GNI	Gross National Income
GOW	Global Ocean Wave
GWP	global warming potential
HFC	hydrofluorocarbons
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
IPPU	industrial processes and product use
IPSL	Institut Pierre Simon Laplace model
km	kilometer
Km^2	square kilometer
kTOE	thousand tonnes of oil equivalent
kW	kilowatts (thousand watts)
kWh	kilowatt-hours (thousand watt-hours)
LNG	liquified natural gas
LPI	livestock production index
m/s	meters per second
MAF	Ministry of Agriculture and Fisheries

MECA	Ministry of Environment and Climate Affairs
mm	millimeter
MPHRU	Medical & Public Health Response Unit
MW	megawatts (10^6 watts)
MWh	megawatt-hours (10^6 watt-hours)
N_2O	Nitrous oxide
NCSI	National Center for Statistics and Information
NPACD	National Plan of Action to Combat Desertification
O_3	Ozone
OAPGRC	Oman Animal and Plant Genetic Resources Center
OFIC	Oman Food Investment Holding Company
OPEC	Organization of Petroleum Exporting Countries
PAEW	Public Authority for Electricity & Water
PDO	Petroleum Development Oman
PFC	perfluorinated compounds
PISCES	Pelagic Interaction Scheme for Carbon and Ecosystem Studies
PM	Particulate matter
ppm	parts per million
RCP	Representative Concentration Pathway
SLR	Sea level rise
SoO	Sultanate of Oman
TRC	The Research Council
TWh	Terawatt-hours (10^12 watt-hours)
UNEP	United Nations Environment Programme
WHO	World Health Organization

1. NATIONAL CIRCUMSTANCES

This chapter outlines the physical, administrative, environmental, economic, and development circumstances of the Sultanate of Oman. Data were obtained primarily from Oman's National Center for Statistics and Information (NCSI), other governmental organizations in Oman, as well as from global organizations such as the World Bank and the International Monetary Fund. This chapter also reflects important changes that have taken place in Oman relevant to climatic change since its Initial National Communication.

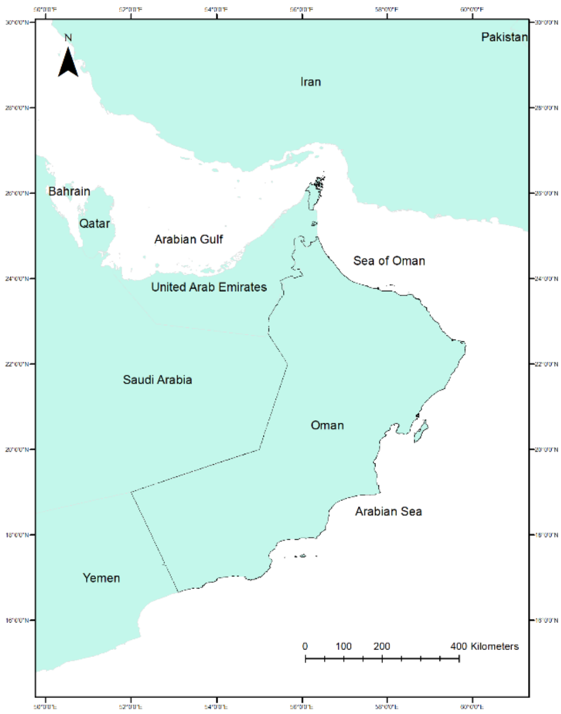


Figure 1-1: Location of Oman on the Arabian Peninsula (source: National Survey Authority)

1.1. Physical circumstances

1.1.1. Geography

The Sultanate of Oman is positioned astride the Tropic of Cancer at the southeastern corner of the Arabian Peninsula between latitudes 16°40´N and 26°20´N and between longitudes 51°50´E and 59°50´E (see Figure 1-1). Total land area is about 309,500 km^2 and is characterized by a diverse range of topography including mountain ranges, arid deserts, and fertile plains.

Overlooking the Arabian Gulf, the Sea of Oman and the Arabian Sea, Oman has a coastline of about 3,165 km. The coast stretches from the Strait of Hormuz in the north to the borders of Yemen in the southwest.

The coastline varies from 40-meter high precipitous cliffs near the shore of Musandam in the far north to shallow sandy beaches with scattered inlets, lagoons, and mangroves in the Al Batinah governorates along the Sea of Oman. There are also extensive sandy beaches along the coast of Central Oman, with areas of salt flats, especially the Barr Al Hikman which joins the Ash Sharqiyah Sands opposite Masirah Island. Oman also has a number of islands, the largest being Masirah to the east of central Oman.

Mountain ranges in the north and southwest occupy about 15% of the country. The Hajar mountains in northern Oman extend in an arc form for 700 km from Musandam in the north and curve eastward towards the coast to Ras Al Hadd, the easternmost part of Oman. Jabal Shams with the highest peak of 3,075 meters above mean sea level, is part of Jebel Akhdar that forms the central part of the northern Oman Mountains (see Figure 1-2). The Dhofar Mountains, located in southwestern Oman, have peaks ranging from 1,000 to 2,000 meters above mean sea level.

Coastal plains serve as important agricultural areas and occupy about 3% of the total land area. They extend from the Al Batinah governorate along the Sea of Oman to the Salalah Plain in the southwest of the country along the Arabian Sea. Interior areas occupy the remaining 82% of total land area and consist of sandy, wasteland desert regions with elevations up to 500 meters above sea level (see Figure 1-2).

1.1.2. Mineral Resources

Oman has a vast wealth of industrial rocks, minerals, and metals. In addition to oil and natural gas, its natural resources include limestone, dolomite, marble, granite, gabbro, gypsum, wollastonite, guano, olivine, and rock salt. Oman has about 950 million tonnes of gypsum reserves and 500 million tonnes of dolomite deposits.

As of 2016, Oman had more than 150 quarrying and mining operations for the provision of fill materials. During the 2000-2015 period, gypsum production grew by 56%, followed by limestone by 31% and cement by 12%. Oman's mineral industry is expected to continue to grow in the coming years.

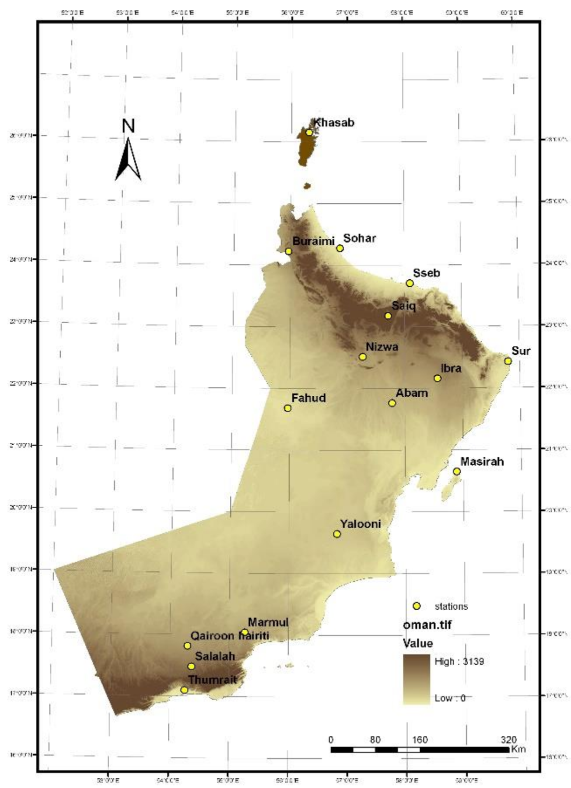


Figure 1-2: Topography of Oman (National Survey Authority)

1.1.3. Water Resources

Oman is a water-stressed country, with less than 1,000 cubic meters in freshwater availability per person per year (UNEP, 2008). Ensuring water supply and demand are in a sustainable equilibrium remains a constant challenge.

There are four main types of water resources, as illustrated in Figure 1-3 and briefly described in the bullets below.

- Groundwater accounts for roughly 78% of the water supply. Most are renewable in nature, being recharged annually by rainfall or through surface water infiltration. Non-renewable groundwater exists in the interior regions of Oman in the Al Najd, Al Masarat and Ash Sharqiyah Sands.
- Desalinated water accounts for the next highest share of water supply, about 15%. Currently, there are nearly 100 desalination plants in Oman with roughly a 50-50 split regarding seawater or brackish water as the feedstock.
- Surface water accounts for about 6% of the total water supply. Annual average wadi flow is estimated at 211 million m^3. While average rainfall is estimated at 9.5 billion m3 per year, about 80% of this precipitation evaporates.
- Treated wastewater accounts for the remaining 1% of the total water supply. In the Muscat Governorate, the current treatment capacity of 25 million cubic meters per year is projected to increase to 100 million cubic meters per year by 2030.

1.1.4. Energy

Since the 1970s to the present day, the total primary energy supply has relied exclusively on diesel oil and natural gas. There is no coal, biofuel/waste, renewable, or nuclear resources used in Oman. Total energy supply has grown rapidly between 2000 and 2015, from 7.6 to 25.4 kTOE, or 8.4% per year. Most of this growth is attributed to increasing shares of natural gas in the electric supply system from 2000 to 2015. Currently, there are fourteen (14) power stations in Oman, comprised of open-cycle gas turbines and combined cycle units for the co-production of water and desalinated water.

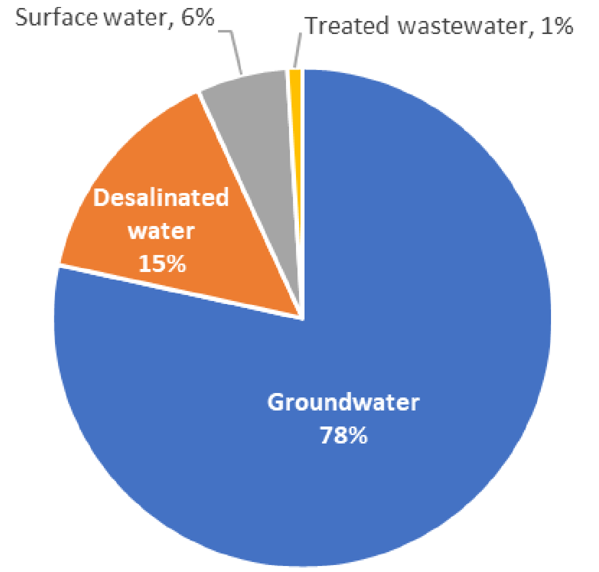


Figure 1-3: Oman's water supply profile (Source: SoO, 2013)

Oman is a part of the Gulf Cooperation Council's (GCC) grid interconnection system, which allows for bulk power transfers between the six connected countries. Electric generation is predominantly natural gas-fired (i.e., about 97%) and has increased significantly between 2000 and 2015; from 8.6 TWh to 31.9 TWh, or about 9.1% per year. The industrial sector accounts for the greatest growth, about 19.4% per year, followed by the commercial/public service and residential sectors with annual average growth rates o of 10% and 8.7%, respectively. Transmission and distribution losses have declined from 20.8% to 9.6% over the 2000-2015 period.

Regarding refined petroleum products, Oman consumed 186,000 b/d of petroleum and other liquids in 2016, most of which were petroleum products refined at Oman's refineries and a small amount that was imported (EIA, 2017). There are two refineries, Mina al Fahal (106,000 b/d) and Sohar (116,000 b/d), with plans underway to complete an upgrade to the Sohar facility in 2017.

1.2. Government circumstances

1.2.1. Administrative divisions

Administratively, Oman is divided into 11 Governorates; Muscat, Al-Batinah North and South, Ad-Dakhiliya, Al-Buraimi, Adh-Dhahirah, Musandam, Ash-Sharqiyah North and South, Al-Wusta, and Dhofar (see Figure 1-4). These governorates are divided into a further 61 administrative provinces or *wilayat* as follows:

- Muscat governorate: 6 wilayat;
- Al-Batinah North governorate: 6 wilayat;
- Al-Batinah South governorate: 6 wilayat:
- Ad-Dakhiliya governorate: 8 wilayat;
- Al-Buraimi governorate: 3 wilayat;

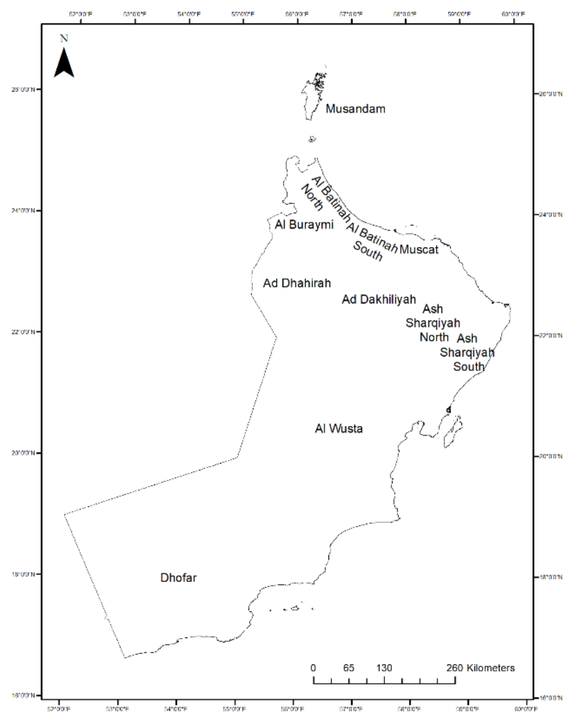


Figure 1-4: Oman regional administrative divisions

- Adh-Dhahirah governorate: 3 wilayat;
- Musandam governorate: 4 wilayat;
- Ash-Sharqiyah North governorate: 6 wilayat;
- Ash-Sharqiyah South governorate: 5 wilayat;
- Al-Wusta governorate: 4 wilayat; and
- Dhofar governorate: 10 wilayat.

1.2.2. Government structure

Oman's legislative activities are undertaken by the Council of Oman, a body established by His Majesty Sultan Qaboos bin Said. The Council develops general policies of the state and possesses legislative and auditing powers. The Council meets at the request of the Sultan to study and discuss matters raised by him taking all its decisions on the basis of a majority vote.

The Council of Oman (*Majlis Oman*) is comprised of the State Council (*Majlis al Dawla*) and the Consultation Council (*Majlis Al-Shura*). These councils underpin and expand the traditional Omani consultation system which aims to build and foster national consensus in responding to community needs and aspirations.

Members of the State Council are selected from eminent Omanis that include former ambassadors, former senior judges, and retired senior military officers. The Consultation Council is composed of elected members representing the governorates. The number of members of the Council is determined so that each wilayat (province) shall represent one member if its population does not exceed thirty thousand and two members when the population exceeds that limit.

1.2.3. Implementation arrangements

The Ministry of Environment and Climate Affairs (MECA) is the government institution mandated to carry out all activities and functions necessary to ensure the protection of the environment in the country. Since 2007, the Directorate General of Climate Affairs in MECA is the primary entity that is responsible for administrative and regulatory action in response to national and international requirements regarding climate change.

Implementation arrangements for the preparation of this second national communication consisted of the following national institutions:

- The Directorate General of Climate Affairs was responsible for coordination and oversight of all aspects of project implementation in collaboration with project partners;
- The UNEP Regional Office for West Asia was the implementation agency of the grant support received from Global Environment Facility and responsible for project execution and technical assistance.
- Sultan Qaboos University was the main technical partner that carried out the data collection, and analytical tasks associated with GHG inventory development, vulnerability assessments, and GHG mitigation analysis.

- Project coordination was carried out by a steering committee that was comprised of experts from the Directorate General of Climate Affairs, Sultan Qaboos University, and other relevant public and private entities.

1.2.4. Global Environment Facility funding support

The Second National Communication of the Sultanate of Oman to The United Nations Framework Convention on Climate Change (UNFCCC) was made possible through the funding support of the Global Environment Facility (GEF) through United Nations Environment Programme, Regional West Asia Office, along with further funding from the Ministry of Environment and Climate Affairs. The funds received allowed the improvement of the emissions inventory and supported the development of studies on climate change mitigation and adaptation in Oman.

1.3. Environmental circumstances

1.3.1. Climate

Oman is an arid region according to the Köppen-Geiger classification system (1928). The climate in Oman is determined by interactions between regional physiography and atmospheric circulation in the 10°–50°N segment of Eurasia.

The large latitudinal extent and complex topography of Oman introduce many climatic particularities at local scales. From the intense summer heat of the Rub al Khali desert in the southern Arabian Peninsula to the moderate climate of the Hajar mountains in northern Oman, climatic conditions range from the hyper-arid (< 100 mm of annual rainfall) to the semi-arid (250–500 mm of annual rainfall). These extremes combined with varying temperatures have shaped the distribution and abundance of vegetation in Oman (Fisher and Membery, 1998).

Temperatures are affected by major air masses that occur in the Arabian Peninsula. The Polar Continental air mass brings cold temperatures and high pressure in the winter months.

The Tropical Continental air mass brings hot and very dry air in the summer months. Average monthly temperatures typically fluctuate between 10°C to 30°C.

Figure 1-5 shows some annual temperature indicators, averaged over the period 1950-2000. Major patterns are summarized in the bullets below.

- *Annual average (Figure 1-5, left):* Average annual temperatures range from 10°C to 12°C in the Hajar Mountains in the north while ranging from 16°C to 18°C in the Dhofar Mountains in the south. Across the hillsides of these mountain ranges, average annual temperatures are about 24°C while about 26°C over the rest of Oman. The highest annual average temperatures of 28°C are found along the Sea of Oman coastline between Muscat and Sur.
- *Annual maximum (Figure 1-5, middle):* The average maximum temperature of the hottest month ranges from 23°C to 42°C. Coastal regions are hot and humid in summer with high temperatures of 40°C and more than 90% humidity. In the interior plain, high temperatures in summer can exceed 42°C.
- *Annual minimum (Figure 1-5, right):* The average minimum temperature of the coldest month ranges between -3°C to 20°C. During the winter season, the coldest minimum

temperature is encountered in the highland and mountainous areas in the northern and southern parts of Oman.

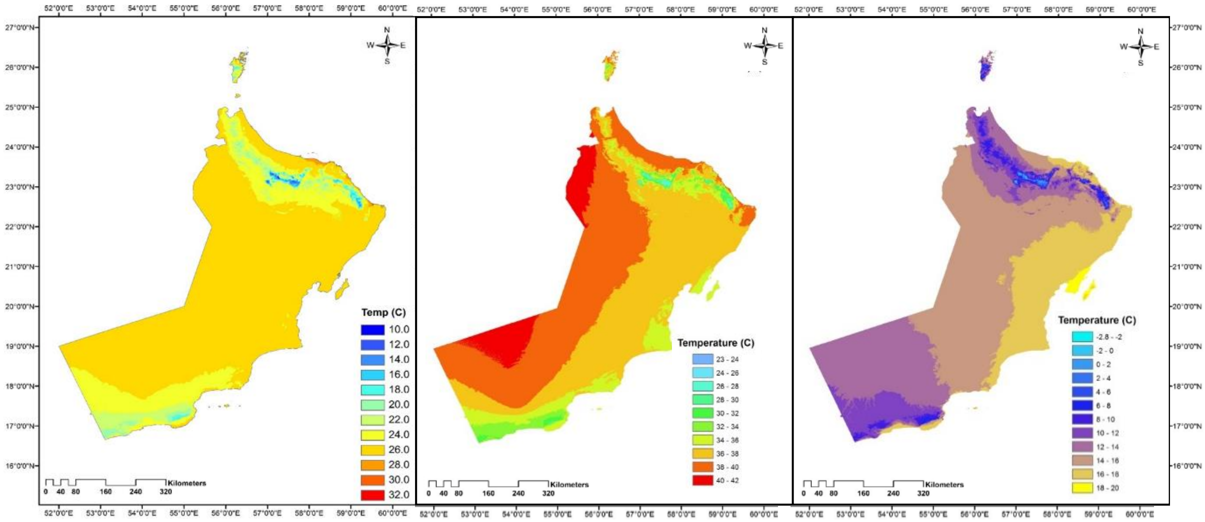


Figure 1-5: Temperature in Oman, 1950-2000. Left: Annual mean temperature; Middle: Average of maximum temperature of warmest month; Right: Average of minimum temperature of coldest month (source: Charabi, *et al*, 2015)

Rainfall in the Arabian Peninsula occurs primarily as a result of four main meteorological conditions originating from the Mediterranean, Central Asia, the tropical maritime regime of the Indian Ocean and tropical Africa. During different times of the year, these atmospheric influences bring varying rainfall to different parts of the peninsula.

In general, the Arabian Peninsula is dominated by two air masses, namely, the Polar Continental that occurs from December to February and the Tropical Continental that occurs in summer from June to September. Both systems are affected by minor incursions of Polar Maritime and Tropical Maritime (Fisher and Membery, 1998). Rainfall patterns depend on four principal mechanisms, namely convective rainstorms, cold frontal troughs, southwesterly monsoon currents, and tropical storms and cyclones over the Arabian Sea.

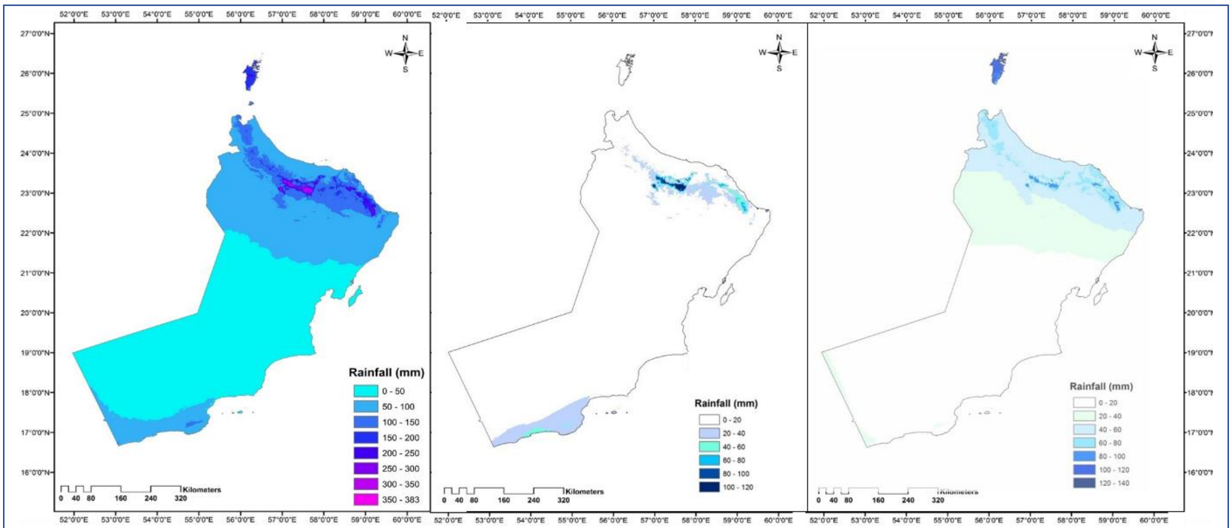


Figure 1-6: Precipitation in Oman, 1950-2000. Left: Annual average precipitation; Middle: Average summer precipitation; Right: Average winter precipitation (source: Charabi, *et al*, 2015)

Figure 1-6 shows some annual rainfall indicators, averaged over the period 1950-2000. Major patterns are summarized in the bullets below.

- *Annual average (Figure 1-6, left):* Average annual rainfall ranges from 150 mm to 300 mm in the Hajar Mountains in the north while ranging from 50 mm to 150 mm in the Dhofar Mountains in the south. Across the hillsides of these mountain ranges, average annual rainfall is between 100 mm and 150 mm. Over the rest of Oman, annual rainfall is between 0 mm and 50 mm.
- *Average summer (Figure 1-6, middle):* During the summer months of June through September, average seasonal rainfall is between 0 mm and 20 mm for most of the country. The summer Monsoon influences the southern part of Oman and the seasonal average ranges from 50 to 100 mm.
- *Average winter (Figure 1-6, right):* During the winter months of November through April, average seasonal rainfall is between 20 mm and 60 mm for northern parts of the country, and between 0 mm and 20 mm for the rest of Oman.

1.3.2. Extreme weather events

On-shore southwesterly monsoon currents occur from June to September and bring humid conditions to much of Oman accompanied by frequent drizzle, fog, mist and rain *(khareef)* in Dhofar coast and bordering mountain areas. Occasionally, the monsoon currents penetrate further inland to produce powerful convective storms. During the monsoon season, parts of Dhofar region are transformed into lush landscapes of green field and verdant vegetation. The monsoon season in Dhofar region brings about 100–400 mm of rainfall.

There have been destructive tropical depressions, tropical cyclonic storms and severe cyclonic storms that have tracked toward Oman over the past decades from the north Indian Ocean and the Arabian Sea. Such storms typically occur during the pre-monsoonal period (May-June) and the post-monsoonal period (October-November).

Table 1-1 lists the most dangerous tropical cyclones/storms that directly impacted coastal areas of Oman, with the most recent extreme weather events briefly described in the bullets below.

Table 1-1: Worst extreme weather events that have impacted coastal areas of Oman, 1889-2018 (source: Public Authority for Civil Aviation, 2019)

#	Year	Month	Type of extreme event
1	1889	June	Storm
2	1890	June	Cyclone
3	1948	October	Cyclone
4	1959	May	Cyclone
5	1963	May	Cyclone
6	1966	November	Cyclone
7	1977	June	Cyclone
8	1983	November	Storm
9	1993	October	Storm
10	1992	November	Storm
11	1996	June	Storm
12	1998	December	Storm
13	2002	May	Storm
14	2007	June	Cyclone
15	2010	June	Cyclone
16	2011	November	Storm
17	2014	October	Cyclone
18	2015	June	Storm
19	2018	May	Cyclone
20	2018	October	Cyclone

- *Gonu (June 2007):* The Super Cyclonic Storm Gonu reached the Sea of Oman and is considered the strongest extreme weather event of the last 100 years, causing 50 deaths. Windspeeds reached 130 km/h and were accompanied by 900 mm of rain over a 2-day period.
- *Phet (June 2010):* The Very Severe Cyclonic Storm Phet dropped heavy rainfall, about 450 mm, over northeastern Oman leading to

extensive flash flooding that destroyed infrastructure. Windspeeds reached 155 km/h and there were 24 fatalities.

- *Mekunu (May 2018):* The Extremely Severe Cyclonic Storm Mekunu, was the strongest cyclone to strike Oman's Dhofar governorate since 1959. It dropped about 617 mm of rainfall in Salalah, causing landslides and extensive flooding. Windspeeds reached 175 km/h and there were 7 fatalities.

1.3.2. Desertification

About 95% of Oman's land area is characterized as a desert or having more than moderate desertification. Land degradation from desertification is most acute in the Al-Batinah, Ash-Sharqiyah and Dhofar governorates. With regional climate models predicting higher temperatures and less rainfall, combating land degradation will present an even more serious and complex challenge than it already is.

To address the impact of encroaching desertification, the National Plan of Action to Combat Desertification (NPACD) was developed in 1993 as joint cooperation with UNEP, ESCWA, and FAO. The NPACD identified several physical and socio-economic causes of desertification, as briefly outlined in the bullets below.

- *Overgrazing.* Livestock overgrazing is a major cause of plant cover loss, particularly in the northern Hajar Mountains, southwestern areas and coastal plains.
- *Groundwater overpumping.* The overpumping of fossil groundwater has resulted in the dropping of water tables and consequently, the intrusion of seawater into coastal aquifers. This has led to severe salinization of cultivated lands, particularly in the Al-Batinah and Ash-Sharqiyah governorates.
- *Unsustainable farming practices.* Traditional farming, widely practiced on large numbers of small farms, relies on high levels of irrigation to compensate for low-yielding, under-fertilized crops. This has led to a deterioration in soil productivity and water quality.
- *Uncontrolled sand drifting.* In Ash Sharqiyah Sands region, as well as plains and wadis areas of the Al-Dakhliya, Al-Wusta, and Dhofar governorates, sand drifting has become a serious hazard to roads and other structures in the region.
- *Other.* Off-road vehicles, construction, and tourist activities have contributed to the loss of vegetation throughout the country.

1.3.3. Biodiversity

Due to Oman's geographic and climatic variability from North to South, there is a great plant, animal, marine, and microbiological biodiversity in the country. In fact, Oman is a habitat for more than 1,250 species of documented crop and wild plants, 180 species of forest plants, 509 species of marine plants, 766 species of marine invertebrates, 988 species of fish, 103 species of amphibians and reptiles, 526 species of birds, and 93 species of mammals. About 13,216 km^2, or about 4.27% of Oman's total land area, is protected either by national legislation or by international designation.

Oman puts priority emphasis on maintaining its fragile biodiversity which provides many ecosystem services for human activities and wellbeing. To protect genetic diversity and constrain potential threats from human activities, five national institutions work together to coordinate and harmonize productive activities that ensure the protection of biological diversity. These institutions are the Ministry of Environment and Climate Affairs, the Ministry of Agriculture and Fisheries, Sultan Qaboos University, Oman Botanical Garden, and The Research Council (TRC) through the Oman Animal and Plant Genetic Resources Center (OAPGRC).

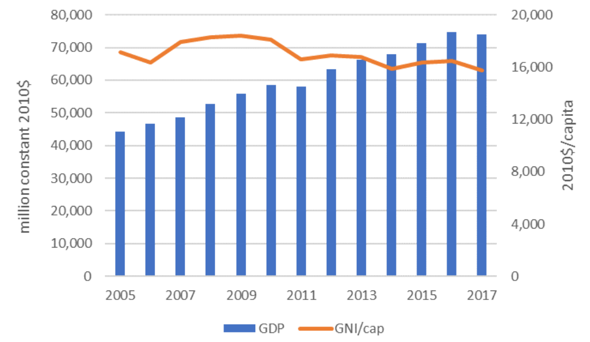


Figure 1-7: GDP and GNI/capita trends, 2007-2017 (source: World Bank, 2019)

1.4. Economic circumstances

1.4.1. Economy

Oman has the fifth largest economy in the GCC region. As illustrated in Figure 1-7, gross domestic product (GDP) has experienced steady growth, roughly 4.1% per year over 2007-2017, (World Bank, 2019). Over this same period, gross national income (GNI) per capita declined at an average annual rate of 1.3% per year, from US$17,935 to US$15,756, in constant 2010$ (World Bank, 2019).

The structure of the Omani economy has changed significantly over the years, thanks in large part to concerted efforts to diversify the economy away from a dependence on oil and gas. Since even before 2013 when Oman Vision 2020 was released, the government has focused on the development of five main sectors other than oil and gas: manufacturing, transportation and logistics, mining, and agriculture, which consists of agriculture, livestock, and fisheries.

The impact of the government's economic diversification strategy has been significant. In 2000, the oil and gas sector represented the largest share of GDP at nearly 48%. By 2016, preliminary estimates from the Central Bank of Oman indicate that the oil and gas share of GDP had dropped by nearly half, to only 27.4% of GDP, with 72.6% of GDP consisting of non-hydrocarbon activities.

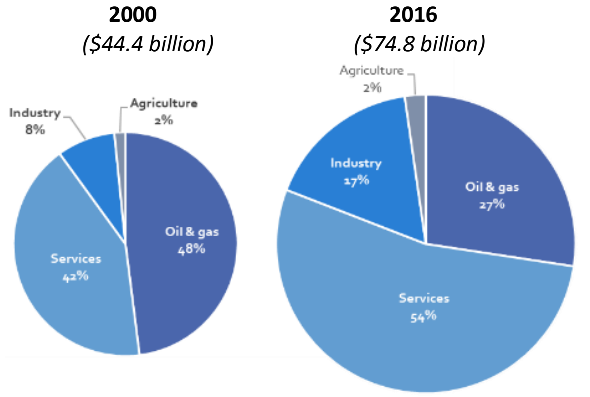


Figure 1-8: GDP sectoral composition, 2000 and 2016 in constant 2010$ (source: Central Bank of Oman, 2019)

This trend is summarized in Figure 1-8. Services increased from 42% in 2000 to 53.5% in 2016 and industry has exhibited notable increases from 8.4% in 2000 to 17% in 2016. While the agriculture share of GDP has stayed relatively flat, with a contribution of less than 2%, this sector has been increasingly affected by rural-urban migration, in which the labor force is being attracted to the higher wages of industry and the service sector in urban areas.

1.4.2. Oil & Gas

Oman is a fossil fuel exporting country. Oil and gas remain the primary revenue source, accounting for nearly 73% of government revenues in 2017.

Oman enjoys Observer status in the Organization of Petroleum Exporting Countries (OPEC) and regularly coordinates on initiatives such as voluntary supply cuts to harmonize policy objectives between OPEC and non-OPEC members. In 2016, Oman exported 912,500 b/d of crude oil and condensate, about 86% of total production and its highest level since 1999. Most of the remaining crude oil is converted into refined oil products – diesel, gasoline, and jet kerosene – and consumed in Oman's transport sector.

Oman is also member of the Gas Exporting Countries Forum (GECF) and exports natural gas as liquified natural gas (LNG) through LNG facilities near Sur, along the Sea of Oman coastline. In 2016, Oman exported 358 billion cubic feet (bcf) of natural gas, about 31% of total production. The remaining natural gas is used for power generation and industrial applications (i.e., smelters, refineries).Industry

The industrial sector has witnessed substantial growth in recent years. Much of this growth is associated with to promote investment. Three of the most important initiatives are briefly described in the bullets below.

- *Port of Sohar:* This is a deep-sea port with an adjacent 4,500-hectare economic free zone that has attracted about $26 billion of investments. The Port handles over one million tonnes of sea cargo each week and around 3,500 ships a year.
- *Free trade zones:* Oman has four free trade zones located in Al Mazunah, Sohar, Duqm, and Salalah. Among other benefits, these zones offer opportunities for regional manufacturing and a distribution base. Modern airports in Muscat Duqm, Sohar, and Salalah support these zones.
- *Industrial zones:* Industrial zones have been established in Muscat, Sohar, Nizwa, Buraimi, and Salalah. These zones provide infrastructure such as electricity and telecommunications to facilitate manufacturing of industrial products such as chemical and electrical materials, building materials, fiber optic cables, clothing, stationaries, paints, and foodstuffs.

1.4.3. Agriculture

The agricultural sector in Oman is market-oriented and is a relatively small sector of Oman's economy. As depicted in Figure 1-9, the contribution of agriculture to Oman's GDP has declined precipitously from 74% in 1962 to only 2.3% in 2017, consistent with the expanding role of oil and gas over this period. Nevertheless, agricultural production at increased in recent years – relative to these lower levels - with an annual average growth rate of 8.5% over the period 2009-2013 (MAF, 2019).

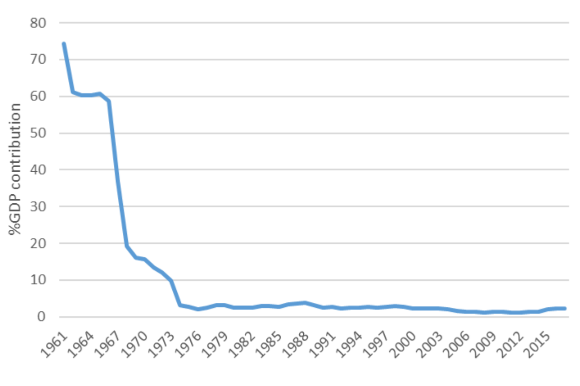


Figure 1-9: Agriculture, percent value added to GDP, 1961-2017 (source: World Bank, 2019)

The national soil survey carried out over 2004-2005 determined that 2.2 million hectares are suitable for agricultural activities, which accounts for 7.2% of the total land area of Oman. Of this potential, roughly 4.6%, or 1.4 million hectares, was under cultivation as of 2017, with a sharp increase starting in 2000 (see Figure 1-10).

Water availability represents the most critical constraint for agricultural production in Oman. Farming is wholly dependent on irrigation as there is neither rain-fed farming nor surface water for irrigation. Most of the water for irrigation is obtained through the *falaj* system, a traditional irrigation system relying on groundwater (see Box 1-1). Modern irrigated areas were introduced in the 1970s and they currently cover 5,090 hectares or 12% of total cultivatable land.

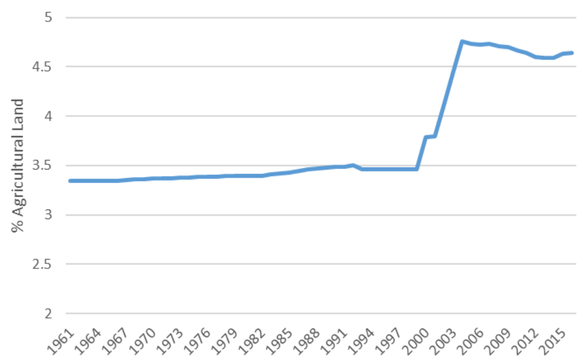
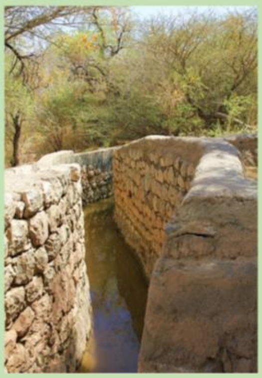


Figure 1-10: Agricultural land, percent of total land area, 1961-2017 (source: Ministry of Agriculture and Fisheries, 2019)

The overwhelming majority, about 90%, of farms are currently small in size, less than 2.1 hectares. Over the period 2004-2013, average farm size trends show a slight decrease. However, these farms represent only about 25% of all cultivated land in 2013, down slightly from 26% in 2004.

Box 1-1: Oman's traditional irrigation system

Oman's *falaj* irrigation systems are ancient water channels located in Dakhiliyah, Sharqiyah and Batinah for accessing and dividing groundwater among farmers and croplands. A typical system consists of a vertical shaft dug from the surface to reach groundwater in porous rock. From the bottom of this shaft, a gently sloping tunnel is dug to tap the water, allowing it to flow to a point on the surface at a lower level or into a cistern or underground pool, from which it can accessed by bucket or pump. The picture at right is Falaj Daris in Dakhiliyah.



Major agricultural products include fruit (i.e., dates, limes, bananas, pomegranates), fodder (i.e., alfalfa), field crops (i.e., sorghum, barley, wheat, maize) and a large variety of vegetables. Dates are considered one of the most important food crops in Oman and plantations occupy approximately half of the country's agricultural land; domestic cultivation meets local demand and produces a significant surplus for export.

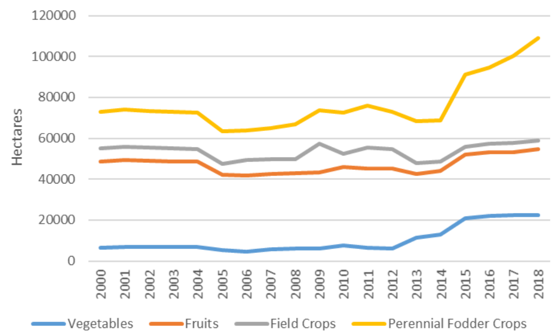


Figure 1-11: Cultivated agricultural land area by crop type, 2009-2018 (source: Ministry of Agriculture and Fisheries, 2019)

Cultivated area by major crop type is shown in Figure 1-11. There has been a significant expansion in cultivated areas for perennial fodder crops and vegetables over the period 2009-2017. These areas have expanded at average annual rates of 13% and 18%, respectively. This expansion has more than offset the significant contraction in cultivated areas for fruits and field crops (e.g., sorghum, barley, wheat, maize) over the period 2009-2018. These areas have contracted at average annual rates of 2% and 14%, respectively.

Most of the newly cultivated areas in recent years are located in coastal areas, with the most intensely farmed areas located along a 320-km stretch in the Al Batinah coastal region northwest of Muscat, and a 100-km long stretch in Salalah coastal plain in the Dhofar governorate. Other major areas for agricultural production include the interior plains, oases, and lands adjacent to wadis.

Figure 1-12 illustrates the crop production index (CPI) for all crops except fodder relative to base period production levels of 2004-2006. From a value of 16.1 in 1961, the CPI has increased to 148.3 by 2016, demonstrating Oman’s enduring commitment to expanding its agricultural activities. Some major trends have become evident over the latter part of this period, 2009-2017, as summarized in the bullets below.

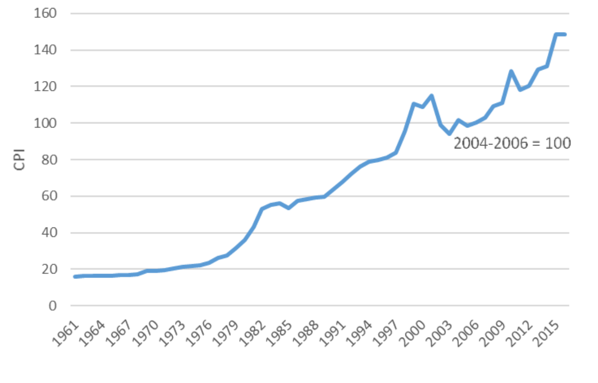


Figure 1-12: Crop production index, 1961-2016 (source: World Bank, 2019)

- Total production of vegetables, fruits, and field crops increased from 0.56 to 1.24 million tonnes per year or almost 11% per year.
- Vegetable production alone accounts for a fourfold increase, from 0.20 to 0.81 million tonnes per year, or about 19% per year.
- Fruit production increased modestly, from 0.32 to 0.42 million tonnes per year, or about 19% per year; and
- Field crops declined substantially from 0.03 to 0.01 million tonnes per year or almost 13% per year.

1.4.4. Fisheries

Fisheries represent an important economic subsector in Oman. Fishing activities are prevalent along the entire 3,165 km coastline, encompassing a total commercial fishing area of about 350,000 km^2. Artisanal fishery operations employ around 40,000 fishermen operating about 18,000 fishing boats, 90% of which are 8-10 meters in length. Artisanal fishing accounts for the overwhelming portion of annual fish landings, about 96%.

Fish landings have shown steady growth over the past decades. In 2017, 347,000 tonnes of fish were harvested compared to 95,000 tonnes in 1985, an average annual growth rate of 4.1% per year (see Figure 1-13, top). Key trends over the 2010-2017 period are summarized in the bullets below (see Figure 1-13, bottom).

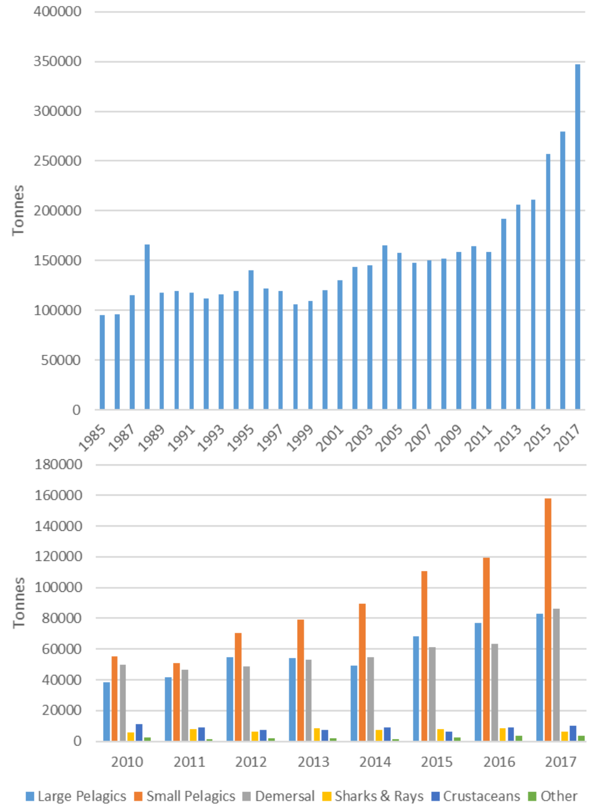


Figure 1-13: Fishery production in Oman. Top: Total fish landings, 1985-2017; Bottom: Total fish landings by species, 2010-2017 (source: National Center for Statistics and Information, 2019)

- *Small pelagics:* Small pelagic fish such as the Indian oil sardine *(Sardinella longiceps)* have consistently accounted for the largest share of fish landings, a trend that has noticeably intensified over the period;

- *Large pelagics and demersals:* Large pelagic fish such as yellow fin tuna *(Thunnus albacares)* and demersal fish such as the emperor *(Lethrinus nebulosus)*, while remaining consistently large, have declined from 57% to 48% of total fish landings over the period; and
- *Other fish:* The share of sharks, rays, crustaceans, and other while remaining consistently small, have declined over the 2010-2017 period, from 8% to 5% of total fish landings over the period.

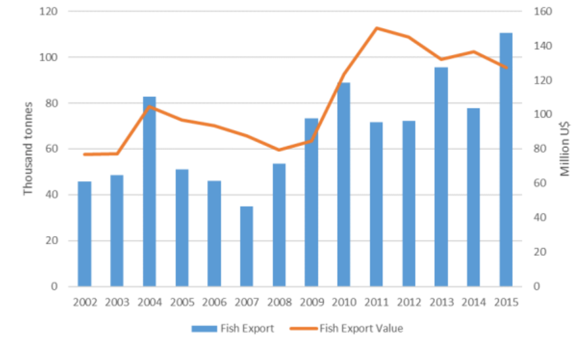


Figure 1-14: Fish exports and export values, 2002-2015 (source: National Center for Statistics and Information, 2019)

Oman has historically exported a large share of its annual fish catch to regional markets such as the United Arab Emirates Saudi Arabia, and Qatar, as well as Asian markets such as Thailand. Overall, fish exports have increased from 45,700 tonnes in 2002 to 110,580 tonnes in 2015, representing about and 29% and 43% of total fish catch, respectively (see Figure 1-14, columns). The value of these fish exports has been very inconsistent, with strong cyclical patterns evident over the 2002-2015 period (see Figure 1-14, line).

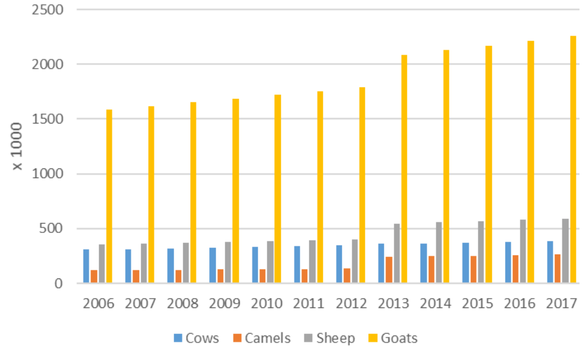


Figure 1-15: Estimated number of livestock, by animal, 2006-2017 (source: National Center for Statistics and Information, 2019)

1.4.5. Livestock

Oman has a well-diversified livestock population that includes large numbers of cows, sheep, goats, and camels. Altogether, the total number of livestock has grown from 2,373,000 in 2006 to 3,502,000 in 2017, roughly. Major features of these levels over the 2006-2017 period are illustrated in Figure 1-15 and summarized in the bullets below.

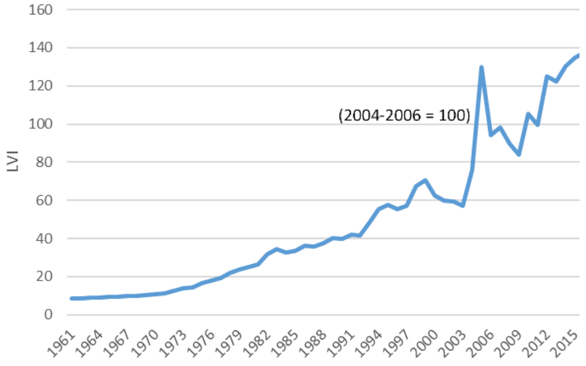


Figure 1-16: Livestock Production index, 1961-2017 (source: World Bank, 2019)

- Livestock herds have been growing at a slower rate than Oman's human population, from 0.92 head per capita in 2006 down to 0.76 head per capita in 2017;
- Goats account for most livestock, accounting for between 64% and 68% of total heads of livestock over the period;
- Sheep account for the next largest share over the period, between 15% and 17% and
- Camel numbers have shown the largest relative growth, over doubling the herd size over the period, equivalent to an average annual growth rate of 8.7%/year.

Figure 1-16 illustrates the livestock production index (LPI) for the quantities of all products provided by livestock relative to production levels of 2004-2006. Livestock products include meat, milk, dairy products (e.g., cheese), and eggs, honey, raw silk, wool, and hides & skins. From a value of 8.6 in 1961, the LPI increased to 137.5 by 2016, demonstrating, an average annual growth rate of 5.2% per year.

1.5. Development circumstances

1.5.1. Population

Table 1-2 provides a summary of some key population and demographic indicators. As shown in the table, Oman's population has been growing rapidly, reaching 4.4 million in 2016. Over the 23-year period 1993-2016, the population grew at a rate of 3.5% per year.

Most of the population growth took place in urban areas along the Sea of Oman coast in the Muscat and the Al- Bathina regions, as well as cities in the Ad Dhahirah, Ad Dakhliyah, and Ash Sharqiyah governorates. These urbanization trends stand in contrast to population centers during the 1970s when more than 85% of the total population lived in rural areas. Oman's National Center for Statistics and Information projects that population will reach 7.65 million by 2040.

Oman has a well-educated population, with a 96% literacy rate. A large percentage of the population is between 15 and 64 years of age. This age group has been growing at around 4.7% per year.

Per capita income has been growing at faster rate than the overall population, indicating real economic growth. The Omani labor force is employed mostly in the public sector, which after dipping to only 53% in 2010, climbed to nearly 90% by 2016. The employed labor force has been growing at roughly the same rate as per capita income.

Table 1-2: Major demographic indicators for Oman (source: National Statistics Report, 2016)

Indicator	Units	1993	2003	2010	2016
Total Population	Thousand	2,018.07	2,340.82	2,773.48	4,414.05
Omani citizens	%				
Expatriates	%				
Per Capita Income	PPP, US$	12,671.5	16,895.39	25,438.71	41,320.00
Urban Population	% of total	71.7	71.5	75.0	78.1
Population by gender	Gender Ratio	140.2	127.8	138.8	189.0
Population, <15 years	%	41.0	33.8	27.8	21.9
Population, 15-64 years	%	56.7	63.6	69.5	74.1
Population, ≥ 65 years	%	2.3	2.6	2.7	4.0
Illiteracy	% of total population	30.5	15.9	11.7	4.0
Total labor force	Thousand	704.80	873.47	1,245.57	2,255.41
Employed Omanis					
Public Sector	%	NA	62.6	53.3	83.89
Private Sector	%	NA	27.4	39.7	11.56

1.5.2. Urban Development

Urban development in Oman has largely focused on the coast during the past five decades, a trend that seems certain to continue through the 21st century. Coastal population growth in Oman has led to widespread conversion of natural coastal landscapes to industrial and residential uses. There are seven Governorates with coastal borders, namely: Musandam, North Al Batinah, South Al Batinah, and Muscat along the Sea of Oman; and Al-Wusta and

Dhofar along the Arabian Sea. Approximately 48% of the total built-up area of the seven coastal Governorates has been developed within a 200-meter distance from the shoreline.

1.5.3. Public Health

The government currently spends roughly 6.3% of total annual expenditures on health care for citizens. In 2016, this amounts to about US$ 2.1 billion, or roughly US$475 per person per year.

All public health indicators show positive trends in life expectancy (see Figure 1-17, top), child neonatal mortality rate (see Figure 1-17, middle), and maternal mortality ratio (Figure 1-17, bottom), consistent with the corresponding rates in other GCC countries.

In 2017, there were 76 hospitals in Oman, an increase of 2 hospitals compared to the previous year. More than a quarter (i.e., 27.6%) of these hospitals were privately owned and operated. Figure 1-18 shows trends for selected parameters for health indicators from 2008 to 2017. Major trends are summarized in the bullets below.

- Except for the number of hospital beds whose numbers declined at about 3% per year, all other indicators showed positive growth per 10,000 people;
- While still low, the presence of dentists has been expanding in the health care system, reaching 3 dentists per 10,000 people in 2017, equivalent to a growth rate of 13% per year; and
- The availability of doctors, nurses, and pharmacists, with notable ebbs and flows, have shown overall annual average growth rates of 1.2%, 1.3%, and 2.7%, respectively, over the 2008-2017 period.

1.5.4. Food Security

In 2018, Oman ranked 29th out of 113 countries with a score of 74.4 out of 100 in the

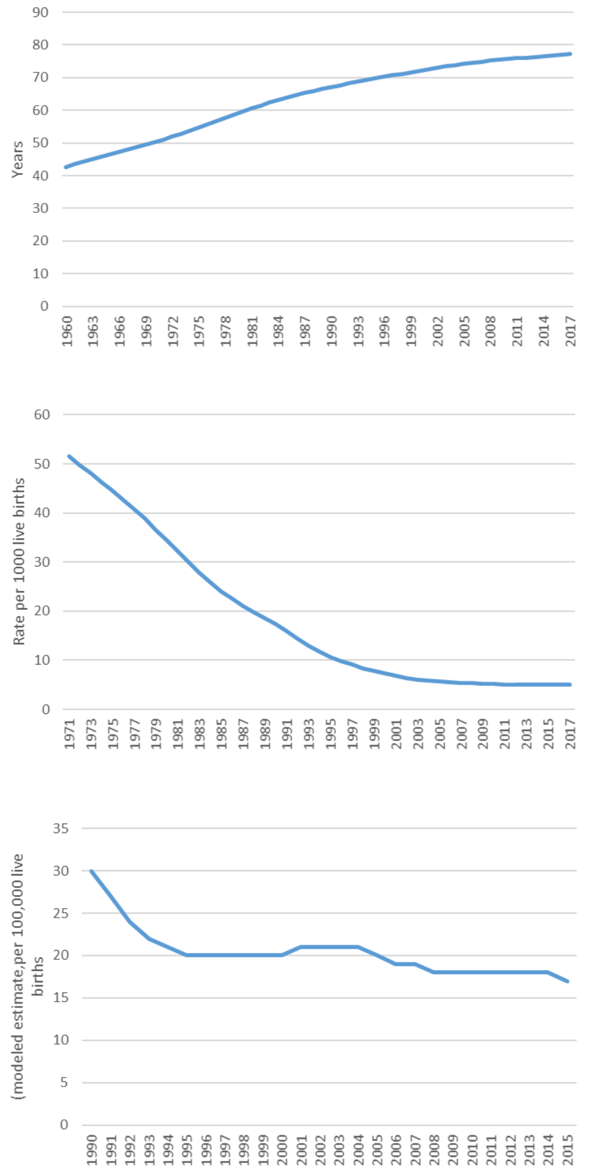


Figure 1-17: Mortality indicators in Oman. Top: Life expectancy at birth, 1960-2017; Middle: Neonatal mortality rate, 1971-2017; Bottom: Maternal mortality ratio, 1990-2015 (source: National Center for Statistics and Information, 2019)

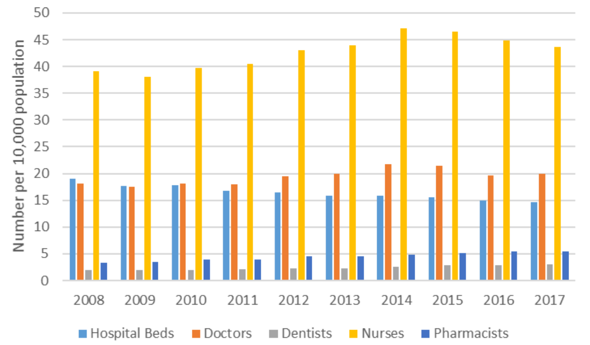


Figure 1-18: Public health resource indicators, 2008-2017 (source: Ministry of Health, 2019)

Global Food Security Index (GFSI), a composite measure of overall food security relative to key indicators of food availability, affordability, quality/safety, as well as natural resources & resilience (The Economist, 2018). Despite its arid to semi-arid climate, this score indicates that Oman is a relatively food-secure country, the third most food secure in the Middle East after Qatar and Kuwait.

Oman has promoted public-private partnerships in an effort to enhance food security. For example, an agreement was reached in 2018 between the privately-owned Oman Global Logistics Group (ASYAD) and the publicly-held Oman Food Investment Holding Company (OFIC). The aim of the agreement is to enhance cooperation through logistics hub to meet local food demand and contribute to meeting global food demand. The agreement commits both parties developing sustainable agro-food value chains, as well as developing food storage/distribution infrastructure in Oman.

Finally, the government has been directly investing in the food and agricultural sectors through various funds. Several large projects have already been implemented, with some others in the process of implementation. Some of the more notable projects are briefly summarized in the bullets below.

Figure 1-19: Food security projects in Oman. Top: Million Date Palm Project; Bottom: Aquaculture development project along the southeastern seaboard (source: Diwan of Royal Court, 2018)

- *Nakheel Oman Project.* This is a landmark venture launched in response to His Majesty the Sultan's Million Date Palm Programme (see Figure 1-19, top). The project is expected to provide the market with 85,000 tonnes per year of dates by 2034.
- *Aquaculture development project*. This is a subsidiary project promoting a large portfolio of marine finfish and shrimp farming along the Sultanate's coast (see Figure 1-19, bottom).
- *A'Namaa project.* This is a major public-private poultry project capitalized at US$265 million, with an OFIC equity contribution of 20%. The project aims to contribute to increasing self-sufficiency in the poultry sector from 36% to 70% by 2030.
- *Al Bashayer Meat project*. This is a company with publicly traded stock shares capitalized at around US$100 million. The company's vision to be the Trusted Meat Supplier for Oman.

1.5.5. Transport

Oman is committed to achieving a high level of regional and international competitiveness in the transport sector. Key priorities include the following:

- Road network expansion consistent with international standards for design and safety;
- Transport infrastructure upgrades at airports and marine ports;
- Prefeasibility studies for new railways; and

▪ Improvement in the quality of public transport services.

Much progress has already been achieved regarding the road network expansion priority. Since 1990, the paved road length has nearly quadrupled to 14,846 km (see Figure 1-20). Notably, these are only those that are under the Ministry of Transport & Communications. There are also many kilometers of paved roads under other governmental entities like Muscat Municipality, Dhofar Municipality, and the Ministry of Defense.

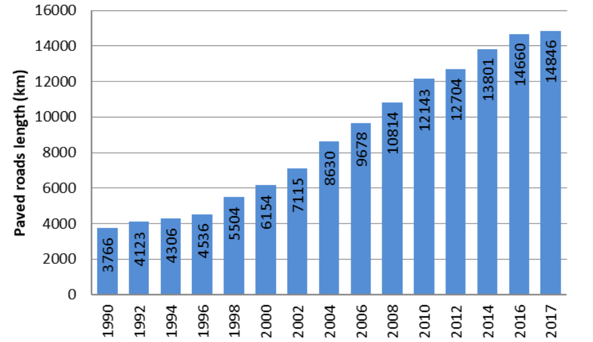


Figure 1-21: Development of Oman's road network, 1990-2017 (source: National Center for Statistics and Information, 2019)

There has also been significant improvement in airport infrastructure. The passenger terminal building and maintenance yard buildings of the Muscat International airport, with its Omani-themed architecture and advanced technology, commenced commercial operation in March 2018 (see Figure 1-21, top). This new facility will help facilitate the large growth in passenger volume that fly through Oman, which has reached 15.6 million in 2017, or growing at about 14.5% per year since 2013 (see Figure 1-21, bottom).

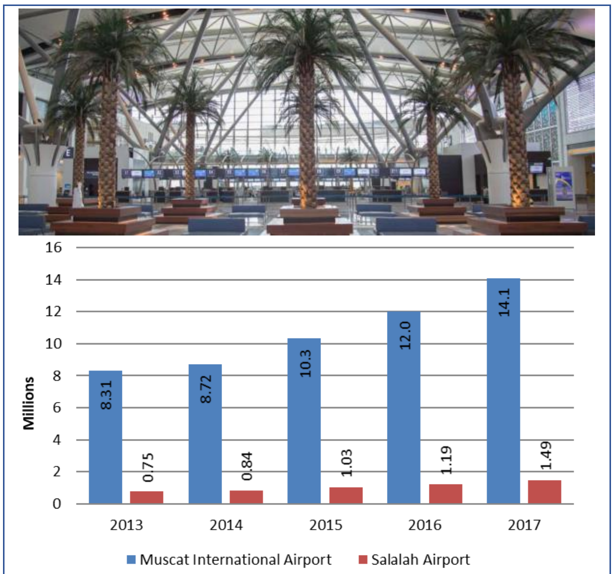


Figure 1-20: Air travel in Oman. Top: View of Muscat International Airport; Bottom: Passenger volume in main airports, 2013-2017 (source: National Center for Statistics and Information, 2019)

1.5.6. Waste management

Oman Environmental Services Holding Company "Be'ah" was established in 2009 to oversee solid waste management in Oman. The company implements government policy with regard to the management and operation of waste sector activities in accordance with the sector strategy developed by the National Economy Ministry (source, 2010).

Oman currently produces an average of 0.7 tonnes per capita per year of municipal solid waste, the lowest level in the GCC and lower than the global average. Nevertheless, national policies are in place to reduce the amount of solid waste disposed at landfills through increased recovery recycling and reuse. The waste management operation in Oman is divided into three main categories:

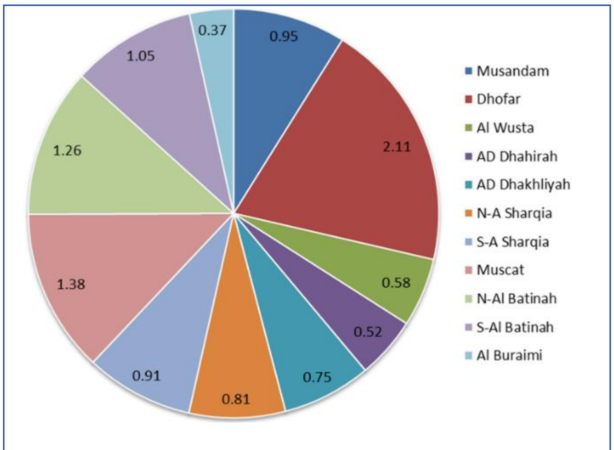


Figure 1-22: Waste generation in Kg/capita/day in Oman governorates, 2017 (source: Oman Environmental Services Holding Company, 2019)

municipal waste, industrial waste, and healthcare waste. Figure 1-22 shows waste generation in kg/capita/day in 2017 for each of the governorates.

1.6. List of references

- Central Bank of Oman, 2019. (https://cbo.gov.om/).
- Charabi, Y., Al-Rawas, G., Al-Wardy, M., Al-Maskari, J., Al-Sarmi, S., and Al-Yahyai, S. 2015. "Observed and projected changes in climate of Oman", Sultan Qaboos University.
- Diwan of Royal Court, 2019. (https://isfu.gov.om/);(https://mdp.gov.om/).
- EIA, 2017. (www.eia.gov)
- Fisher and Membery, 1998. Climate. – Pp. 5-38 in: Ghazanfar, S. A. & Fisher, M. (ed.),Vegetation of the Arabian Peninsula.
- Membery, 2001. Monsoon tropical cyclone: Part1. Volume56, Issue12. December 2001. Pages 431-438.
- Ministry of Agriculture and Fisheries (MAF), 2019. (http://www.maf.gov.om/).
- Ministry of Health, 2019. (https://www.moh.gov.om/).
- National Center for Statistics and Information, 2019. (https://data.gov.om/).
- National Statistics Report, 2016. (https://data.gov.om/).
- Public Authority for Civil Aviation, 2019. (https://www.paca.gov.om/).
- UNEP, 2008. Vulnerability Assessment of Freshwater Resources to Climate Change:
- Implications for Shared Water Resources in the West Asia Region (http://cedarekmp.net/unep_vuln/downloads/Full_Report_Hi.pdf).
- The Economist, 2018 (https://www.economist.com/topics/oman).
- World Bank, 2019. (https://www.worldbank.org/).

2. Greenhouse Gas Inventory

2.1. Introduction

This chapter presents estimates of Oman's anthropogenic greenhouse gas emissions (GHG) and sinks for the year 2000, with estimates in the year 2015, based on the inventory assessment prepared by Charabi *et al*., (2019). The inventory includes four categories: energy; industrial processes and product use (IPPU); agriculture, forestry and other land use (AFOLU); and waste.

1.1.1. Methodology

The inventory was compiled according to the Tier 1 methodology for inventories described in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006) and accompanying Inventory Software (Version 2.54). Quality assurance (QA) and quality control (QC) verification procedures were applied consistent with the 2006 IPCC inventory preparation Guidelines, as well as the Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories (IPCC, 2000). Data cross-checking and verification for accuracy, consistency, completeness, and integrity of the database after data entry were subject to technical review by international experts.

1.1.2. Assumptions

The Base Year for the inventory is 2000, with emission estimates up through the year 2015. Activity data were obtained from Oman's National Center for Statistics and Information (NCSI). IPCC default values were used for emission factors, carbon content, and net heating value while carbon dioxide-equivalent (CO_2e) calculations were carried out using 100-year global warming potentials (GWP) from the IPCC's Fifth Assessment Report.

2.2. Overall results

In the subsections that follow, GHG emissions are reported at the national level in absolute units of carbon dioxide, methane, nitrogen oxide emissions, high-GWP gasses, as well as in units of CO_2e.

2.2.1. Total GHG emissions

Table 2-1 presents total GHG emissions and sinks for the year 2000. Total GHG emissions in 2000 were 21,666 Gg CO_2e, which includes 17,196 Gg from energy; 2,865 Gg from IPPU; 799 Gg from AFOLU; and 806 Gg from waste. There are no carbon sinks associated with managed green spaces and parks. There are also no emissions of hydrofluorocarbons (HFCs), Perfluorinated compounds (PFCs) or Sulphur hexafluoride.

Table 2-1: GHG emissions in Oman, 2000 (Gg)

GHG Sources & Sinks	CO_2e	CO_2	CH_4	N_2O
Energy	17,196	10,590	234.8	0.1
Industrial processes and product use	2,865	2,863	0.1	0.0
Agriculture, forestry and other land use	799	27.9	26.6	0.1
Waste	806	0	26.9	0.2
Total National Emissions	**21,666**	**13,481**	**288.4**	**0.4**

Energy-related activities accounted for the dominant portion of GHG emissions in Oman in 2000. Approximately 79% of all GHG emissions are associated with the combustion of fossil fuels or the release of fugitive emissions from oil and gas operations. Industrial processes and product use accounted for about 13% of all GHG emissions, followed by the waste sector that accounted for about 4% of total emissions. Emissions from agricultural and land use activities are small, accounting for about 4% of total national emissions.

2.2.2. GHG emissions by type

The following bullets provide an overview of total GHG emissions by all GHG types for the year 2000.

- *CO_2:* Total CO_2 emissions were estimated to be 13,481 Gg, or 62% of Oman's total greenhouse emissions on a CO_2e basis. Figure 2-1a summarizes the contribution associated with CO_2 emissions at both the source category (left) and subcategory (right) levels.
- *CH_4:* Methane accounted for the largest share of greenhouse gas emissions. Total CH_4 emissions were estimated to be about 288.4 Gg, or about 37% of Oman's total greenhouse emissions on a CO_2e basis. Figure 2-1b summarizes the contribution associated with CH_4 emissions at both the source category (left) and subcategory (right) levels.
- *N_2O:* Nitrous oxide emissions were very small compared to other GHGs. Total N_2O emissions were estimated to be only about 0.42 Gg, or about 1% of Oman's total greenhouse emissions on a CO_2e basis. Figure 2-1c summarizes the contribution associated with N_2O emissions at both the source category (left) and subcategory (right) levels.

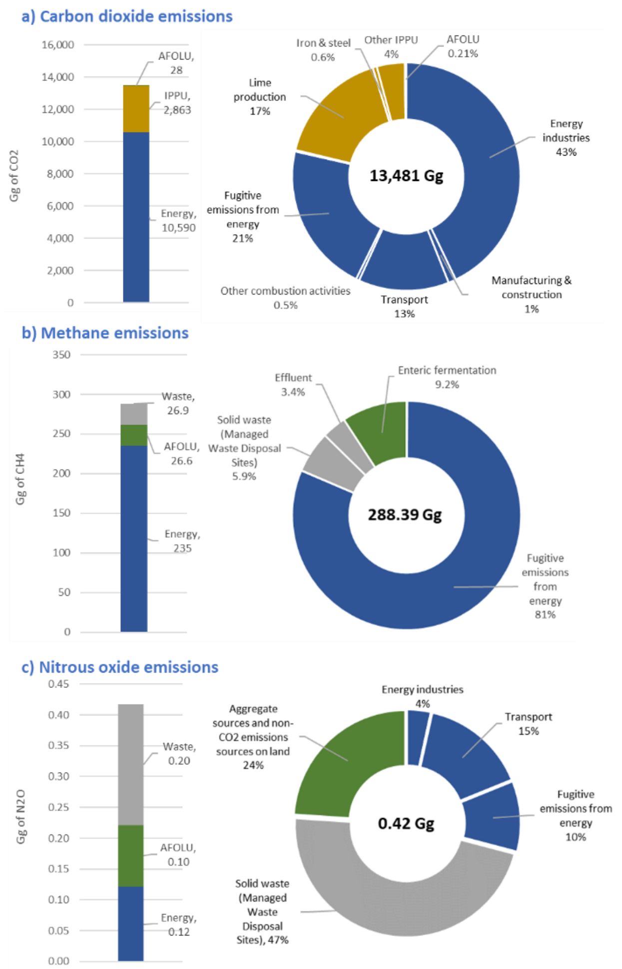


Figure 2-1: Breakdown in GHG emissions by gas type and emitting sector and subsector, 2000

2.2.3. GHG emissions trends

Figure 2-2a presents the trend in total GHG emissions by type of GHG for the years 1994, 2000, and 2015. Over the 1994-2015 period, total emissions have increased by nearly 4.6 times; from 20,719 Gg CO_2e in 1994 to about 96,072 Gg CO_2e in 2015, or roughly 8%/year. Emissions of CH_4 are increasing slightly above this rate, roughly 9% per year. Notably, HFC emissions accounted for about 13.4% of all CO_2e in 2015, compared to no HFC emissions in 1994 and 2000.

Figure 2-2b presents the trend in net GHG emissions by the emitting sector for the Base Year 2006 and projected GHG emissions in 1994, 2000 and 2015. Energy remains the main component responsible for the overall increasing trend in GHG emission levels. Over the 1994-2015 period, CO_2e emissions from energy use have increased over 4 times, or about 8% per year, due primarily to increased energy use for electricity generation, desalinated water production, and process heat in manufacturing. Notably, CO_2e emissions from IPPU, though less than 31% of total emissions in 2015, increased by nearly 50 times, or about 20% per year. A large portion of this increase is associated with new industrial operations coming online during the intervening years (i.e., aluminum, methanol, and ammonia production facilities).

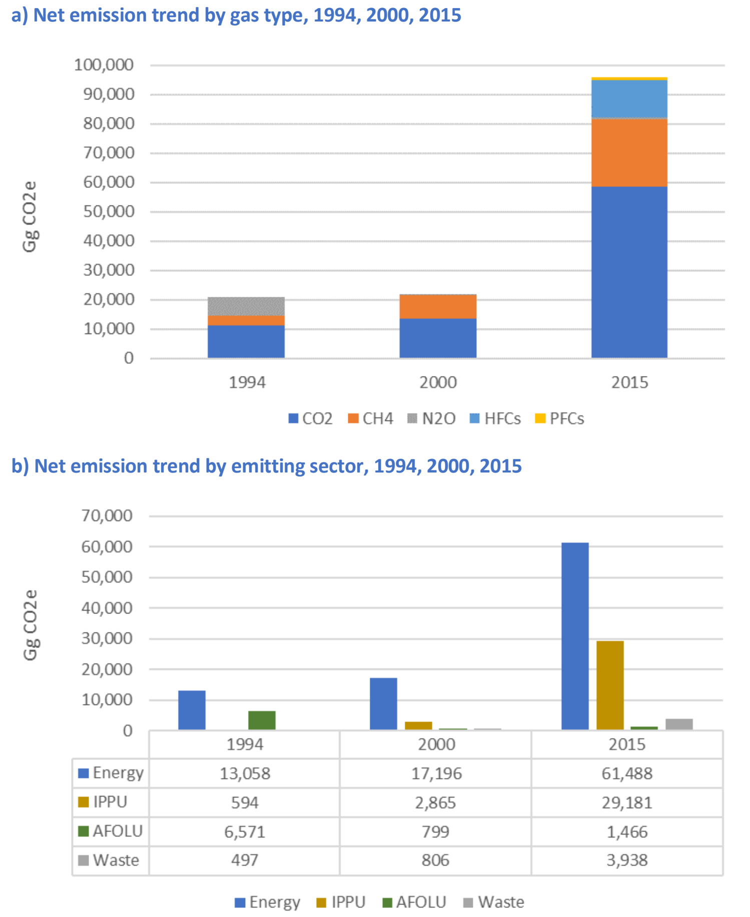


Figure 2-2: Trends in total GHG emissions by gas type and emitting sector

2.3. Sectoral results

In the subsections that follow, GHG emissions are reported at the sectoral level in absolute units of carbon dioxide, methane, nitrogen oxide emissions, high-GWP gasses, as well as in units of CO_2e.

2.3.1. Energy sector

The energy sector includes electricity generation, water desalination, manufacturing industries and construction, other fossil fuel combustion activities, and fugitive emissions from oil & gas operations. Table 2-2 provides a breakdown in energy sector GHG emissions for the year 2000 for these source categories. Relative to overall anthropogenic GHG emissions in Oman, the 17,196 Gg CO_2e represents about 79% of total national emissions.

Table 2-2: GHG emissions from energy use in Oman, 2000 (Gg)

GHG source category	GHG Source	CO_2e	CO_2	CH_4	N_2O
Fuel Combustion Activities	Electricity & water	5,786	5,779	0.1	0.0
	Manufacturing & construction	147	147	0.0	0.0
	Transport	1,754	1,732	0.2	0.1
	Other combustion activities	62	62	0.0	0.0
Fugitive emissions from fuels	Oil & natural gas	9,447	2,870	234.5	0.0
Total National Emissions		17,196	10,590	234.8	0.1

Figure 2-3 illustrates the breakdown in energy-related GHG emissions in 2000 and 2015 by activity. Total CO_2e emissions over this period increased to 61,488 Gg, or roughly 8.9% per year. In 2000, fugitive emissions associated with oil and gas production showed the highest share of sectoral GHG emissions, about 55% of total energy sector emissions. This emission source remains the largest share by 2015 at 35%.

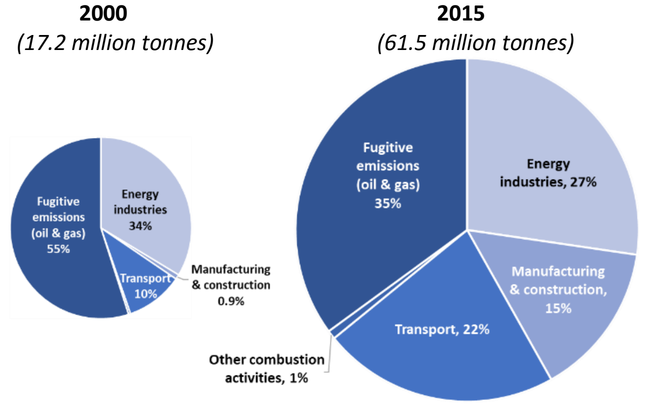


Figure 2-3: Breakdown of CO_2e emissions associated with energy activities, 2000 and 2015

Electricity production at power/desalination plants, as well as electricity generated onsite at manufacturing and construction enterprises, increases from about 34.9% of energy sector emissions in 2000 to 42% by 2015. Transport activities are based overwhelmingly on the use of gasoline and diesel oil and accounted for about 10% and 22% of total emissions from energy-consuming activities in 2000 and 2015, respectively. While there were no other combustion activities in 2000, this category accounted for 1% of total emissions in 2015.

2.3.2. Industrial Processes & Product Use

Table 2-3 summarizes GHG emissions associated with industrial processes and product use in 2000. Industrial processes are the second-largest emitter of anthropogenic GHG emissions in Oman, accounting for 2,865 Gg of CO_2e, or about 13.2% of national CO_2e emissions in 2000.

Table 2-3: GHG emissions from industrial processes and product use in Oman, 2000 (Gg)

GHG source category	GHG Source	CO_2e	CO_2	CH_4	N_2O	PFCs	HFCs	SF6
Mineral Industry	Cement	519	519	0.00	0.00	0.00	0.00	0.00
	Lime production	2,223	2,223	0.00	0.00	0.00	0.00	0.00
	Glass	16	16	0.00	0.00	0.00	0.00	0.00
Metals Industry	Iron & steel	79	77	0.07	0.00	0.00	0.00	0.00
Non-energy products & solvent use	Lubricant use	28	28	0.00	0.00	0.00	0.00	0.00
Product Uses as Substitutes for Ozone Depleting Substances	Refrigeration and Stationary Air Conditioning	0	0	0.00	0.00	0.00	0.00	0.00
Total National Emissions		**2,865**	**2,863**	**0.07**	**0.00**	**0.00**	**0.00**	**0.00**

Mineral industries represented the major source of emissions from industrial processes and product use. Together, the production of cement, lime, and glass accounted for about 96% of total sectoral GHG emissions in 2000. The shares of industrial emissions from iron and steel production and non-energy products & solvent use are small in comparison, about 3% and 1%, respectively.

Figure 2-4 illustrates the breakdown in industry-related CO_2e emissions in 2000 and 2015 by industrial emission source. Total CO_2e emissions over this period increased to 29,181 Gg, or roughly 16.7% per year. This is due to several new industrial activities that commenced operations during this period, namely methanol, ammonia, and aluminum production. It is also due to accounting for fugitive emissions associated with refrigeration and stationary air conditioning.

While still, a major contributor to IPPU emissions, the share of mineral industry emissions decreases significantly, from 96% to 40%. Most of this lower share is associated with lime production which declines from a 78% share in 2000 to only 32% in 2015, while emissions from lime production are growing about 10% per year in absolute terms.

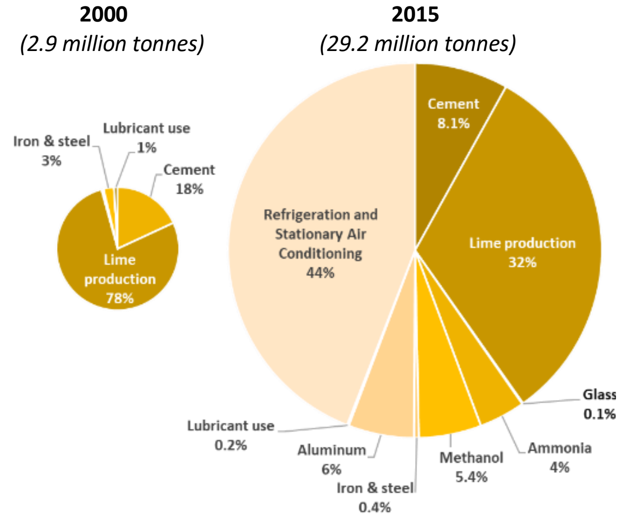


Figure 2-4: Breakdown of CO_2e emissions associated with IPPU activities, 2000 and 2015

In contrast, emissions from new industrial activities accounted for roughly 59% of total IPPU emissions in 2015. Fugitive emissions associated with refrigeration and stationary air conditioning alone accounted for about 44% of total IPPU emissions, while the chemical industry (i.e., ammonia and methanol production), as well as aluminum production, accounted for 9% and 6% of total IPPU emissions, respectively.

2.3.3. Agriculture, forestry, other land use

Table 2-4 summarizes GHG emissions associated with agriculture, forestry, and other land use in 2000. Agricultural practices are the smallest source of anthropogenic GHG emissions in Oman, accounting for only 799 Gg of CO_2e, or about 3.7% of total national CO_2e emissions in 2000. Most of the emissions from AFOLU activities are associated with methane production from livestock.

Table 2-4: GHG emissions and sinks from agriculture, forestry and other land use in Oman, 2000 (Gg)

GHG source category	GHG Source	CO_2e	CO_2	CH_4	N_2O
Livestock	Enteric fermentation	745	0.0	26.6	0.0
Aggregate sources and non-CO_2 emissions sources on land	Cropland	0	0.0	0.0	0.0
	Urea	28	27.9	0.0	0.0
	Direct N_2O Emissions from managed soils	26	0.0	0.0	0.1
Total National Emissions		**799**	**27.9**	**26.6**	**0.1**

Figure 2-5 illustrates the breakdown in AFOLU-related total CO_2e emissions in 2000 and 2015 by activity. Total CO_2e emissions over this period increased to 1,466 Gg, or roughly 4.1% per year. While enteric fermentation associated with livestock dominates emissions throughout the period, its share of AFOLU emissions decreased from 93% in 2000 to 83% in 2015. On the other hand, the share of aggregate sources and non-CO_2 emissions on land (i.e., urea and direct N_2O Emissions from managed soils) increased nearly 5 times over the period.

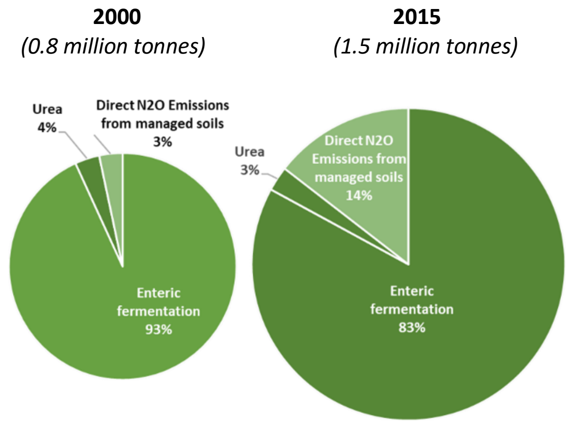


Figure 2-5: Breakdown of total CO_2e emissions associated with AFOLU activities, 2000 and 2015

2.3.4. Waste

Table 2-5 summarizes GHG emissions associated with waste management activity in 2000. Relative to overall anthropogenic GHG emissions, the 806 Gg of CO_2e represented about 3.7% of total national emissions. Waste-related GHG emissions are associated with solid waste disposal, as well as wastewater treatment and discharge from domestic and industrial sources.

Table 2-5: GHG emissions from waste in Oman, 2000 (Gg)

GHG source category	GHG Source	CO_2e	CO_2	CH_4	N_2O
Solid waste (Managed Waste Disposal Sites)	Managed Waste Disposal Sites	476.0	0.0	17.0	0.0
	Unmanaged Waste Disposal Sites	0	0.0	0.0	0.0
	Uncategorised Waste Disposal Sites	0	0.0	0.0	0.0
Wastewater Treatment and Discharge	Domestic Wastewater	327.7	0.0	9.9	0.2
	Industrial Wastewater	1.96	0.0	0.1	0.0
Total National Emissions		**806**	**0.0**	**26.9**	**0.2**

Figure 2-6 illustrates the breakdown in waste-related total CO_2e emissions in 2000 and 2015 by activity. Total CO_2e emissions over this period increased to 3,938 Gg, or roughly 11.2% per year. While the share of emissions associated with industrial wastewater treatment remained the same (i.e., 0.2% of waste-related emissions), other sources show significant differences over the 2000-2015 period. Solid waste emissions increased from 59% to 86%; domestic wastewater treatment shares decreased from 41% to 14%.

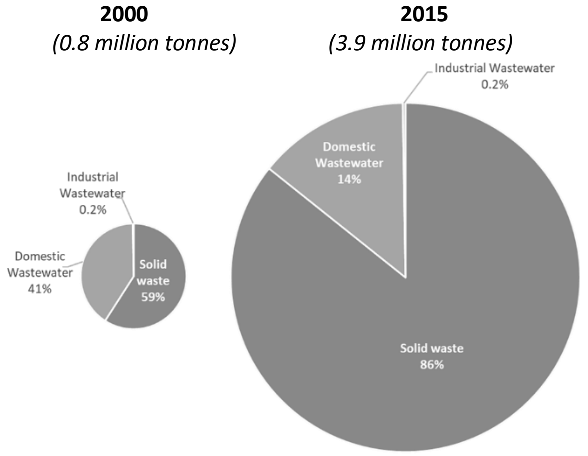


Figure 2-6: Breakdown of total CO_2e emissions associated with waste management activities, 2000 and 2015

2.4. Quality assessment and quality control

The 2006 IPCC Guidelines on National Greenhouse Gas Inventories have been used for reporting GHG inventory for the SNC of Oman to the UNFCCC. The methodology used has encompassed only TIER 1, as Tier 2 and Tier 3 methodologies could not be used due to technical and capacity constraints. A Quality Assurance (QA), Quality Control (QC) and verification procedure was developed according to the 2006 IPCC Guidelines. The national expert team from Sultan Qaboos University and MECA collaborated in the development of the GHG inventory using a QC checklist consistent with Table 6.1 and Annex 6A.1 of 2006 IPCC guidelines. Data cross-checking and verification for accuracy, consistency, completeness, and integrity of the database after data entry in 2006 IPCC software were carried out by UNEP-ROWA experts.

2.4.1. Uncertainty assessment

An uncertainty assessment was carried out to help prioritize future efforts to improve the accuracy of the GHG inventory and guide subsequent decisions on methodological choices. A Tier 1 uncertainly analysis across the sectors was carried out in line with IPCC Good Practice Guidelines (IPCC, 2000; IPCC, 2003). IPCC default conversion factors were used for all sectors.

Activity data were obtained mainly from nationally published sources, such as the Statistical Yearbook, published by the National Center for Statistics and Information. This publication, provides a an integrated statistical tables to the following: climate, population, housing, public sector, private sector, agriculture and livestock, fisheries, oil and gas, electricity, water, internal industry and commerce, foreign trade, transport, communications, public national accounts, finance, financial institutions, price indices, health care, education, social services, security and safety, media and tourism. In addition, sectoral specific activity data were collected from relevant public entities as follows:

- *Energy:* There is a low level of uncertainty regarding energy-related activity data. Fuel combustion for energy industries, manufacturing & construction, and other combustion activities are well-documented and reliable. Activity data were mainly collected from published sources (e.g., annual reports of the Authority for Electricity Regulation which details electricity generation and consumption). Fugitive emissions from fuels activity data were based on a nonpublished technical report from the Ministry of Oil and Gas. Hence, the level of confidence in emission results for these categories is high. For the transport sector, however, available data is only available for fuel quantities, by category, sold at retail pump stations for road transportation. Therefore, several assumptions were developed related to the ratio between international and domestic aviation, the share between road transport categories and the ratio between international water-born navigation and domestic water-born navigation. Asa result, the level of confidence for the transport subsector is low; going forward, the transport sector will require evaluation and revision to address current high uncertainty levels.
- *Industrial Processes and Product use:* There is a high level of uncertainty regarding IPPU-related activity data. These data were collected mainly from the annual reports of the manufacturing companies and disaggregated according to IPCC subcategories. The level of confidence for this data is too low since it is not verified and published by official sources. For example, there is no information about the ratio of the imported clinker in the annual production of the Cement. The annual report of the Ministry of Commerce and Industry provides detailed data about the industry sector in terms of monetary values, not as a produced amount as required for the inventory. It will be important to account for industrial production in terms of produced quantities in the annual report of the Ministry of Commerce and Industry to reduce current high levels of uncertainty.
- *Agriculture, forestry and other land use*: There is a high level of uncertainty regarding AFOLU-related activity data. While nitrous oxide from soils represents a significant share of emissions from agricultural activities (i.e., roughly 14% of AFOLU emissions in 2015), there currently exists high uncertainty regarding the type and the quantities of nitrogen inputs to the soils. In addition, some assumptions used in the current inventory (I.e., ratio between dairy and nondairy cattle), will require further examination and potential revisions to reduce current high uncertainty levels.
- *Waste:* There is a high level of uncertainty regarding waste-related activity data. There is limited data on waste composition, and the population/GDP activity data were used to estimate the amount of waste deposited to Solid Waste Disposal Services (SWDS). This approach encompasses high uncertainties, due to the ratio assumption for municipal solid waste and industrial waste disposed on unmanaged shallow, unmanaged deep, managed anaerobic, managed semi aerobic and uncategorized SWDS. In addition, domestic

wastewater treatment and discharge were assumed throughout the country. These assumptions will require future vetting and potential revisions to reduce current high uncertainty levels.

2.4.2. Key category analysis

Given Oman's hydrocarbon-based economy, the major source of GHG emissions is from energy sector, particularly associated with fugitive emission from oil and gas operations, as well as energy industries. The cumulative contribution from these two sectors is 70.2% of CO_2e in the year 2000. Other key category emissions contributing to threshold level of 95% are detailed in Table 2-6.

Table 2-6: Key Source Analysis of Greenhouse Gas Emissions for 2000

Sector	GHG Category/Source	GHG type	Emissions (Gg) Per type	Emissions (Gg) CO2e	Level assessment (%) Per category	Level assessment (%) Cumulative
Energy	Fugitive emissions (oil & gas)	CH_4	234	6,565	30.3%	30.3%
Energy	Energy industries	CO_2	5,779	5,779	26.7%	57.0%
Energy	Fugitive emissions (oil & gas)	CO_2	2,870	2,870	13.2%	70.2%
IPPU	Mineral Industry-Lime production	CO_2	2,223	2,223	10.3%	80.5%
Energy	Transport	CO_2	1,732	1,732	8.0%	88.5%
AFOLU	Livestock -Enteric fermentation	CH_4	27	745	3.4%	91.9%
IPPU	Mineral Industry-Cement	CO_2	519	519	2.4%	94.3%
Waste	Solid waste- Managed Waste Disposal	CH_4	17	476	2.2%	96.5%
Subtotal - key categories				20,909	97%	
Total national emissions				21,666	100%	

2.5. Challenges and recommendations

The primary challenges in developing the GHG emission inventories for the years 2000 and 2015 are related to data scarcity and poor data quality for most of the subsectors. To address this challenge for future inventories much more must be done by MECA regarding the building of sound measurement, reporting and verification (MRV) system to ensure collection of data for all parts of the inventory, many of which are currently absent from statistical yearbooks, annual reports, or governmental websites. Developing a tailored MRV system is an essential primary step towards the development of a complete and transparent GHG inventory of Oman.

Prioritizing MRV will not only help to adequately document the current emission situation but also help policymakers to clarify their options and priorities for reducing GHG emissions. Given that MRV systems are an essential element of the Enhanced Transparency Framework under the Paris Agreement, there is a clear need for Oman to develop a strategy to build national capacities in MRV to ensure the sustainability of reporting processes. Engagement of key stakeholders from relevant institutions and the development of a communication strategy within and between ministries are also crucial for Oman to move forward to an accurate accounting of its annual GHG emissions.

2.6. List of References

- Charabi, Y., Al-Rawas, G., and Al-Wardy, M., 2019. "Inventory of Greenhouses Gas Emission in the Sultanate of Oman for the reference year 2000", Sultan Qaboos University.

- IPCC, 2000. Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories.
- IPCC, 2006. Guidelines for National Greenhouse Gas Inventories.

3. VULNERABILITY AND ADAPTATION

Oman's vulnerability to climate and its strategic options for adaptation focuses on five key sectors, water resources; marine biodiversity and fisheries; agriculture, urban areas, tourism & infrastructure; and public health. After a review of regional climate change projections, this chapter provides a review of the magnitude of vulnerability in these sectors together with a set of strategic adaptation actions.

3.1. Regional climate modeling

3.1.1. Recent climatic trends

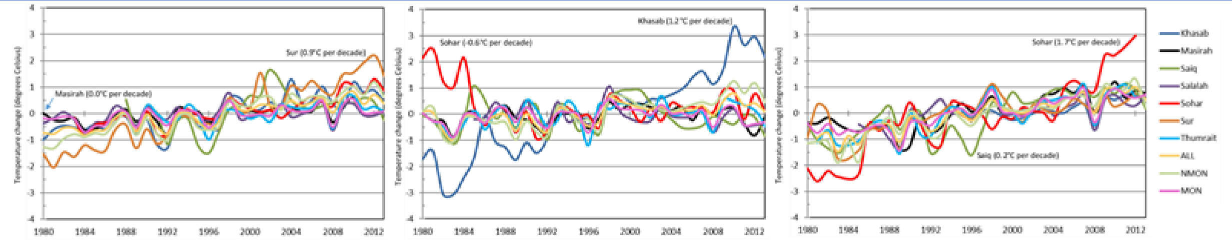
Oman's climate has clearly changed during the past three decades (Charabi, et al., 2015). This is consistent with recent studies for the Arabian Peninsula and vicinity (Almazroui et al., 2012; Athar, 2012; Al Sarmi and Washington, 2013; Donat et al., 2013; Hartmann et al., 2013; Zarenistanak et al., 2014).

Over the period 1980 - 2013, meteorological stations throughout Oman showed evidence of a clear warming trend, with the highest trends around Khasab, Sohar, Saiq, Seeb and Sur and northwards; and the weakest warming trends along the southeastern coast. On average, annual temperatures have increased in Oman by around 0.4°C per decade (see Figure 3-1a). This increase shows a large variation across the country, ranging from 0.0°C per decade around Masirah to about 0.9°C per decade around the Sur region.

There is also clear evidence that extreme temperatures in Oman – both maximums and minimums - have been increasing over the past decades. Figure 3-1b shows the change in mean maximum temperature range from -0.6°C per decade around Sohar to about 1.2°C per decade around Khasab. Figure 3-1c shows the change in minimum annual temperatures ranges from 0.2°C per decade around Saiq to about 1.7°C per decade around Sur.

On average, mean minimum temperatures have increased by around 0.5°C per decade across all areas of Oman. Other notable trends include the increase of nighttime temperature extremes which have been evident across the country, while the increases of daytime temperature extremes more evident in the north.

Rainfall patterns over the past three decades has also been changing. However, unlike temperature, trends are far less robust. There is a high change in rainfall from year to year, with Saiq showing high fluctuations during the 1980s and 1990s. Overall, rainfall has been decreasing during the 1980-2013 period.



a) Average annual temperature b) Maximum temperature c) Minimum temperature

Figure 3-1: Temperature trends in Oman (Charabi et al, 2015)

3.1.2. Future climatic projections

Representative Concentration Pathways, or RCPs, are GHG concentration pathways used by the IPCC as a basis by which to explore future climatic projections. RCPs are GHG concentration - as opposed to emission - trajectories the IPCC used in its 5th Assessment Report and supersede the previous GHG storylines (e.g., A1, B1). RCP8.5 can be considered analogous to a business-as-usual scenario. RCP2.6 assumes stabilization of GHG emission concentration in the atmosphere by 2100.

Four RCPs were considered to explore future climate in Oman: RCP8.5, RCP6, RCP4.5, and RCP2.6. Figure 3-2 shows global GHG concentrations for each of the RCPs, and identifies the two periods – 2041-2060 and 2061-2080 that were considered to assess Oman's future climate under each RCP. The period 1950-2000 was assumed to be the historical climatic period.

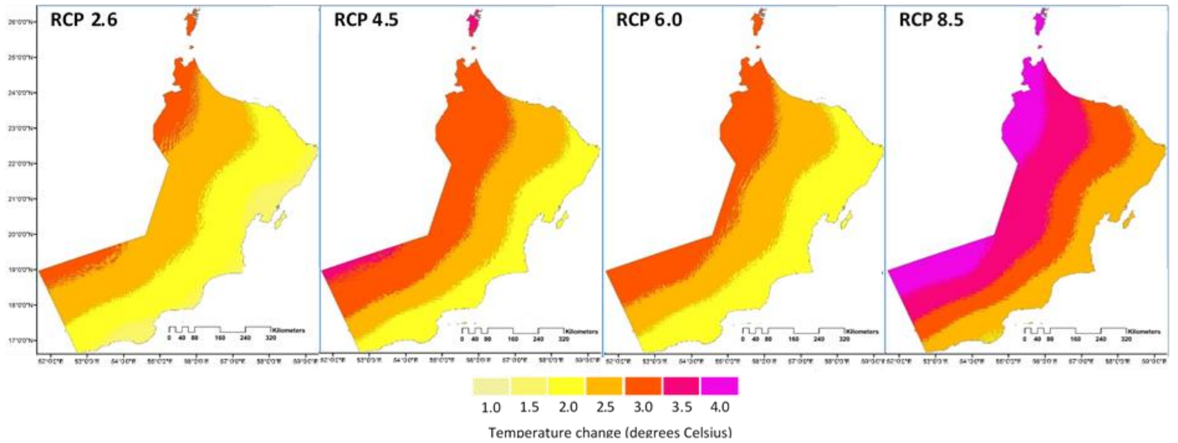


Figure 3-2: Maximum temperature change by 2041-2060 relative to historical period, for all RCPs (Charabi et al, 2015)

At the methodological level, Oman's future climate was projected by statistical downscaling and interpolating the coarse resolution HadGEM2 general circulation model to a finer resolution. Bias correction techniques were applied to ensure that the model closely matched historical climatic conditions in Oman. Further details of the methodological approach are available in Charabi, et al (2015).

Figure 3-3 illustrates the change in maximum annual temperature by the middle of the 21st century relative to the historical period for each of the RCPs. As can be seen in these maps, Oman's future climate will be considerably different that its historical climate. By the middle of the 21st Century, maximum annual temperatures will have increased substantially regardless of RCP.

In the best case (RCP 2.6), maximum temperatures are expected to rise by at least 2°C along southern coastal areas. In the worst case (RCP 8.5), maximum temperatures are expected to reach 4°C above historical levels in the interior and north, including Musandam.

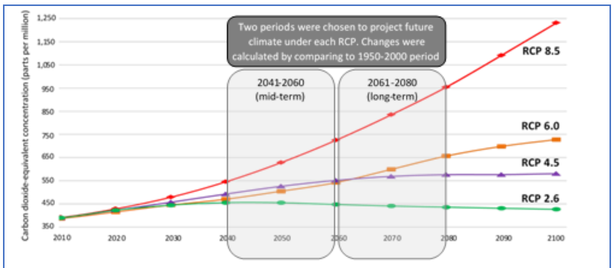


Figure 3-3: Assessment framework to project Oman's future climate (Charabi et al, 2015)

The least change in projected maximum temperature across all scenarios corresponds to the east and southeastern coast. The maps also show that maximum temperature increases from the coastal (i.e., eastern) areas to the inland (i.e., western) areas over the country across all RCPs.

Figure 3-4 illustrates the change in maximum annual temperature between the middle and end of the 21st century for each of the RCPs. By the late-21st Century, maximum annual temperatures will have continued to change substantially. In the worst case (RCP 8.5), maximum temperatures are expected to further increase by 1.0°C over mid-21st Century levels and reaching 5.0°C above historical levels. These increases are projected for all inland areas of Oman, as well as some of its coastal areas in the northern parts of the Sea of Oman and western parts of the Arabian Sea.

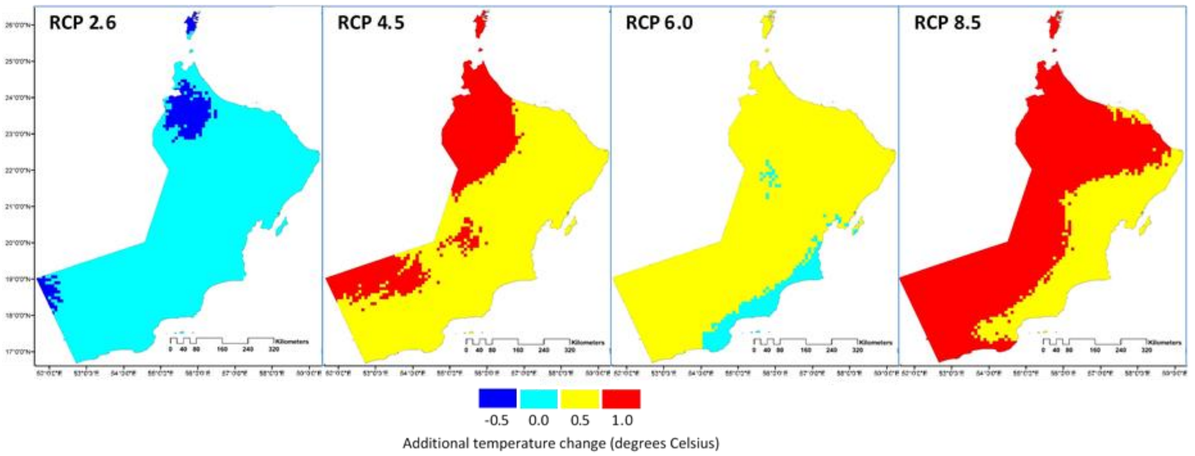


Figure 3-4: Maximum temperature change by 2061-2080 relative to the 2041-2060 period, for all RCPs (Charabi et al, 2015)

Notably, in the best case (RCP 2.6), maximum temperatures are not expected to increase further by the late 21st century in most areas of the country. In fact, some areas in the Al Hajar mountains in the far north and near Ramlat Amilhayt in the west are projected to experience temperature decreases by up to 0.5°C.

Figure 3-5 illustrates the change in minimum annual temperature by the middle of the 21st century relative to the historical period for each of the RCPs. By mid-21st Century, minimum

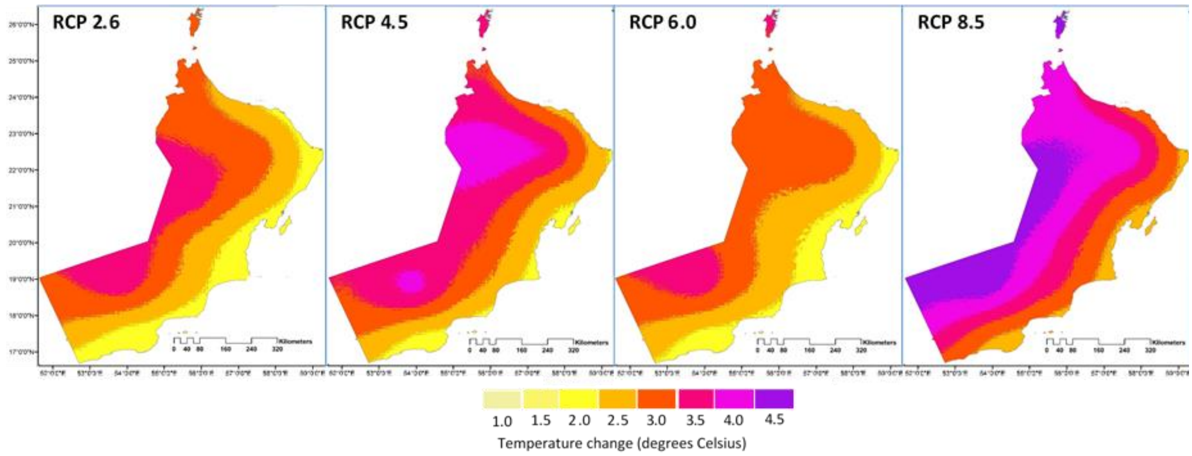


Figure 3-5: Minimum temperature change by 2041-2060 relative to historical period, for all RCPs (Charabi et al, 2015)

annual temperatures will have increased substantially regardless of RCP. In the best case (RCP 2.6), minimum temperatures are expected to rise by at least 2°C along all southern coastal areas along the Arabian Sea, as well as the southern limits of the Sea of Oman. In the worst case (RCP 8.5), maximum temperatures are expected to reach 4.5°C above historical levels in the interior and far north in Musandam. It is important to note that all coastal areas in Oman are projected to experience an increase in minimum temperatures of at least 2.5°C.

Figure 3-6 illustrates the change in minimum annual temperature between the middle and end of the 21st century for each of the RCPs. By the late-21st Century, minimum annual temperatures are projected to change substantially. In the worst case (RCP 8.5), minimum temperatures are projected to increase by 1.5°C above mid-21st Century levels - or a total of 5.5°C above historical levels - in the far northern areas of the Al Hajar mountains. Most of the rest of Oman will experience an additional increase in minimum temperatures between 0.5°C and 1.0°C above mid-21st Century levels.

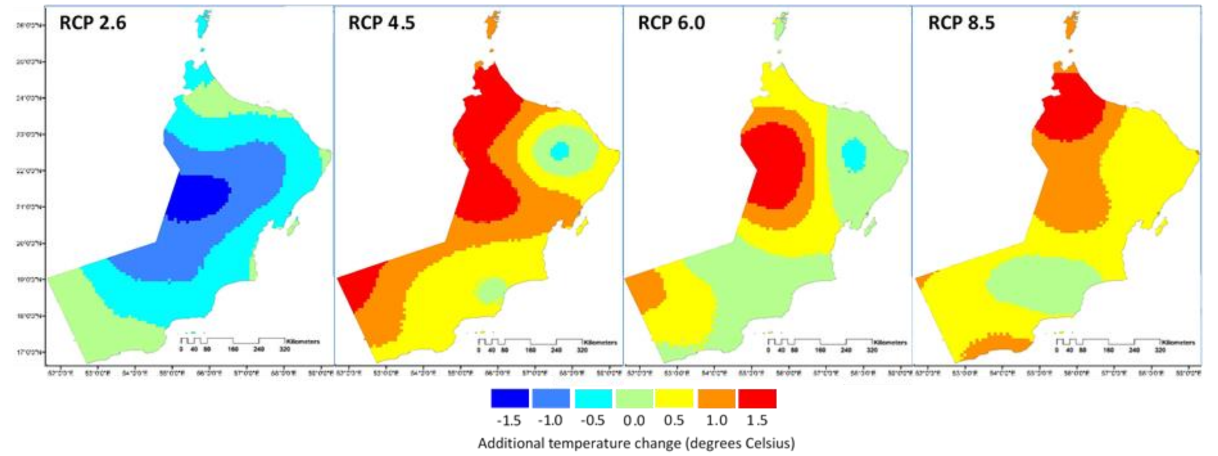


Figure 3-6: Minimum temperature change by 2061-2080 relative to the 2041-2060 period, for all RCPs (Charabi et al, 2015)

In the best case (RCP 2.6), minimum temperatures are expected to decrease from the middle to the late portions of the 21st century for most areas of the country. In fact, some areas in the interior part of the country are projected to experience decreases in minimum temperature by up to 1.5°C.

Unlike projected temperature changes, the change in annual average rainfall shows mixed results under climate change. Figure 3-7 illustrates the change in average annual rainfall by the middle of the 21st century relative to the historical period for each of the RCPs. In the best case (RCP 2.6), the change in average annual rainfall is expected to be between zero and 10 mm/year *more* in most areas. In the worst case (RCP 8.5), average annual rainfall decreases by up to 10 mm/year in most areas, with only the areas in the vicinity of the southwestern and eastern coastlines showing a change in the range from zero to an additional 10 mm/year.

Figure 3-8 illustrates the change in average annual rainfall between the middle and end of the 21st century for each of the RCPs. By the late-21st Century, average annual rainfall will have changed substantially across Oman. In the best case (RCP 2.6), average annual rainfall is expected to further decrease by up to an additional 10 mm/year in interior areas south of the Al Hajar mountains.

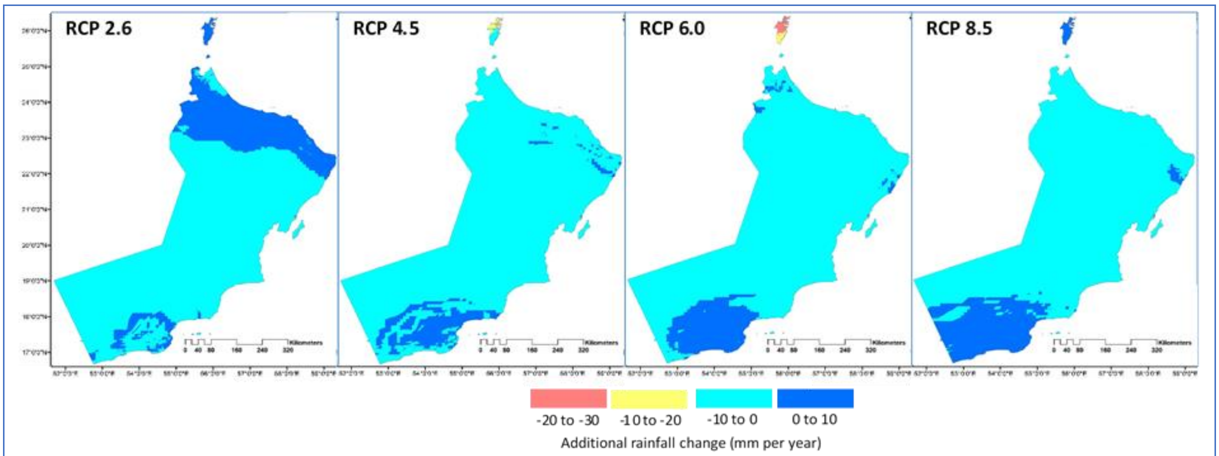


Figure 3-7: Average annual rainfall change by 2061-2080 relative to the 2041-2060 period, for all RCPs (Charabi et al, 2015)

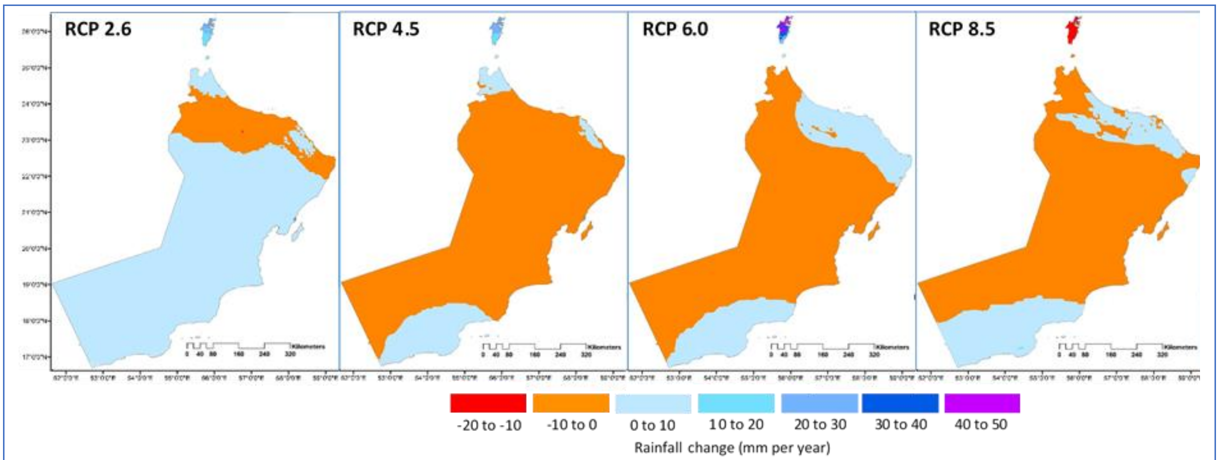


Figure 3-8: Average annual rainfall change by 2041-2060 relative to historical period, for all RCPs (Charabi et al, 2015)

Only in the Al Hajar mountains does average annual rainfall either remain the same as mid-21st-century levels or slightly increase. In the worst case (RCP 8.5), average annual rainfall decreases in most areas by up to an additional 10 mm/year below mid-21st Century levels. Only in portions of the Dhofar Governorate does average annual rainfall either remain the same as mid-21st-century levels or slightly increase.

3.1.3. Strategic actions

Effective adaptive responses in Oman will need to rely on a sound knowledge of anticipated changes. Therefore, a high priority for research must be the generation of reliable projections of likely climatic changes spatially (i.e., at the regional level) and temporally (i.e., accounting for seasonal differences). The results point to several promising areas of future research building off the datasets generated by the study, as follows:

- Build awareness and improve access to information by a) ensuring effective communication of climate change information as well as industry-specific and region-specific information; b) developing awareness-raising program on climate change; and c) providing easy access to complete information on climate change risks, hazards, guidance to adaptation for private sector, and the public at large.

- Strengthen climate data development and monitoring by a) maintaining effective climate data collection, distribution and analysis systems to link into ongoing evaluation and adaptation; b) developing climate projections that can be downscaled to be relevant to farm, catchment and coastal scales; and c) accessing bilateral/international funding.
- Maintain the research and development base (i.e., people, skills, institutions) to enable ongoing evaluation of climate change impacts and to streamline R&D responses regarding new adaptation responses or climate change scenarios.
- Conduct additional scientific studies regarding a) the costs and benefits of adaptation to climate risks; b) the development of a streamlined database of adaptation options implemented at different spatial and temporal scales; c) interactions across adaptation and mitigation activities; d) critical thresholds beyond which social and/or ecological systems are unable to adapt to climate change; and e) adaptation to extreme events such as droughts, floods, intense storms, and heatwaves.
- Launch a Climate Change Research Center to conduct scientific research, develop and fund capacity building programmes; and identify training and education requirements.

3.2. Water resources

Due to climate change, Oman will likely experience adverse impacts on its precious water resources, both surface water and groundwater. The frequency of destructive flash flooding is already evidenced by an increased frequency of extreme wadi flows while future sea level rise is projected to impose serious adverse impacts on groundwater quality in some of Oman's most important aquifers.

The impacts of climate change on water resources and their management are mainly due to the observed and projected increases in sea level, temperature, and precipitation variability/extremes (Bates et al. 2008; Jiménez Cisneros, 2014). Climate change also poses indirect impacts on groundwater supplies as higher evaporation and transpiration rates will lead to increased water demand for irrigation of crops. A coordinated strategy is needed to cope with climatic impacts, with clear links to development priorities, groundwater extraction protocols, monitoring systems, crop choice, etc.

3.2.1. Extreme rainfall and surface water

Oman is an arid and semi-arid country. Conditions of chronic water stress, catastrophic flooding and prolonged drought prevail, making the country particularly vulnerable to the impacts of extreme climate events.

Recent experience with Cyclone Gonu in 2007 emphasized the destructiveness of extreme weather in Oman. The cyclone caused 50 deaths and about $4.2 billion in damage due to heavy rainfall near the eastern coastline.

Over 2000-2014, meteorological stations in Oman showed evidence of a clear change in the intensity of extreme rainfall events, with the highest positive change in 1-hour events around Adam, Masirah, and Thumrait; and highest positive change in 1-day events around Masirah and Thumrait (Hewawasam and Al-Rawas, 2015).

Figure 3-9 compares the percentage of rainfall that was considered extreme in Oman for two periods, 2000-2008 and 2009-2014. The map on the left compares data for “1-hour” extreme rainfall events for the two periods; the map on the tight compares the data for “1-day” extreme rainfall events.

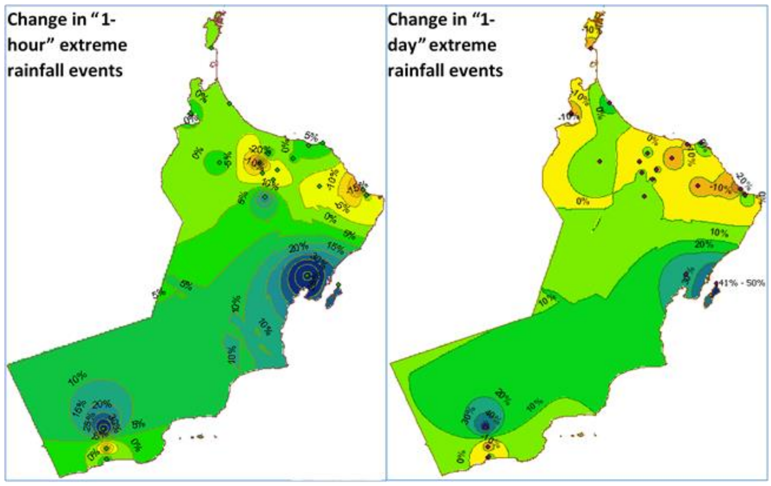


Figure 3-9: Change in extreme rainfall events during 2009-2014, relative to the 2000-2008 period (Hewawasam and Al-Rawas, 2015)

The maps show that the frequency of these potentially destructive events increased in Oman during 2009-2014 compared to the 2000-2008 period. The changes are less than 10% near Rustaq, Bahla, Adam and Ibri, while the Qalhat area shows a significant decline in extreme rainfall events. On the other hand, there is a strong increase in extreme rainfall events in Masirah and Thumrait areas, as evidenced by the dark blue contours in Figure 3-9 for both the 1-hour and 1-day rainfall events.

These findings are central to strategic considerations for coping with surface water. Were these trends to continue into the future under a changing climate, population and infrastructure would be at significant risk from overflowing wadis throughout Oman. That is, extreme weather events will affect the frequency and magnitude of destructive wadi flows which can lead to erosion, flooding, and infrastructure damage. The likelihood of more frequent and intensive wadi flows correlates closely with future patterns of more frequent extreme weather events with climate change.

Estimates of maximum daily wadi flow for different return periods offer insight into the risk of flash flooding. Figure 3-10 shows projected maximum daily wadi flow for the periods 2040-2059 and 2080-2099 for one important river basin in Oman: the Al-Khod water basin near Muscat. By combining the outputs of GCM ensembles from the Coupled Model

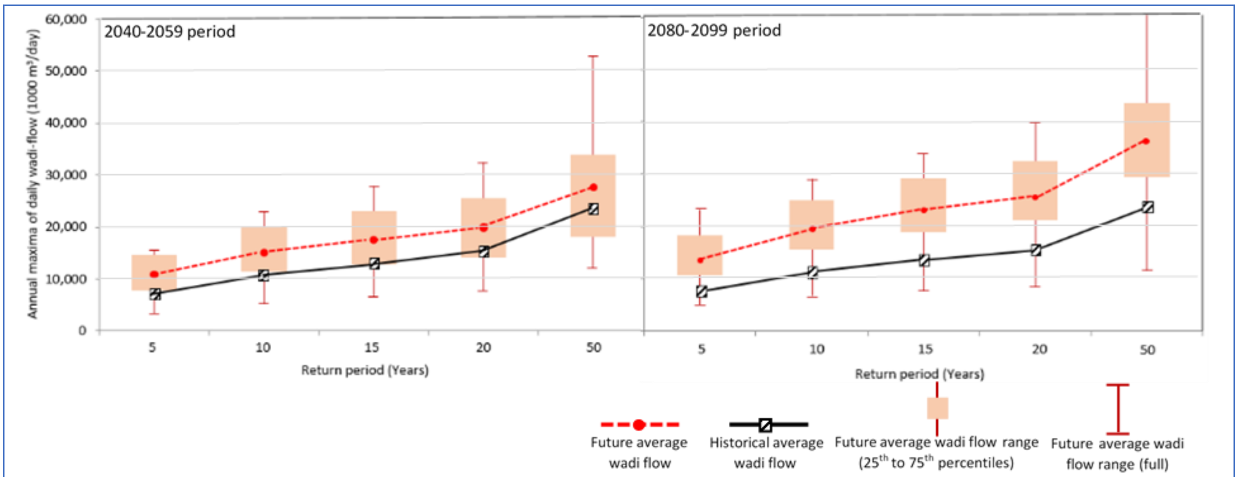


Figure 3-10: Maximum daily wadi flow in Al-Khod waterbasin near Muscat for the periods 2049-2059 and 2080-2099 (Hewawasam and Al-Rawas, 2015)

Intercomparison Project Phase 5 (CMIP5) with local flow data, maximum daily wadi flows across all return periods were estimated.

The "return period", shown as the horizontal axis in Figure 3-10, is simply the years before an extreme maximum wadi flow event returns. A high value of maximum daily wadi flow in the future compared to the past indicates a greater potential for flash flooding during extreme weather events. The charts show that maximum daily wadi flows across all return periods are roughly 1.3 times the historical rate by 2040-2059 and up to 1.6 times the historical rate by 2080-2099.

3.2.2. Groundwater

Climate change-induced sea-level rise is due to dynamic sea-level rise, global thermal ocean expansion, and glacier melting. While much uncertainty underlies the magnitude of the latter two key factors, even current low estimates of sea-level rise suggest serious risks to groundwater in the form of deteriorating water quality (Al Maktoumi et al, 2018).

Figure 3-11 shows the effect of sea level intrusion on the Jamma aquifer in south Al-Batinah area. This region represents about 50% of the total agricultural land in Oman, with groundwater from the intensively developed Jamma aquifer providing the only water supply source for agricultural activities. Using the current (low) IPCC estimates for sea-level rise, three impacts are evident by 2070 across all RCPs, as outlined in the bullets below:

- The 1,500 ppm iso-concentric line is projected to shift inland by nearly 1 kilometer (left time series plot);
- About 8 km^2 of valuable agricultural land will become salinized and unsuitable for cultivation using groundwater from the Jamma aquifer (middle pie chart); and
- Nearly 2 billion cubic meters of groundwater will become unsuitable for irrigating agricultural lands (right bar chart).

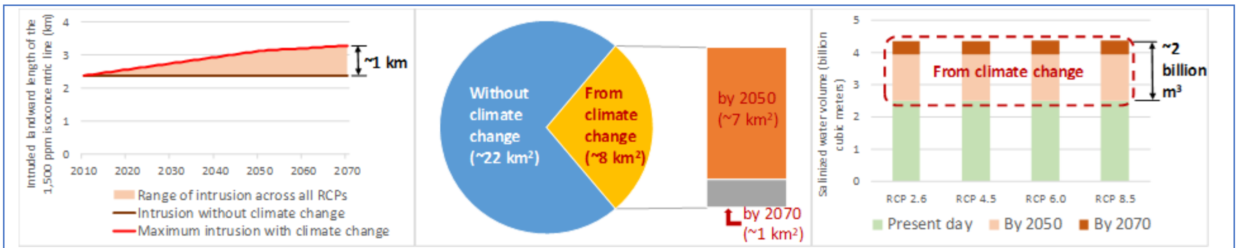


Figure 3-11: Impacts of sea level intrusion in the Jamma aquifer in south Al-Batinah area by 2070. Left: Projected inland shift of 1,500 ppm iso-concentric line over time; Middle: Projected land loss from sea level rise; Right: Projected amount of salinized groundwater from sea level rise (Al Maktoumi et al, 2018)

Figure 3-12 shows the effect of sea level intrusion on the Samail lower catchment aquifer near Muscat. Groundwater from the Samail lower catchment aquifer is used mainly for domestic water supply, with only about 15% of annual withdrawals for irrigation purposes. Unlike the Jamma aquifer, it has not been intensively developed and is currently a healthy aquifer with groundwater flows toward the sea. Using the same IPCC estimates for sea-level rise, only negligible impacts were discovered by 2050 and 2070 across all RCPs, as outlined in the bullets below:

▪ Only about an additional 0.005 million cubic meters of seawater intruding on the aquifer (left plot);

▪ There is only about 0.008 million cubic meters per day of additional evapotranspiration (middle plot); and

▪ Only around 25 centimeters of additional water table height from seawater intrusion (right plot).

Continued protection of the Samail lower catchment aquifer is essential to maintaining its function under rising seas.

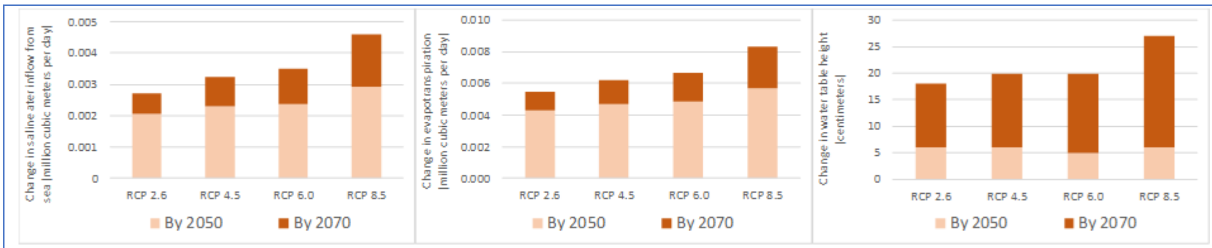


Figure 3-12: Impacts of sea level intrusion in the Samail lower catchment aquifer near Muscat by 2050 and 2070. Left: Projected quantity of seawater intrusion; Middle: Projected increase in evapotranspiration; Right: Projected increase in groundwater table (Al Maktoumi et al, 2018)

3.2.3. Strategic actions

Water resources throughout Oman are vulnerable to climate change impacts due associated with an increased frequency and magnitude of extreme rainfall events, as well as seawater intrusion into aquifers due to sea level rise. Effective adaptation should first involve the development and implementation of an integrated water resource management system that accounts for the interdependency of water and other sectors of the economy. Within this planning framework, some key adaptation measures include:

▪ Improve knowledge for managing vulnerable groundwater resources by:
  a) conducting similar vulnerability studies for other regions for different climatic conditions;
  b) improving data quality management; and commissioning a study on the economic benefits of the implementation of the adaptation responses.

▪ Improve management of treated sewage water through:
  a) injecting treated wastewater into coastal aquifers on a pilot basis;
  b) establishing water quality standards for coastal aquifers into which treated sewage water has been injected; and
  c) designing and implementing a groundwater quality monitoring program.

▪ Improve management of surface water through:
  a) expanding gauge station infrastructure for wadi flow monitoring;
  b) updating flood hazard maps;
  c) assessing flash flooding risks under climate change;

d) updating zoning plans to account for additional flash flooding risks under climate change;

e) install storm drainage infrastructure in projected flash flood zones; and

f) introducing measures to reduce erosion potential under flash flooding events.

- Strengthen capacity to manage water resource management risks by:

a) improving ministry-level technical capacity for conducting climate change impact studies using state- of-the-art methods and tools;

b) implementing knowledge exchange programmes with other countries on effective adaptation responses;

c) developing a prioritized list of adaptation ideas in water resource management;

d) accessing adaptation funding from the Green Climate Fund (GCF) and other funding sources; and e) implementing a flood warning system (including early warning) and emergency planning (including evacuation).

- Improve governance on adaptation policy through:

a) integrating climate change vulnerability into Ministry policymaking and planning;

b) enhancing inter-ministerial collaboration/coordination on flood risk management;

c) introducing measures to encourage development outside high flood risk zones and measures to discourage development inside high flood risk zones; and

d) encouraging new development (enforce existing zoning protocols) in higher elevations (e.g., along foothills instead of adjacent to wadis).

3.3. Marine biodiversity & fisheries

Marine ecosystems house a large proportion of earth's biodiversity, and provide a wide range of ecosystem goods and services to humans. One of the most important services that humans obtain from the ocean, besides the production of oxygen and absorption of carbon dioxide, is through fisheries. Gross revenues from FAO marine capture fisheries worldwide are currently estimated up to $85 billion annually (2011; Sumaila et al. 2007; World Bank 2008).

Climate change is projected to lead to changes in the physical and chemical properties of the western Arabian Sea. Such changes may pose important threats to the future sustainability of the annual catch of sardines and yellowfin tuna, two species that are central to the commercial fishing industry of Oman.

3.3.1. Recent changes in the Arabian Sea

The Western Arabian Sea encompasses an area of about 900,000 square kilometers and is home to diverse ecosystems and biota. Oceanographically, it is a highly complex region influenced by strong monsoon winds, climatically-driven ocean current patterns, the Indian Ocean Dipole and the El Niño Oscillation (Piontkovski, 2015c). The Arabian Sea is also characterized by its high primary productivity which is driven by summer monsoon-driven upwelling along the Somali and Oman coastal areas, with a peak in the summer Monsoon.

These characteristics lead to productive fisheries, a large concentration of mesopelagic fish, high marine biodiversity, and an extended oxygen-rich minimum zone. However, over the past several decades, data from local and international sources showed evidence of clear changes in the physical and chemical properties of the Western Arabian Sea, suggesting ecological consequences to Oman's marine biodiversity and commercial fisheries.

Based on the results of an analysis of data maintained by the National Center for Atmospheric Research in the US, it is clear that the waters of the Western Arabian Sea have been changing over the past 50 years or so (Piontkovski, 2015). Figure 3-13 shows that the physical properties of the Western Arabian Sea have become both warmer and more saline, as detailed in the bullets below:

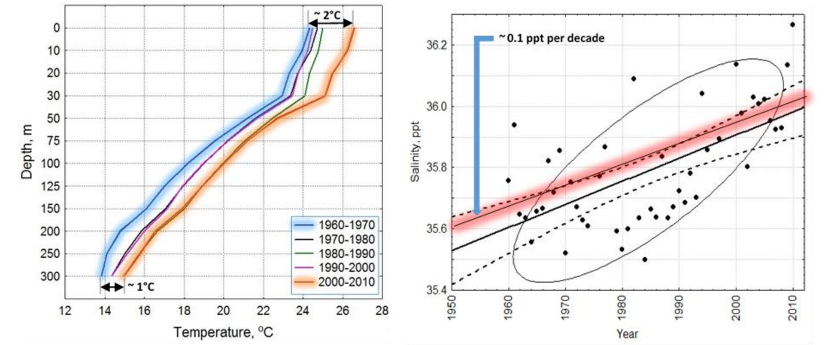


Figure 3-13: Change in temperature and salinity in the Western Arabian Sea (Piontkovski, 2015a)

- Average sea temperatures in the summer have risen since 1960 by over 2°C at the surface and about 1°C at a depth of 300 meters (left plot);
- Average salinity at lower depths has been increasing at a rate of about 0.1 parts per thousand per decade since 1950 (right plot).

In addition to these physical changes, the Western Arabian Sea has experienced significant change in some of its chemical properties over the past 50 years. Acidity, dissolved oxygen, and nitrate concentrations are some of the key chemical properties that underlie the productivity of marine biodiversity and commercial fisheries and have significantly changed over the past decades.

Based on local data derived from local oceanographic stations near Oman, Figure 3-14 illustrates that the chemical properties of the waters of the Western Arabian Sea have changed significantly, as briefly outlined below:

- Waters have become more acidic as evidenced by pH dropping by 0.1 units at the surface and 0.2 units at a depth of 350 meters (top plot);
- The concentration of nitrates has declined by about 30% over the past 30 years, as evidenced by the difference between the blue, for 1960-1970, and red lines, for 1990-2010 (second from top plot).
- There has been a decline in dissolved oxygen concentration, with levels of 1 milligram per liter now at a depth of about 75 meters as opposed to 120 meters in the 1960s (third from top plot); and
- The chlorophyll-a concentration has declined by about 40%, from 1950s to 2010, as evidenced by the red trend line (bottom plot).

The above chemical changes have all contributed to increased fish kill incidents and compressing of habitats of large and small pelagic fishes over Omani shelf. Moreover, the decline in the concentration of nitrates in the upper layer has likely limited primary production (i.e., free-living microscopic organisms called phytoplankton, including mesopelagic micronekton). The parallel changes in temperature and salinity can affect the patterns of marine biodiversity, the structure and dynamics of ecosystems and the productivity of fisheries (Brander 2007; Cheung et al. 2010).

3.3.2. Fish landings: past trends

There are two fish species - yellowfin tuna and sardines - that are of critical importance to commercial fisheries in Oman. Intermediate size yellowfin tuna (*Thunnus albacares*) are abundant in artisanal fisheries in the Arabian Sea where they concentrate for feeding. The Indian oil sardine *(Sardinella longiceps)* is a species of ray-finned fish that contributes approximately 80% of all sardine landings from traditional fisheries in Oman. Collectively, sardine species account for over 50% of total landings (or total fish catches) reported for the western and eastern sides of the Arabian Sea.

A variety of factors account for the magnitude of the annual fish landings. For yellowfin tuna landings, climatic factors such as variations in Siberian high meridional winds, salinity and dissolved oxygen concentrations in the upper layers are ecologically important factors. For sardines, fluctuations of outgoing long-wave radiation, rainfall trends, sea surface temperatures, availability of phytoplankton biomass, and the North Atlantic Oscillation index are key factors (Piontkovski, 2015b).

There is growing evidence that suggest a decline in Oman's yellowfin tuna and sardine annual fish catch. The metric catch per unit effort (CPUE) is an indirect measure of the abundance of a fish species that was used to evaluate catches of sardines and yellowfin tuna in the Western Arabian Sea. Changes

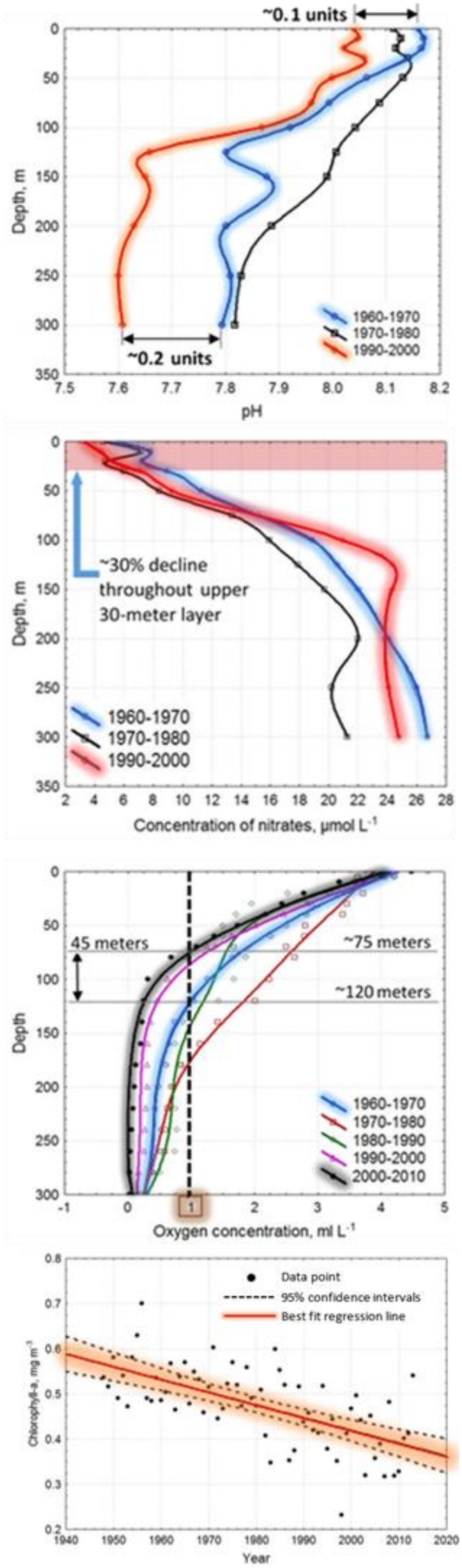


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Figure 3-14: Projected changes in the Western Arabian Sea. Top: Change in pH; Second from top: Change in dissolved oxygen; Third from top: Change in nitrates; and Bottom: Change in chlorophyll-a (Piontkovski, 2015a)

over time for this metric imply that there are changes to these species' true abundance.

For sardines and yellowfin tuna, an analysis of a multi-decade artisanal fish catch data record for the period from 1991 to 2013 for the western Arabian Sea reveals a trend showing a sharp decline in CPUE. Figure 3-15 illustrates the extent to which fish catch has declined in the Eastern Arabian Sea, as briefly outlined in the bullets below.

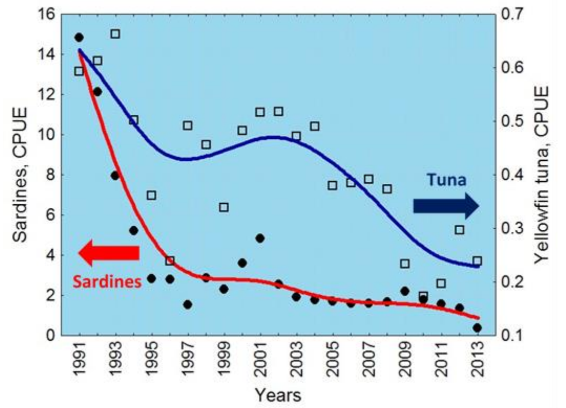


Figure 3-15: Trends in sardine and yellowfin tuna landings in the Western Arabian Sea (Piontkovski, 2015b)

- Annual sardine landings declined sharply at the rate of nearly 2.0 CPUE per year during the 1991-1997 period and declined at a lower rate of about 0.1 CPUE per year during the 1997-2013 period. On average, annual sardine landings have declined about 0.56 CPUE per year;
- Annual yellowfin tuna landings declined sharply at the rate of nearly 0.03 CPUE per year during the 1991-1997 period. Landing rebounded between 1997 and 2003, then continued to decline at the rate of 0.03 CPUE per year from 2003 to 2013.

It is important to note that the above findings are preliminary because they are based on a 22-year record which is a shorter than desired time series record. Typically, a minimum data record of 60 years is considered to be best practice. While the specific role of climate change in these findings remains unclear at this time, there is a strong statistical signal in the decline that warrants strategic action going forward.

3.3.3. Yellowfin tuna productivity: projected trends

There was sufficient data to conduct an analysis of the impacts of climate change on yellowfin tuna. A pragmatic approach was used that involved the use of the outputs of three different earth climate models under RCP8.5 to drive a coupled ocean circulation-biogeochemical model (Piontkovski, 2015c).

The earth climate models used were the Institut Pierre Simon Laplace model (IPSL), the Geophysical Fluid Dynamics Laboratory model (GFDL), and the Norwegian Earth System Model (NorESM). The biogeochemical model used was the Pelagic Interaction Scheme for Carbon and Ecosystem Studies (PISCES). The historical period used for model validation was 1980-2010. Model projections were made for the period 2010-2100 for two regions: Oman's Exclusive Economic Zone (EEZ) and the Arabian Sea (see Figure 3-16, left plot). To isolate the impact of climate change, the projections were carried out assuming no fishing was conducted in these regions.

Projected ocean temperature and primary production under climate change in the Arabian Sea and Oman EEZ show quite similar trends. Across the three earth climate models, there is an increase in temperature for the upper 200 meters of the ocean where there is enough sunlight to allow photosynthesis. The temperature increase is mild between 2010 and 2060, and steeply increases after 2060, ranging between 1.0°C and 2.5°C above historical sea temperatures by 2100.

In addition, there is a decrease in primary production across the three earth climate models. This is due to the increase in water temperature which produces greater stratification of the upper water column which reduces the supply of nutrients from deeper layers and thus the productivity by photosynthesis. Between 2010 and 2100, primary production in the Arabian sea and Oman EEZ is projected to decrease by about 30% compared to historical primary production levels.

Figure 3-16 shows the impact of climate change on adult yellowfin tuna density in the Arabian Sea (middle plot) and Oman EEZ (right plot). Across all three earth climate models, yellowfin tuna stock declines significantly over 2040 to 2100. These projections closely follow the decline in the production of mesopelagic micronekton, suggesting a strong link to this part of the food supply.

Figure 3-16 (middle plot) shows that by the end of the century, the decline in yellowfin tuna stock by 2100 in the Arabian Sea ranges from about 40% under the GFDL model to about 65% under the IPSL model. The results are similar for the Oman EEZ by 2100, ranging from a decline of about 28% under the GFDL model to about 68% under the IPSL model (right plot).

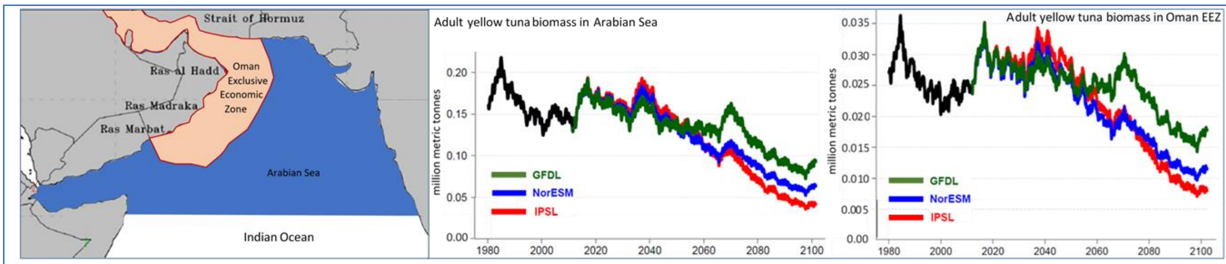


Figure 3-16: Spatial domains for the modeling (left plot), productivity of adult yellow tuna in Arabian Sea (middle plot) and Oman EEZ (right plot) (Piontkovski, 2015c)

It is important to note that the results described above are based on simulations without fishing impacts. Past and future levels of fish catches would likely have a significant impact on these results. It should be noted also that yellowfin catch data are under- or simply not reported by several national fisheries in the region. This could also have a serious impact on the results.

3.3.4. Strategic actions

Marine resources and fisheries in the Arabian Sea and Oman EEZ are vulnerable to climate change impacts due to changes in marine physical properties (i.e., temperature, salinity) and chemical properties, (i.e., pH, dissolved oxygen, nitrates, chlorophyll-a). Effective adaptation should focus on knowledge generation, capacity building, and improved governance and planning. Within this planning framework, some key adaptation measures include:

- Improve knowledge for managing vulnerable marine resources by:
  a) collecting and analyzing data on the impacts of climate variability and trends on marine biology;
  b) assessing climate change impacts on fisheries giving priority to threatened and endangered species;
  c) monitoring climate change effects on coral reefs as a biological indicator;

d) developing robust genetic strains for aquaculture species that perform well in future environments, and examine industry locations and opportunities under future climate scenarios;

e) investigating regional case studies for the impacts of climate change on the biological, social and economic relationships in fisheries and aquaculture; and

f) developing a downscaled climate change prediction impact model on marine ecosystem and fisheries resources.

- Strengthen capacity for assessing vulnerability of marine biodiversity and evaluating adaptation options by establishing and/or engaging with international collaborative networks for transboundary fisheries under climate change.
- Improve governance and planning in Oman through:

a) encouraging diversification of livelihoods and income sources, including activities unrelated to fishing and aquaculture;

b) analyzing the costs and benefits of a range of potential adaptation options by harvesters, processors, and dependent communities seeking to respond to lower fish productivity under climate change.

c) mobilizing funding resources to conduct additional marine biodiversity vulnerability and adaptation studies.

3.4. Agriculture

Oman's agricultural sector depends overwhelmingly on irrigation from high-quality groundwater resources. There is no rain-fed agricultural production in the country and virtually no surface water available for irrigation. Of the critical elements that affect yields in Oman, ensuring timely supplies of good quality irrigation water is among the most critical.

Currently, there are about 72,820 hectares of irrigated land in Oman, roughly 0.2% of the total land area (Zekri, 2015). Major crops consist of date palms and other fruits (45%); perennial forage/fodder crops (29%); vegetables (19%); and field crops (7%). Small farms, less than 1 hectare in size dominate agricultural production at 72% of all farms; less than 0.2% of farms exceed 100 hectares in size. The agricultural sector grew at a rate of 2.3% per year over the 2006-2010 period, with higher growth rates evident in recent years associated more efficient practices, different crops, and the introduction of better technology (Zekri, 2015).

Most groundwater for irrigation is obtained through the traditional *falaj* system, in which a vertical shaft is dug from the surface to reach water in porous rock. From the bottom of this shaft, a gently sloping tunnel is dug to trap the water and allow it to flow to an underground cistern, from which it is withdrawn by bucket or pump.

While the future changes in temperature and precipitation discussed previously are expected to have very small impacts on agricultural productivity in Oman, climate change still poses enormous risks to the future sustainability of Oman's agricultural sector. As agricultural productivity depends entirely on groundwater, rising sea levels will lead to seawater intrusion into aquifers, thereby degrading the quality of water extracted for irrigation. Sea level rise also implies a steady decline in cropland available for cultivation as cultivatable land becomes inundated. Together these impacts will impose substantial economic losses to farmer households.

Figure 3-17: Loss of cultivatable land due to groundwater quality deterioration from sea level rise in Al Batinah (Google maps)

The impact of climate change was evaluated for the Jamma aquifer in the south Al-Batinah governorate (see Figure 3-17). This is one of the most important and most productive agricultural regions in Oman, having vast plantations of date palms; papaya, lime, and mango trees grown along the coast in irrigated farms, which also produce vegetables and some cereal grains. Many of these cultivated areas are deteriorating, due to seawater intrusion caused by excessive pumping from the aquifer. Fodder crops are now beginning to replace deteriorating date palm plantations, being more tolerant to more saline groundwater.

3.4.1. Groundwater quality

Water supply for the nearly 6 square kilometers of cropland currently under cultivation in the south Al-Batinah region relies exclusively on fresh groundwater having salinity less than 1,500 mg per liter. Two RCPs, RCP8.5, and RCP2.6 were considered to explore future impact on the Jamma aquifer due to seawater intrusion associated with sea-level rise.

The MODFLOW groundwater transport and flow model was used to simulate the extent of irrigated area in Al Batinah that would be affected by groundwater deterioration under climate change for two future years, 2050 and 2070. The year 2015 was assumed to be the Base Year for the assessment (Zekri, 2015).

Sea level rise assumptions were integrated into the analysis consistent with the IPCC projections reported in their 5th Assessment report. For RCP2.6, sea-level rise was assumed to be 0.24 meter and 0.40 meters above current levels by 2050 and 2070, respectively. For RCP8.5, sea-level rise was assumed to be 0.30 meter and 0.63 meters above current levels by 2050 and 2070, respectively (Zekri, 2015).

Figure 3-18 shows the impact of seawater intrusion on the Jamma aquifer and the extent of cultivatable land impacted. With sea level rise, the extent of land that is underlain by low-quality groundwater (i.e., salinity greater than10,000 mg/liter and hence unsuitable for groundwater irrigation absent costly desalination equipment), increases from 2 km^2 to 7 km^2 in 2050 and to 8 km^2 in 2070. Moreover, the extent of land that is underlain by high-quality groundwater (i.e., salinity less than or equal to 1,500 mg/liter), and hence suitable for direct groundwater irrigation, decreases from 6 km^2 to 2 km^2 in 2050 and to 1 km^2 in 2070.

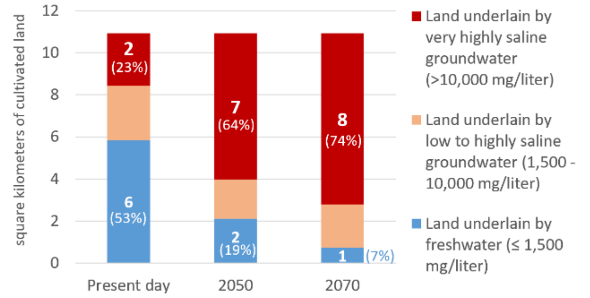


Figure 3-18: Loss of cultivatable land due to groundwater quality deterioration from sea level rise in Al Batinah (Zekri, 2015)

Currently, about 53% of all cultivatable land in the south Al-Batinah region relies on irrigation with high quality groundwater. By 2070, only 7% of currently cultivatable land will be able to be irrigated by groundwater from the Jamma aquifer. Notably, these results are the same for both RCPs, indicating that even a small rise in sea level will severely compromise the agricultural productivity of this fertile region and require serious changes to current agricultural practices.

3.4.2. Crop water requirements

In addition to sea-level rise impacts, changes in evapotranspiration will also likely affect agricultural production throughout Oman under climate change. Evapotranspiration is the process by which water is transferred from the land to the atmosphere by evaporation from the soil and other surfaces and by transpiration from plants.

Under climate change, an increase in temperature in an arid area such as the Arabian Peninsula could lead to an increase in evapotranspiration by 10% to 27% (Chowdhury, et al., 2013), thereby increasing crop water requirements in order to maintain current crop yields.

Figure 3-19 shows the potential impacts on evapotranspiration under climate change for various crops. With significantly higher temperatures forecasted for Oman in the future, evapotranspiration rates could also increase substantially. Based on research conducted on Arabian Peninsula, this could lead to additional water requirements of 6.0%, 5.6%, 6.3%, and 7,2% for dates, vegetables, clover, and field crops, respectively (Zekri, 2015) just to maintain current harvest yields.

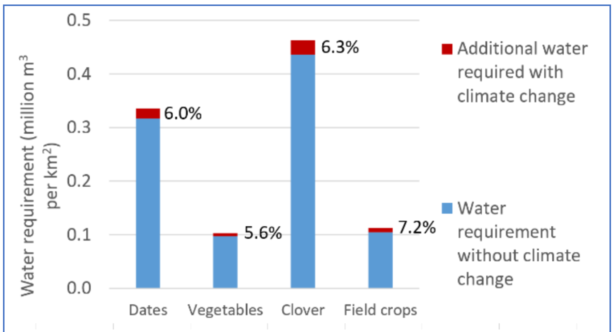


Figure 3-19: Impact of evapotranspiration on crop water requirements in Oman (Zekri, 2015)

Hence, climate change is projected to adversely affect agriculture in Oman through two mutually reinforcing process. On the one hand, sea-level rise will contribute to groundwater quality deterioration through seawater intrusion, resulting in sharply less cultivatable land with access to irrigation using good quality groundwater. On the other hand, increased evapotranspiration rates will contribute to the need for withdrawing more groundwater for the crops on remaining cultivatable lands relying on good quality groundwater.

3.4.3. Farmer incomes

There will be economic impacts associated with groundwater deterioration and higher evapotranspiration rates under climate change. The annual incomes of small farmers in South Al-Batinah will be adversely affected by the reduction in arable land and increased crop water requirements. The losses are beginning now and absent adaptation interventions are projected to steepen with oncoming sea level rise in the Sea of Oman.

The same two RCPs, RCP8.5, and RCP2.6, were considered to explore economic impacts on agricultural production relying on the Jamma aquifer under climate change. A simple damage costing methodology was carried out that monetized lost income associated with the reduction in cultivable land from seawater intrusion. The costs and benefits associated with potential adaptation remedies to improve groundwater quality (e.g., brackish water desalination units) were not considered in the analysis

Figure 3-20 shows the impact on net income from climate change. As cultivable land relying on high-quality groundwater declines - and cultivatable lands that can no longer be irrigated increases – annual net incomes are projected to drop from the current level of $790/ha to $467/ha by 2070 for RCP8.5. Of the $330/ha lost due to climate change, most of it, $250/ha, occurs by 2050. These results are very similar to RCP2.6.

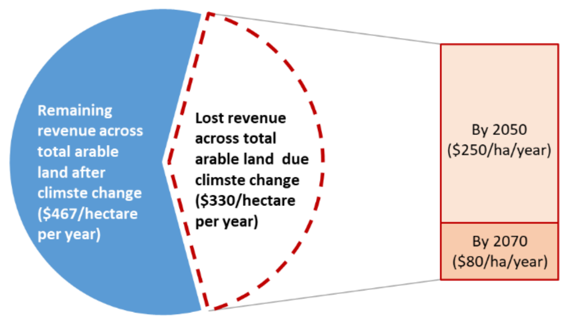


Figure 3-20: Impacts on net income from agriculture in Al-Batinah by 2070 under RCP8.5 (Zekri, 2015)

3.4.4. Strategic actions

Agricultural production along coastal areas in Oman is vulnerable to climate change impacts due to sea-level rise leading to seawater intrusion to freshwater aquifers, as well as increased evapotranspiration rates leading to higher crop water requirements. Effective adaptation should focus on knowledge generation, capacity building, and improved governance and planning. Within this overall framework, some key adaptation measures include:

- Improve knowledge for managing coastal aquifers by:
  a) Developing simulation models of different primary crops & continued economic viability under different climate scenarios;
  b) Strengthening research to develop new crop varieties (saline, water stress and heat/ temperature tolerant crops);
  c) Strengthening, collecting and conserving indigenous plant, crops, and animal genetic resources;
  d) Developing behavior simulation models of pests and diseases under different climate conditions;
  e) Assessing potential emerging problems and develop a risk map for the most persistent and impactful pests and diseases;
  f) Researching sustainable management approaches for agricultural pests, diseases, and invasive species; and
  g) Strengthening research on water management in agriculture under drought and saline conditions.
- Strengthen capacity for assessing the vulnerability of irrigated agricultural production by:
  a) Establishing and/or engaging with international collaborative networks for relevant emerging issues in agriculture; and
  b) Conducting training in agroecological technologies and practices on issues related to climate change.
- Improve governance and planning in Oman through:

a) Developing policies concerning challenging agribusiness issues in the face of climate change.
b) Identifying cost-effective short-, mid- and long-term agricultural adaptive strategies for key crops and livestock.
c) Increasing on-farm resilience to climate vulnerabilities in affected areas.
d) Undertaking analysis and planning for the conservation and development of agricultural lands affected by climate change.
e) Encouraging the adoption of adequate technologies for water use efficiency in agriculture.
f) Encouraging the adoption of integrated adaptation and mitigation measures in agriculture through climate-smart agriculture.

3.5. Urban areas, tourism, & infrastructure

Urban areas are characterized by high concentrations of people, infrastructure, business and industry. Such areas can be vulnerable to extreme climatic events and other disaster-inducing events in the absence of adequate planning and governance (Satterthwaite et al. 2009).

Urban areas can concatenate hazards as a primary hazard leads can lead to secondary and tertiary hazards. For example, an extreme rainfall event can lead to flash flooding, which can, in turn, lead to contamination of water-supply. This domino effect can also adversely affect municipal services such as telecommunication and banking services if electricity transmission is interrupted.

The scale of the devastation to urban populations and economies caused by extreme weather events in recent years highlights their vulnerabilities. Worldwide, there has been a rapid growth in the number of people killed or seriously impacted by storms and floods, accompanied by steadily increasing economic damages (Satterthwaite et al. 2009).

Coastal development has increased dramatically over recent decades in Oman, a trend that seems certain to continue through the 21st century. According to the census of 2010, 80% of the Omani population lives in low-lying areas such as coastal plains which are considered high-risk flood-prone zones (Charabi et al, 2015). Moreover, nearly 60% of the population is concentrated in Muscat and in the Al Batinah coastal plain.

As a result, there are substantial amounts of vulnerable urban infrastructure located in close proximity to flood-prone areas, or subject to coastal inundation and storm surge associated with sea-level rise. In 2007, the Tropical Cyclone of Gonu showing the potential impact of an extreme climatic event on an urban center by its high toll in loss of life, infrastructure destroyed, and economic damage.

With climate change, Oman's low-lying urban areas along the coast will be vulnerable to flooding from the combined impact of sea-level rise and storm surge associated with extreme weather events. In addition, flash flooding magnitude and frequency could increase in the future from heavy rainfall events. Oman's development plans for urban areas and infrastructure should be reevaluated to account for these risks.

3.5.1. Flash flooding risks

Urban expansion in Omani cities has typically not accounted well for even historical risks of flooding, much less the greater flooding risks that will accompany climate change (Charabi et al, 2015). Today, the impact of floods in the built-up area of Sohar Wilayat, Saham, Al-Khaburah, As-Suwayq and Muscat can wreak havoc on transportation and power systems. These risks have increased substantially over the past 50 years.

Figure 3-21 illustrates the links between urban expansion and flash food risk in Muscat. Combining urban cover maps with flood risk maps shows that built up areas are situated in close proximity to recurring flooding episodes (left plot). This pattern has yielded a nearly 10-fold increase in the urban areas at-risk over the period 1960-2010 (right plot). With climate change, these risks are projected to increase still further, especially if current patterns of development in high-risk flood-prone zones continue.

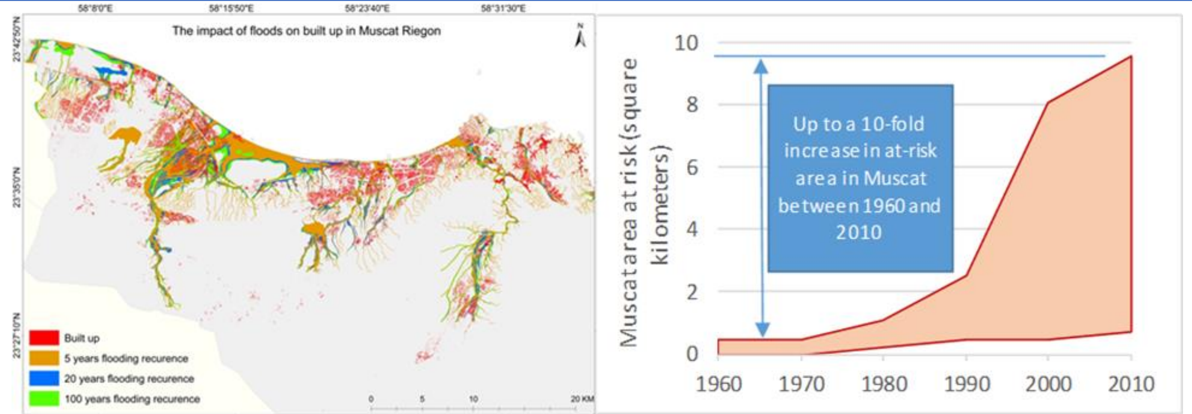


Figure 3-21: Location of built up areas and flood zones in Muscat (left) and increase of flood risk areas in Muscat between 1960 and 2010 (right) (Charabi et al, 2015)

3.5.2. Sea level rise risks

Changes in sea level occur over a broad range of temporal and spatial scales, with many contributing factors making it an integral measure of climate change (Milne et al., 2009; Church et al., 2010). The primary contributors to contemporary sea-level change are the expansion of the ocean as it warms and the transfer of water currently stored on land to the ocean, particularly from land ice (glaciers and ice sheets) (Church et al., 2013).

Global sea levels are projected to continue to rise as the world warms, increasing mean sea level rise at the local level. The IPCC's Fifth Assessment Report projected that the rate of global mean sea-level rise during the 21st century will exceed the historical rate observed during the 1971–2010 period for all RCPs. Between 0.26 and 0.55 meters of sea-level rise are projected for RCP2.6 by 2100, between 0.52and 0.98 meter of sea-level rise are projected under RCP8.5 by 2100. Estimates of regional sea-level rise can differ from global estimates for a number of reasons. Deviations in sea level are caused by the influence of localized processes such as sediment compaction and tectonics.

Oman has an extended coastline extending for about 3,165 km, including a number of bays and islands. Most of this coastline is soft and low-lying shore subject to the dynamics of sediment transport and landward retreat of the shoreline caused by anthropogenic factors such as coastal engineering activities, as well as natural processes such as sea-level rise associated with climate change.

Despite their buffer role and resilience, low-lying sandy coasts and the associated tidal inlets, coastal lagoons and numerous salt flats and coastal sabkhas may not be stable in the long term. They are subject to change in their morphology by coastal geomorphic processes of erosion and accretion caused by sea-level changes that continuously modify the shoreline.

Moreover, sea-level rise can exacerbate existing infrastructure development challenges, including coastal erosion, seawater intrusion into aquifers, and effective storm-water drainage during high tide. Understanding potential hotspots is necessary in order to effectively inform future planning.

The vulnerability of Oman's urban areas to sea-level rise was evaluated through the development of a Coastal Vulnerability Index (CVI). Such an index identifies areas of highest risk from a variety of factors including sea-level rise. Six parameters were used to construct the index for the entire Omani coastal zone, namely geomorphology, coastal slope, rate of relative sea-level rise, rate of shoreline erosion/accretion, mean tide range, and mean significant wave height. (Charabi et al, 2015).

The vulnerability of Oman's urban areas to sea-level rise was further evaluated through the development of estimates of the extent of inundated land that would be associated with a set of sea-level rise scenarios for the year 2100; 0.2, 0,5, 1, 2, 3, 4, and 5 meters added to mean high tide. This involved the development of a Digital Elevation Model (DEM) with a horizontal spatial resolution of 40 meters and a precise database of elevation benchmarks throughout the 3,165 km of Oman's coastline. Sea level scenarios were overlain on land use/elevation datasets to estimate the inundation risk among all land use categories (Charabi et al, 2015).

Figure 3-22 summarizes the results of the assessments. The left side of the plot corresponds to the CVI results and the right side of the plot corresponds to the inundation results. A summary of key findings is provided in the bullets below:

- CVI: Al-Batinah is projected to be the most vulnerable area in Oman, with 98.5% of its area classified as a "very high" risk zone according to the CVI. Musandam is projected to be the least vulnerable, with only 21.1% of its coastal area being "very high" risk zones.
- Inundation: Total inundated land from sea level rise ranges from about 386 km^2 with sea level rise under 0.5 meters to over 900 km^2 under sea level rise of 5 meters that correspond to conditions of large-scale glacier melting.

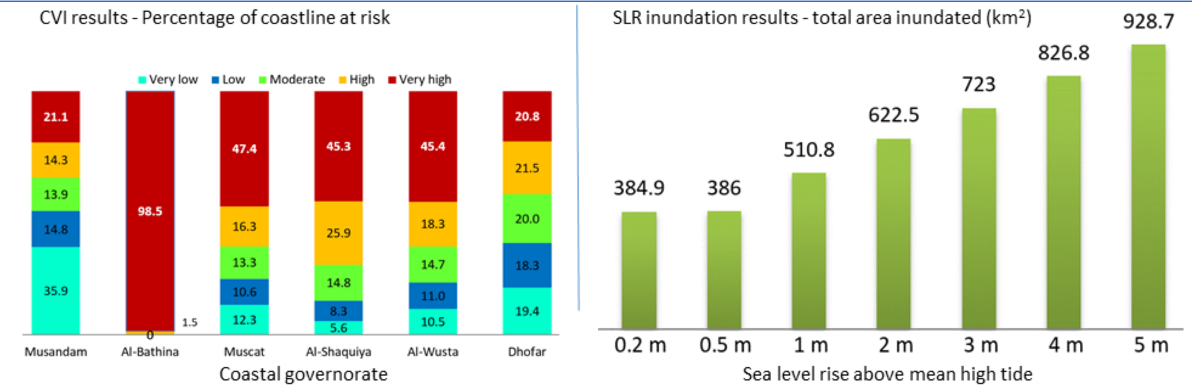


Figure 3-22: Results of the Coastal Vulnerability Index assessment (left) and extent of inundated land under a set of sea level rise scenarios by 2100 (right) (Charabi et al, 2015)

3.5.3. Tropical cyclone risks

Coastal flooding associated with tropical cyclones has become a major concern in low-lying populated areas in Oman. No better warning of the need for preparing for such extreme weather events was Gonu in 2007 which led to 50 deaths in Oman, plus over US$ 4 billion in property damage.

The vulnerability of Oman's infrastructure to tropical cyclones was evaluated through an analysis of the maximum potential storm surge depth associated with historical cyclones (Charabi et al, 2015). The analysis was complex and involved a combination of long-term wave and surge reanalysis for the marine climate together with steps to characterize the potential frequency and intensity of tropical cyclones that have hit the Omani coastline.

The long-term wave and surge reanalysis for the marine climate was based on the existing Global Ocean Wave (GOW) reanalysis database (Reguero et al., 2012), the Climate Forecast System Reanalysis (CFSR) wind and sea level pressure database (Saha et al., 2010). Together, these resources provided information on the regional wave and storm surge at high resolution along the Omani coast.

Developing an understanding of the historical frequency and intensity of tropical cyclones was based on the synthetic generation of hypothetical and plausible tropical cyclones using state-of-the-art trajectory stochastic models (Minguez et al., 2012). It also involved data collection and review of historical tropical cyclone tracks in recent years from events such as Gonu, Phet and Mekunu.

Once the marine climate and tropical cyclone dynamics were characterized, the extent of coastal flooding was simulated using a high-resolution numerical hydrodynamic model to evaluate the storm surge - defined as the rise in seawater level caused solely by a storm - associated with each cyclone event. It is important to note that modeling was conducted assuming historical mean sea levels under the influence of astronomical tides. As future sea level rise scenarios were not integrated into the analysis, the results should be viewed as a lower estimate of potential storm surge associated with tropical cyclones under climate change.

Figure 3-23 shows the results of the assessment. From the over 800 tropical cyclone paths that have entered the Arabian Sea, two were considered as having the potential for maximum impact on infrastructure in Oman (top plot). Two left and right plots characterize storm surge hotspots along the entire Omani coast.

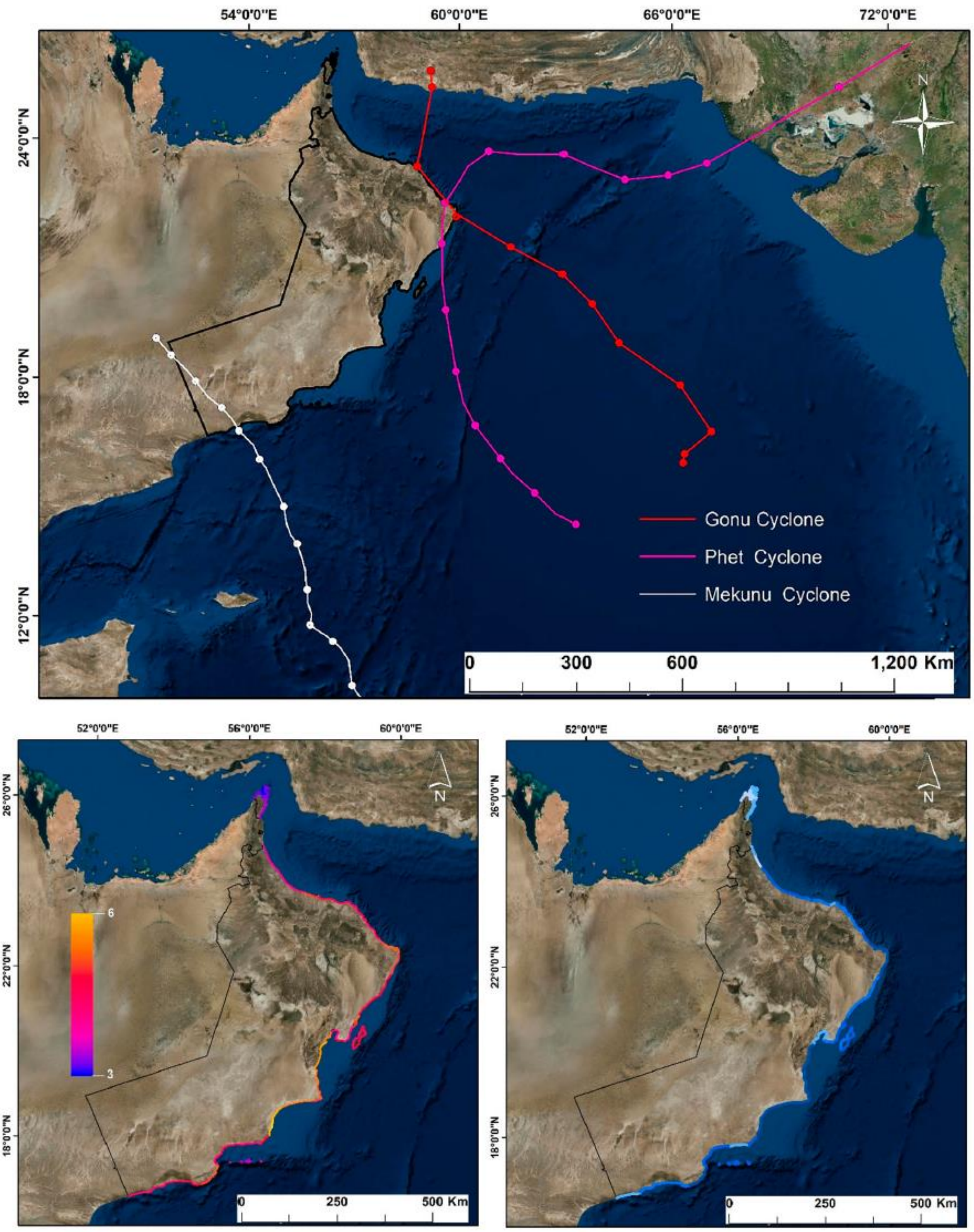


Figure 3-23: Highest-impact cyclone tracks (top), plus minimum (left) and maximum (right) projected storm surge height from an assessment of all potential tropical cyclone tracks (Charabi et al, 2015)

Minimum storm surge from the analysis of all potential cyclone tracks is between 3 and 4 meters high (left plot). Maximum storm surge height reaches nearly 6 meters in parts of the Al

Wusta governorate, with South Al Sharquiya also being highly exposed to storm surges between 4.5 and 5.0 meters (right plot). Any infrastructure located along the coastline where the highest storm surge is projected is clearly at high risk during future cyclonic events.

3.5.4. Strategic actions

Urban areas, tourism facilities and infrastructure along coastal areas in Oman are vulnerable to climate change impacts due to sea level rise and tropical cyclones. Effective adaptation should focus on knowledge generation, capacity building, and improved governance and planning. Within this overall framework, some key adaptation measures include:

- Improve knowledge for managing climate change risks to urban areas, touristic facilities, and infrastructure by:
  a) Ensuring that all hazards maps are updated to reflect designs extreme events under climate change;
  b) Updating coastal zone setback line to incorporate climate change risks to Infrastructure;
  c) Ensuring that existing infrastructure exposed to unacceptable climate change risks are evaluated to address subsequent rehabilitation or other risk-reducing options; and
  d) Conducting climate change impact assessment by tourist region, focusing on the most vulnerable sectors and locations.
- Strengthen capacity for assessing vulnerability of urban areas, touristic facilities, and infrastructure by:
  a) Improving ministry-level technical capacity for conducting climate change impact studies using state- of-the-art methods and tools;
  b) Facilitating exchange of experience and knowledge with other countries on effective adaptation responses; and
  c) Developing a prioritized list of adaptation initiatives in hotspot areas
  d) Accessing adaptation funds available through the Green Climate Fund (GCF) and other funding sources.
- Improve governance and planning in Oman through:
  a) Update regulatory and legislative systems/procedures to ensure that all master plans and subdivision plans (>30 hectares) incorporate climate change risk assessments;
  b) Ensure that all proposed infrastructure projects incorporate climate change risks into project design; and
  c) Develop national building and design codes to promote resiliency of communities to mitigate storm and flood damage.

3.6. Public health

Weather and climate can profoundly affect human health. Climate change threatens to exacerbate today's health problems – deaths from extreme weather events, cardiovascular and respiratory diseases, infectious diseases and malnutrition – whilst undermining Oman's social protection systems.

3.6.1. Sea level rise

About 81,300 people are projected to be affected by flooding due to sea-level rise and extreme weather events between 2070 and 2100, absent the introduction of effective adaption. If there is a major scale-up in the introduction of such measures, the affected population could be reduced to about 100 people between by 2100, as illustrated in Figure 3-24.

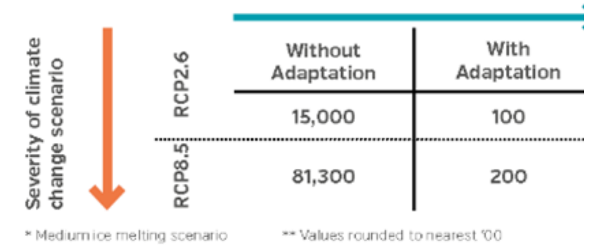


Figure 3-24: Potential public health benefits of adapting to sea level rise (WHO, 2015)

3.6.2. Malaria

By 2050, roughly 200,000 people would be at risk of malaria in Oman, a decline from the baseline value of just over 681,000. Under RCP 8.5 (high global GHG emissions), these gains would be reversed as the Omani population at risk from malaria would double to about 400,000. RCP 2.6 (low global GHG emissions), malaria risks would continue to decline to just over 6,100 by 2070, as illustrated in Figure 3-25.

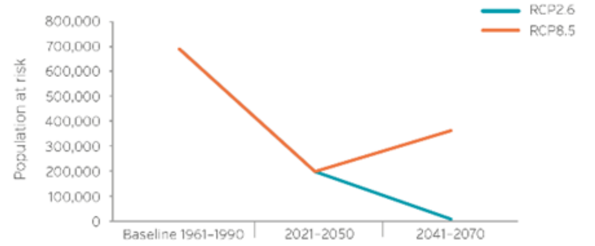


Figure 3-25: Potential public health benefits of adapting to malaria under climate change (WHO, 2015)

3.6.3. Heat stress

Under a high emissions scenario, heat-related deaths in the elderly (65+ years) are projected to increase to about 34 deaths per 100,000 by 2080 compared to the estimated baseline of just over 3 deaths per 100,000 annually between 1961 and 1990, as illustrated in Figure 3-26. A rapid reduction in emissions could limit heat-related deaths in the elderly to about 7 deaths per 100,000 in 2080.

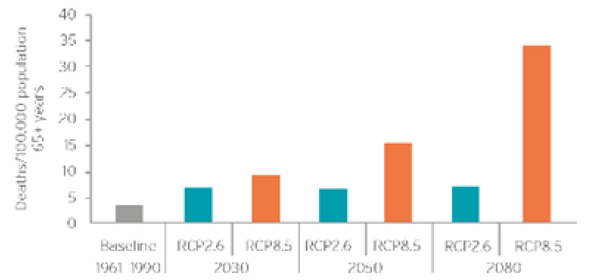


Figure 3-26: Impact of climate change induced heath stress deaths among the elderly under RCP2.6 and RCP8.5, by 2030, 2050, and 2080 (WHO, 2015)

3.6.4. Co-benefits of greenhouse gas mitigation

Carbon dioxide, the principal greenhouse gas, does not pose health risks to the public, per se. However, there are strong linkages between greenhouse gas emissions that contribute to global climate change and air pollution that contributes to local public health impacts. That is, activities that lead to greenhouse gas emissions also lead to air pollutant emissions that harm human health.

Air pollution contributes to a range of diseases, symptoms, and conditions that impair the health and quality of life for urban residents. Numerous epidemiological studies have reported associations between an increase in daily levels of ozone (O_3) and particulate matter (PM) and an increase in the rates of mortality and hospital admissions predominantly related to respiratory and cardiovascular diseases.

GHG mitigation policies can lead to public health "co-benefits", or unintended positive side effects. Specifically, energy efficiency and renewable energy in the electricity and transport sectors can offer a diverse range of health co-benefits, including sharp reductions in morbidity and mortality risks. For example, the estimated reduction in global premature deaths from reduced air pollutant emissions from implementing GHG mitigation strategies approaches 50% in 2050 relative to 2005 levels, as illustrated in Figure 3-27 (Bollen, et al., 2009).

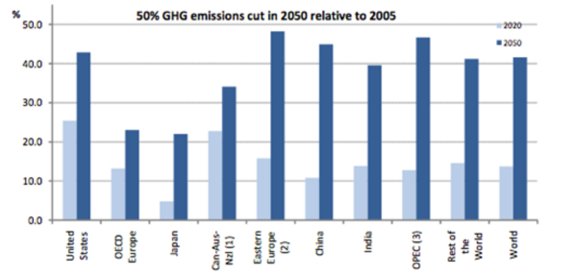


Figure 3-27: Avoided premature deaths from reduced local air pollution through GHG mitigation policies, % differences from baseline (Bollen, et al., 2009)

3.6.5. Strategic actions

Public health in Oman is vulnerable to climate change impacts due to sea-level rise, increased malaria incidence, and heat stress. Moreover, low carbon development strategies can also yield health co-benefits for individuals and societies. Effective adaptation should focus on knowledge generation, capacity building, and improved governance and planning. Within this overall framework, some key adaptation measures include:

- Improve knowledge for managing climate change impacts on human health by:
  - a) Raising public awareness on the detrimental effects of climate change on human health and intensify disease prevention and health promotion.
  - b) Expanding knowledge on science of climate change and its effects on human health, as well as increasing the research capacity in this area (e.g., assessing the health impacts of climate change in Oman).
- Strengthen capacity for assessing vulnerability of urban areas, touristic facilities, and infrastructure by:
  - a) Building institutional and technical capacities for health-related resilience to climate change by both preparedness and response strategies. (e.g., Medical & Public Health Response Unit (MPHRU));
  - b) Strengthening health surveillance and health management information systems; and
  - c) Developing a local data-driven modeling framework for assessing the public health co-benefits of GHG mitigation measures
- Improve governance and planning in Oman through:

a) Developing strong partnerships, coordination and collaboration with the concerned agencies at national, regional and international levels linked to climate change and health issues”.

b) Developing a multi-sectoral, integrated surveillance system to better monitor and respond to disease events triggered by climatic episodes.

3.7. List of references

- Al Maktoumi, A,. Zekri, S., El-Rawy, M., Abdalla, O., Wardy, M., Al-Rawas, G., Charabi Y,. 2018. Assessment of the impact of climate change on coastal aquifers in Oman. Arabian Journal of Geosciences. https://doi.org/10.1007/s12517-018-3858-y.

- Bates, B.C., Z.W. Kundzewicz, S. Wu and J.P. Palutikof, Eds., 2008. "Climate Change and Water", IPCC Secretariat, Geneva, June.
- Bollen, J. Guay, B. Jamet S. and Corfee-Morlot, J., 2009. "Co-benefits of Climate Change Mitigation Policies", Economic Department Working Papers No. 693. Paris: Organisation for Economic Cooperation and Development (OECD).
- Brander, K. M., 2007. "Global fish production and climate change", PNAS 104, 19709–19714.
- Burkett, V.R., A.G. Suarez, M. Bindi, C. Conde, R. Mukerji, M.J. Prather, A.L. St. Clair, and G.W. Yohe, 2014: Point of departure. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L.White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 169-194.
- Charabi, Y., Al Awdhi, T., Al Rawas, G., Al-Wardy, M., 2015. "Quantitative assessment of the impact of climate change on urban areas, tourism and infrastructures", Sultan Qaboos University.
- Cheung, W. et al., 2010. "Large-scale redistribution of maximum fisheries catch potential in the global ocean under climate change",. Glob. Change Biol. 16, 24–35.
- Chowdhury, S., Al-Zahrani, M., Abbas, A., 2013. "Implications of climate change on crop water requirements in arid region: An example of Al-Jouf, Saudi Arabia", Journal of King Saud University – Engineering Sciences.
- Church, J., Woodworth, P., Aarup, T., and Wilson, W., 2010. "Understanding Sea-level Rise and Variability," Wiley Press
- Church, J.A., P.U. Clark, and others, 2013. "Sea Level Change. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. http://www.climatechange2013.org/images/report/WG1AR5_Chapter13_FINAL.pdf
- FAO, 2011. FAOSTAT database. FAO, ROME. (http://www.fao.org/fishery/topic/16140/en).
- Government of Oman, 2010. "National Census results"
- Hewawasam, L., Al-Rawas, G., 2015. "Water Resources - Part 1: Surface Water - Spatio-temporal analysis of extreme rainfall events in the Sultanate of Oman based on hourly database from 2000 to 2014", Sultan Qaboos University, Muscat.
- IPCC, 2007. "Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. [Core Writing Team, Pachauri, R.K. and A. Reisinger (eds.)]. IPCC, Geneva, Switzerland, 104 pp.
- Jiménez Cisneros, B.E., T. Oki, N.W. Arnell, G. Benito, J.G. Cogley, P. Döll, T. Jiang, and S.S. Mwakalila, 2014. " Freshwater resources", In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on

Climate Change, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 229-269.

- Milne, G. A., Gehrels, W. R., Hughes, C. W., and Tamisiea, M. E., 2009. "Identifying the causes of sea-level change, Nature Geosci.,2, 471–478, 2009
- Minguez, R., Abascal, S., Castanedo, S., and Medina, R., 2012. "Stochastic lagrangian trajectory model for drifting objects in the ocean" Stochastic Environmental Research and Risk Assessment, 26:1081-1093.
- Piontkovski, S., 2015a. "Decadal changes of the Western Arabian Sea ecosystem", Sultan Qaboos University.
- Piontkovski, S., 2015b. "Interannual fluctuations of yellowfin tuna and sardine landings over the Omani shelf with regards to atmospheric anomalies and climate change issues", Sultan Qaboos University.
- Piontkovski, S., 2015c. "Modeling the Impact of Climate Change on Fisheries Resources of Oman: Case Study of Yellowfin Tuna", Sultan Qaboos University.
- Reguero, B., Menéndez, M., Méndez,F., Mínguez, R., and Losada, I., 2012. "A Global Ocean Wave (GOW) calibrated reanalysis from 1948 onwards", Coastal Engineering, 65 (2012) 38–55.
- Saha, S., Shrinivas Moorthi, Hua-Lu Pan, Xingren Wu, Jiande Wang, Sudhir Nadiga, Patrick Tripp, Robert Kistler, John Woollen, David Behringer, Haixia Liu, Diane Stokes, Robert Grumbine, George Gayno, Jun Wang, Yu-Tai Hou, Hui-ya Chuang, Hann-Ming H. Juang, Joe Sela, Mark Iredell, Russ Treadon, Daryl Kleist, Paul Van Delst, Dennis Keyser, John Derber, Michael Ek, Jesse Meng, Helin Wei, Rongqian Yang, Stephen Lord, Huug van den Dool, Arun Kumar, Wanqiu Wang, Craig Long, Muthuvel Chelliah, Yan Xue, Boyin Huang, Jae-Kyung Schemm, Wesley Ebisuzaki, Roger Lin, Pingping Xie, Mingyue Chen, Shuntai Zhou, Wayne Higgins, Cheng-Zhi Zou, Quanhua Liu, Yong Chen, Yong Han, Lidia Cucurull, Richard W. Reynolds, Glenn Rutledge, and Mitch Goldberg, 2010. "The NCEP Climate Forecast System Reanalysis", American Meteorological Society, pp. 1015-1057, August.
- Charabi, Y., Al-Rawas, G., Al-Wardy, M., Al-Maskari, J., Al-Sarmi, S., Al-Yahyai, S., 2015. " Observed and Projected Changes in Climate of Oman", Muscat, May.
- Almazroui, M., M. Nazrul Islam, H. Athar, P. D. Jones, and M. A. Rahman, 2012. Recent climate change in the Arabian Peninsula: Annual rainfall and temperature analysis of Saudi Arabia for 1978-2009, Int. J. Climatol., 32(6), 953-966, doi:10.1002/joc.3446.
- Al Sarmi, S. and R. Washington, 2013. Changes in climate extremes in the Arabian Peninsula: analysis of daily data, Int. J. Climatol., n/a-n/a, doi:10.1002/joc.3772
- Athar, H., 2012. Decadal variability of the observed daily temperature in Saudi Arabia during 1979?2008, Atmospheric Science Letters, 13(4), 244-249, doi:10.1002/asl.390
- Donat, M. G., T. C. Peterson, M. Brunet, A. D. King, M. Almazroui, R. K. Kolli, D. Boucherf, A. Y. Al-Mulla, A. Y. Nour, A. A. Aly, T. A. A. Nada, M. M. Semawi, H. A. A. Dashti, T. G. Salhab, K. I. El Fadli, M. K. Muftah, S. D. Eida, W. Badi, F. Driouech, K. E. Rhaz, M. J. Y. Abubaker, A. S. Ghulam, A. S. Erayah, M. B. Mansour, W. O. Alabdouli, J. S. A. Dhanhani, and M. N. Al Shekaili, 2013. Changes in extreme temperature and precipitation in the Arab region: long-term trends and variability related to ENSO and NAO, Int. J. Climatol., n/a-n/a, doi:10.1002/joc.3707
- Hartmann, D., A. Klein Tank, M. Rusticucci, L. Alexander, S. Brönnimann, Y. Charabi, F. Dentener, E. Dlugokencky, D. Easterling, A. Kaplan, B. Soden, P. Thorne, M. Wild, and P. Zhai, 2013. Observations: Atmosphere and Surface. In: Climate Change 2013: The

Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)), Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA

- Zarenistanak, M., A. G. Dhorde, and R. H. Kripalani, 2014. Trend analysis and change point detection of annual and seasonal precipitation and temperature series over southwest Iran, Journal of Earth System Science, 123(2), 281-295
- Satterthwaite D, Huq S, Pelling M, Reid H, Reid P (2009). Adapting to Climate Change in Urban Areas: The possibilities and constraints in low- and middle-income nations [pubs.iied.org/pdfs/10549IIED.pdf].
- Sumaila, U. R., Marsden, A. D., Watson, R. & Pauly, D., 2007. “A global ex-vessel fish price database: Construction and applications”, J. Bioecon. 9, 39–51.
- World Bank, 2008. World Development Indicators.
- Zekri, S., 2015. “Quantitative assessment of the “Impact of climate change on agriculture and livestock”, Sultan Qaboos University.

4. GREENHOUSE GAS MITIGATION

Oman faces the challenge of harmonizing its aspirations for rapid economic growth with a pressing need to address low-carbon, climate-resilient development. In response, it has undertaken domestic efforts to better understand ways to reduce its greenhouse gas emissions. Internationally, Oman has voluntarily agreed to reduce GHG emissions by 2% by 2030 (SoO, 2015). This pledge based on a set of policies that are reconciled with projected macroeconomic trends.

Oman understands the need to transition to a low carbon future that reflects new thinking, new frameworks, and new methods. The transition will also need to find practical ways to promote clean energy initiatives, facilitate access to new low-carbon technologies, and develop long-term partnerships to exploit sustainable energy opportunities. Through such actions, Oman seeks to reflect its solidarity with the international community, as well as its long-term commitment to promote greenhouse gas mitigation in a carbon-constrained world.

The Greenhouse Gas Mitigation theme of the Oman Climate Change strategy focuses on the energy sector, the sector responsible for the largest share of GHG emissions in Oman. The rest of this section provides a review of the GHG emission patterns, together with a set of strategic mitigation actions.

4.1. Greenhouse gas emissions

Figure 4-1 illustrates the shares of total GHG emissions by sector for the year 2015. Energy-related activities accounted for the dominant portion of GHG emissions. About 64% of all GHG emissions are associated with the combustion of oil and natural gas for electricity/desalinated water production and transportation, as well as the release of fugitive emissions from oil and gas operations. Industrial activities accounted for about 30% of all GHG emissions, followed by waste management with 4% and agricultural activities with about 2% of total emissions.

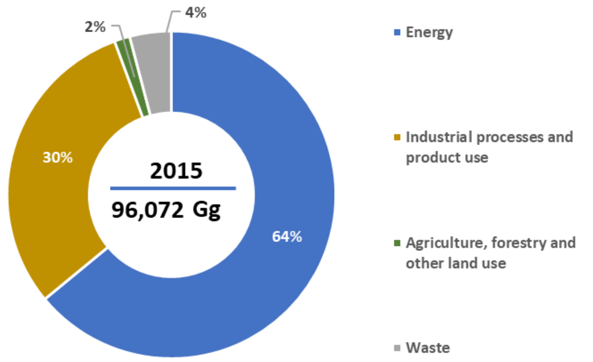


Figure 4-1: Shares of Oman's GHG emissions, 2015 (CHRABI Y. *et al.*, 2019)

Given the important role of energy in Oman's GHG emission profile, mitigation strategies focus exclusively on energy producing and consuming activities. While the agricultural sector contributes a substantial amount to GHG emissions, mitigation measures for agriculture focus on the water-food-energy nexus.

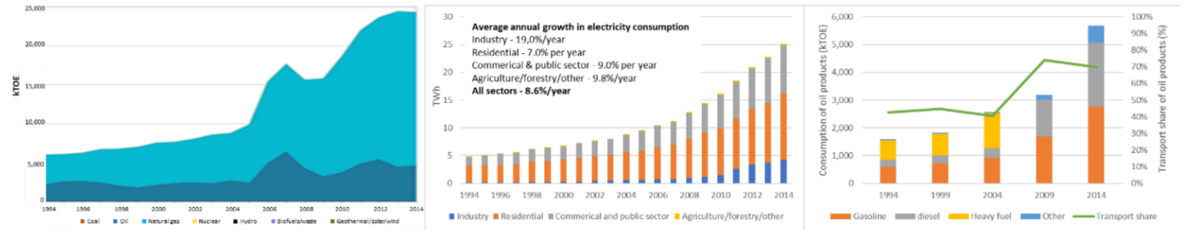
4.2. Energy supply and demand

Oman's production of oil and natural gas plays an important in the national economy. In 2014, crude oil extraction operations accounted for 46,228 kTOE, most of which was exported - 39,221 kTOE, or 85% of total domestic supply (IEA, 2017). Most of the remaining oil that is consumed in Oman converted into refined oil products – diesel, gasoline, and jet kerosene – for use in the transport sector. Natural gas production shows far different characteristics, with extraction of 30,103 kTOE, most of which is consumed within Oman (19,885 kTOE, or 67% of total domestic supply) for power generation and industrial applications (i.e., smelters, refineries).

Figure 4-2a shows that from the early 1970s to the present day, total primary energy supply has relied exclusively on diesel oil and natural gas (IEA, 2017). There are no coal, biofuel/waste, renewable, or nuclear resources used in Oman. Total energy supply has grown rapidly between 1994 and 2014, from 6 to 24 kTOE, or 7.2% per year. Most of this growth is attributed to increasing shares of natural gas in the energy system. From a share of 58% in 1994, natural gas provided 81% of all energy supply in 2014.

Figure 4-2b shows electricity use by sector from 1994 to 2014 (IEA, 2017). Currently, there are fourteen (14) power stations in Oman, comprised of open cycle gas turbines and combined cycle units for the co-production of water and desalinated water. Electricity production from these units is dominated by natural gas at over 97%. Transmission and distributed losses have declined from 14% in 1994 to 11% over the period 1994-2014. Total net electricity generation has increased rapidly during this period, from 4.8 TWh in 1994 to 25.2 TWh in 2014, or 8.6% per year. Highest growth has been in the industrial sector average 15% per year.

Figure 4-2c shows trends in the consumption of refined oil products from 1994 to 2104 (IEA, 2017). Gasoline, diesel, and heavy fuel dominated consumption from 1994 through 2004. Since then, heavy fuel oil has been replaced entirely by natural gas. The transport sector has grown in prominence, accounting in recent years for the highest share of refined oil use, averaging over 70%.



a) energy supply b) electricity generation c) consumption of refined oil products

Figure 4-2: Energy supply and demand in Oman, 1994-2014 (IEA, 2017)

4.3. Renewable energy resources

Major renewable energy resources in Oman consist of solar, wind, and biogas. Other resources include geothermal and wave energy, though at levels below economic viability. If Oman's major renewable resources were to be gradually exploited and integrated into the electricity system, the carbon intensity of electricity generation could be significantly decreased. A review of the resource potential for each major and minor renewable resource type is summarized in the bullets below (Authority for Electricity Regulation, 2008).

- Solar: Total solar energy resources in Oman are huge and could, in theory, fully meet all domestic electricity demands and be available for export as well. High solar energy densities are available in all regions of Oman, ranging from 4.5 to 6.1 kWh/m^2 per day which are some of the highest in the world. The highest solar energy density is found in dessert areas and the lowest are in coastal areas in the south. Photovoltaic and concentrating solar power (CSP) technologies are highly applicable.

- Wind: Oman boasts a long coastline that is exposed to strong summer and winter monsoon winds. Average wind speeds are slightly over 5 m/s with an estimated 2,463 hours of full load per year, making wind power a plentiful resource in Oman. Several locations are suitable for wind power development, namely locations at Thumrait, Masirah, Joba, Sur and Quiroon Hariti. At the Thumrait and Qayroon Hyriti sites alone, 750 MW of wind power is economically viable, conservatively capable of generating 2.3 TWh, or about 8% of Oman's gross electricity production in 2014.
- Biogas: Oman has a large number of farm animals which theoretically could be used to produce electricity from methane in the wastes. Biogas plants can be located at food industries and at big farms with at least 100-200 stabled milk cows or camels. Total technical potential for electricity generation by biogas in Oman is about 35,000 MWh/year corresponding to a continuous power capacity of 4 MW.
- Geothermal: High grade geothermal resources are not available in Oman. While there are about 55 areas where borehole depths of 500 and 1,500 meters have temperatures in excess of 100°C, the minimum temperature required for use of hot water for steam power plants is about 160°C. The highest observed borehole temperatures in the northern part of Oman in the Al Hajar mountains reaches 174°C.
- Wave: The wave energy potential in the Arabian Sea is among the lowest in the world. The wave energy flux in the open sea is in the order of 17 kW per meter of wave length. Wave energy is more suitable for other parts of the world such as Portugal and Chile where the wave energy flux is 48 and 74 kW per meter of wavelength, respectively.

At present, there is no significant penetration of technologies that can exploit these renewable resources such as centralized solar photovoltaics or wind turbine farms. The introduction of even modest amounts of renewable generation could readily achieve Oman's voluntary target to reduce GHG emissions by 2% by 2030.

4.4. Energy efficiency & conservation

There is ample scope for improving the efficiency by which energy is consumed in Oman, together with opportunities for conservation. Initial screening has shown that several types of measures in the industrial, commercial, governmental, and residential sectors have great potential in Oman for reducing energy use. These measures are identified in Table 4-1, which also indicates their potential penetration level and a feasible rate of improvement (JICA, 2013). The bullets below briefly describe each measure.

- Energy management system: This is a system that calls for energy auditing and integrated management of all energy consuming equipment at large buildings, factories, and other facilities across the industrial, commercial, and government sectors. Participating sites develop an energy efficiency plan and submit periodic reports that track the progress in the implementation of energy efficient devices for all energy end uses.
- Labeling systems: Energy rating labels provide consumers with information on the energy efficiency of a product. There are two main types of labels – comparison labels, which allow consumers to compare the energy consumption of similar products and endorsement labels which offer a seal of approval (e.g., Energy Star). These are relevant for lighting in the commercial and governmental sectors, and for lighting, air conditioning, and refrigeration in the residential sector.

- Building codes: A building code (also building control or building regulations) is a set of rules that specify the standards for constructed objects such as buildings and nonbuilding structures. These codes regulate the design and construction of structures when adopted into law. They are applicable to building design (e.g., insulation) for industrial, commercial, and governmental sectors, and for air conditions for the residential sector.
- Smart meters: A smart meter is an electronic device that records consumption of electric energy in intervals of an hour or less and communicates that information at least daily back to the utility for monitoring and billing. Smart meters enable two-way communication between the meter and the central system. While they are applicable to all sectors, they have only been considered to be applicable to the residential sector for the period of the assessment.

Table 4-1: Major energy efficiency and conservation measures applicable to Oman (JICA, 2013)

Sector	Energy efficiency & conservation measure	Potential	Rate of improvement
Industry	Energy management system	90%	1% per year
Commercial	Energy management system	60%	1% per year
	Labeling system for lighting	22%	90%
	Buidling codes	40%	25%
Governmental	Energy management system	60%	1% per year
	Labeling system for lighting	22%	9%
	Buidling codes	40%	25%
Residential	Labeling system (air conditioning, lighting, refigerators)	12% to 39%	9% to 23%
	Buidling codes (air conditioning)	39%	28%
	Smart meters	70% to 80%	2% to4%

An analysis of the potential of these measures for reducing electricity consumption shows that the measures can lead to significant savings (JICA, 2013). Each of the measures was considered within a scenario analysis framework for the period 2010 to 2035 that assumes the same historical fuel mix for electricity generation. An overview of the approach is described in the bullets below.

- Baseline scenario: In this scenario, electricity consumption grows at a rate roughly half of the 1994-2014 rate. Electricity consumption reaches about 60 TWh by 2035 from about 25 TWh in 2014, or an average growth rate of 4.3% per year. There is no significant penetration of energy efficiency equipment or conservation practices.
- Alternative scenario: In this scenario, there is a gradual penetration of energy efficiency and conservation measures consistent with the rate of improvement assumptions in Table 1, starting in 2018. The impact of these measures results in a lowering of electricity consumption through 2035.

The results of the analysis are illustrated in Figure 4-3. The left plot shows that by 2035, the implementation of all the measures would lead to electricity savings of about 15 TWh, or roughly 25% of electricity consumption in the Baseline scenario. Together, electricity savings from labeling systems and energy management systems account for 81% of the total savings.

The right plot of Figure 4-3 shows that the GHG reduction benefits from these electricity savings are considerable, resulting in a reduction of approximately 23 million tonnes by 2035, or 21% less that what national emissions would have otherwise been in 2035.

4.5. Strategic actions

The Public Authority for Electricity & Water (PAEW) has developed the Oman Energy Master Plan 2040 (PAEW, 2015). The development of the Plan was motivated by concerns that

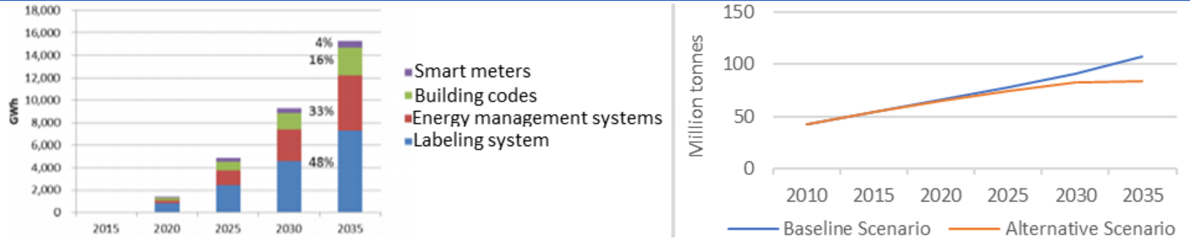


Figure 4-3: Electricity savings from the introduction energy efficiency and conservation measures (left plot) and corresponding GHG reductions (right plot) (JICA, 2013)

economic and demographic growth poses important implications for future energy security as conventional fossil fuel resources dwindle and its young population continues to grow rapidly. The Plan proposes strategies to diversify Oman's energy mix while driving economic growth and technological innovation.

There is significant overlap between the goals of the Oman Energy Master Plan 2040 and the goals of the Oman Climate Change Strategy. Many of the strategies proposed in the Energy Plan will lead to substantial reductions in GHG emissions. Specifically, there are four (4) "streams" within the Energy Plan that have been incorporated into the Climate Change Strategy, as outlined in the paragraphs below.

4.5.1. Stream 1: Energy supply

GHG reductions can be achieved through diversification of its energy supply and exploiting Oman's extensive renewable energy resources. Specific strategies are indicated in the bullets below:

a) Create, adopt and implement a comprehensive energy action plan that can facilitate the immediate implementation of renewables;

b) Establish a Ministry of Energy that would be responsible for renewable energy and energy development; and

c) Establish Small Scale Rooftop and Hybrid Power Generation for local communities that would be backed by a national regulatory body to monitor permitting and building codes/standards

4.5.2. Stream 2: Energy demand

As discussed earlier, substantial levels of GHG reductions can be achieved by providing an enabling environment for the introduction of energy efficiency and conservation measures. Specific strategies are indicated in the bullets below:

a) Cut energy-related subsidies that are barriers to promoting energy efficiency and conservation. Removal of subsidies should account for and assist those that may be particularly vulnerable;

b) Develop and implement national awareness-raising programmes on the benefits of energy efficiency and conservation, thereby promoting a nationwide change in behavior to boost the level of energy efficiency in homes and workplaces throughout Oman; and

c) Centralize energy policy under a single authority that would be empowered to establish a coordinated energy policy that would treat demand side energy management as a priority.

4.5.3. Stream 3: Research & Development

Diversifying the way in which Oman meets the energy service requirements of its growing population will depend on its institutional research and development capacity to exploit economic opportunities. Specific strategies are indicated in the bullets below:

a) Narrow the gap between industry and academia to establish an enhanced R&D culture in order to foster private-partner partnerships and synergies;

b) Establish research clusters and incubators with universities across Oman that are linked with promotional entities; and

c) Encourage a higher number of PhD students to study and work in Oman as they represent the intellectual value and driving force behind top-level research.

4.5.4. Stream 4: Water-food-energy nexus

Energy is closely linked to water resource management and agricultural development. The "water-food-energy nexus" is a framework that views water and food as part of an integrated system, rather than as independent resources. Energy is required to extract, convey, purify, and deliver water for agricultural productions and other end users in the economy. It is also used to treat municipal and industrial wastewater. Specific strategies are indicated in the bullets below:

a) Establish an executive authority that focuses on water, energy and food and identifies/quantifies the linkages between them;

b) Explore the costs and benefits of renewable energy-based seawater desalination for promoting energy and water security; and

c) Enforce building codes and standards for sustainable homes to promote water savings and energy efficiency.

4.6. List of references

- Authority for Electricity Regulation, 2008. "Study on Renewable Energy Resources, Oman", Final Report, May.
- International Energy Agency (IEA), 2017. "Oman: Indicators for 2104", https://www.iea.org/statistics/statisticssearch/report/?country=Oman&product=indicators
- Japan International Cooperation Agency (JICA, 2013. "Project for energy conservation master plan in the Sultanate of Oman", Final Report.
- Ministry of Environment & Climate Affairs (MECA), 2013. "Initial National Communication", Muscat
- Oak Ridge National Laboratory, 2017. "CO2 emissions (kg per PPP $ of GDP)", Carbon Dioxide Information Analysis Center, Environmental Sciences Division, Tennessee, United States. http://data.worldbank.org/indicator/EN.ATM.CO2E.PP.GD
- Public Authority for Electricity & Water (PAEW), 2015. "Oman Energy Master Plan 2040", Muscat.
- Sultanate of Oman, 2015. "Submission on Intended Nationally Determined Contributions (INDCs)", Ministry of Environment and Climate Affairs, Muscat.
- World Bank, 2017. "Oman Data", http://data.worldbank.org/country/Oman

5. OTHER INFORMATION

This chapter presents an overview of other information relevant to addressing climate change in Oman.

5.1. National Strategy for Adaptation and Mitigation to Climate Change 2020-2040

Realizing the importance of addressing the threats and opportunities posed by climate change, The Sultanate of Oman has adopted in October 2019, a comprehensive national climate change strategy for Adaptation and Mitigation to Climate Change, 2020-2040. (SoO, 2019). The key areas addressed in the strategy are briefly outlined in the bullets below.

- *Regional climatic change:* There are current gaps in knowledge about the range of potential climatic change in the region;
- *Vulnerability of key sectors and systems:* A number of needs - financial, technological, and research-oriented - have emerged from the various vulnerability assessments; and
- *Growth in GHG emissions:* Oman faces both constraints and options in transitioning to green growth development pathways.

The development of a comprehensive strategy is a fundamental step in moving forward in the fulfillment of the aspirations of the Paris Agreement of COP-21. To implement the strategy, collective action among stakeholders within Oman will be essential, as well, partnerships with the international community to facilitate the flow of technical and financial resources for undertaking the vision embedded in the strategy.

Indeed, effective action on climate change depends on building a better understanding of the strategic context for adaptation and mitigation activities. On the one hand, the strategy recognizes that the country's need to build resilience to climate change is rooted in exposure to adverse impacts of climate change such as increasing temperatures, rising sea levels intensifying tropical cyclones. Understanding land use, climate, water resources, and agriculture/fisheries are essential context for identifying, designing and implementing preparedness/response measures to reduce the vulnerability of communities, resources, and systems.

On the other hand, the strategy acknowledges that the proper context for mitigation is rooted in the recognition of the need to control a trend of greenhouse gas emissions growth. To slow the growth in national greenhouse gas emissions, the strategy calls for encouraging a low carbon economy, introducing new technologies, and implementing cost-effective efficiency and renewable energy projects.

5.1.1. Purpose

The strategy reflects Oman's understanding that local action against climate change must now be a national development priority that should be coordinated across government agencies, the private sector, and civil society. Hence, the National Climate Change Strategy outlines Oman's long-term vision on climate change. It seeks to inform future policy dialogues by laying out clear strategic actions on adaptation and mitigation. When fully implemented, such a strategy will put Oman on a path to low-emission, climate-resilient growth that promotes job creation for its population, climate risk management for the most vulnerable, and sustainable management of its precious natural resources.

5.1.2. Vision

The vision underlying Oman's Climate Change Strategy is comprised of three major themes and several cross-cutting goals, as briefly described in the bullets below and illustrated in Figure 5-1.

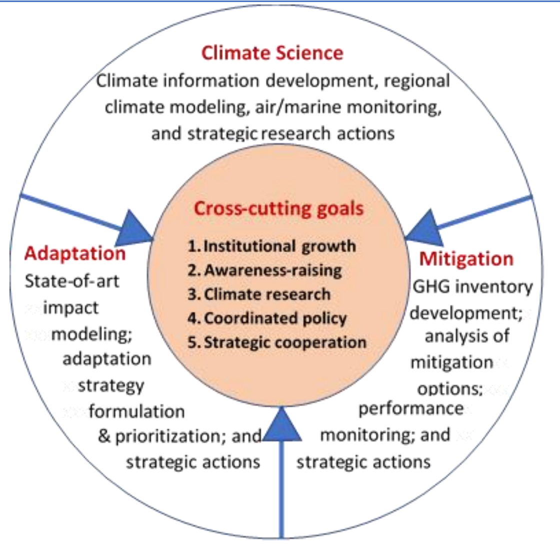


Figure 5-1: Themes and cross-cutting goals of Oman's Climate Change Strategy

- *Climate science:* This focuses on an assessment of historical climatic trends for Oman and projections of future climate change relative to a set of Representative Concentration Pathways.
- *Vulnerability and adaptation:* This focuses on the vulnerability of five key sectors to climate change forms the basis for a set of strategic adaptation actions in each sector. These sectors are water resources; marine biodiversity and fisheries; agriculture, urban areas, tourism & infrastructure; and public health.
- *Greenhouse gas mitigation:* This focuses on the identification of five key areas in which specific strategies contribute to a low-emission development trajectory. These areas are energy supply, energy demand, research and development, labor, and the water-food-energy nexus.

5.2. Steps to implement the Convention

The government of Sultanate of Oman has already carried out several commitments and actions to address the challenges of Climate Change. First, in Paris in 2015, Oman committed to the goal of reducing GHG emissions by 2% by 2030 (SoO, 2015).

Second, the Sultanate of Oman is in the process of implementing twelve renewable energy projects to demonstrate its commitment to the global effort to reduce emissions. Combined, these projects will account for at least 2.6 GW of new electric generating capacity. The focus on renewable energy is in direct response to the prominence of energy in the national GHG inventory. By increasing the role of renewable energy technologies in meeting national demand for energy, Oman is transitioning to a green growth energy pathway.

A list of the key projects is provided in Table 5-1. Some of the more notable efforts are briefly described in the bullets below.

- *Solar for schools initiative:* In 2015, Shell-Oman announced and funded projects using solar energy for electricity in public schools, with the aim to increase awareness of the viability of solar energy technologies in meeting electricity demand (see Figure 5-2, top). In the coming years, the initiative calls for a total of 22 public schools across Oman to be equipped with photovoltaic panels. Notably, this initiative will encourage Small and Medium Enterprises (SMEs) to take advantage of sustainable energy opportunities.

Table 5-1: List of key sustainable energy projects in Oman (source: Authority for Electricity Regulation, 2019)

#	Project	Organization	Year	Project Size (MW)
1.	Miraah Solar Thermal Facility	Petroleum Development Oman (PDO)	2018	1,021
2.	Ibri II solar project	Oman Power and Water Procurement Co	2022	500-1,000
3.	Wind 2023 Project	Oman Power and Water Procurement Co	2023	300
4.	Waste-to-energy project	Oman Power and Water Procurement Co	2023	125-160
5.	Amin solar power project	Petroleum Development Oman (PDO)	2020	105
6.	Dhofar Wind Farm	Rural Areas Electricity Company of Oman (Tanweer)	2019	50
7.	Solar Car Park	Petroleum Development Oman (PDO)	2018	6
8.	Qurayyat Sewage Treatment Plant	Haya Water	2019	0.100
9.	Solar parking shades	Sultan Qaboos University	2018	0.082
10.	Solar Car Park	Salalah Port	2019	0.030
11.	Solar into Schools (22 schools)	Shell Oman	2017	various
12.	Nimr Reed Beds	Petroleum Development Oman (PDO)	2010	-
Total				~2,107-2,642

- *Miraah solar project:* Inaugurated in 2018, the Miraah solar project was implemented by Petroleum Development Oman (PDO) and is one of the largest solar thermal plants in the world in terms of peak energy production (see Figure 5-2, middle). This project aims to generate steam for enhanced oil recovery in the Amal steam project. This project will cut CO2 emissions by more than 300,000 tonnes/year.
- *Nimr Reed Beds Water treatment:* Launched in 2010, this is considered to be the largest industrial constructed wetland system in the world. It consists of a series of sloping reed fields and evaporation ponds, in all the size of 640 football pitches, which processes and treat over 110,000 m3/day of produced water from the Nimr oilfields in southern Oman. Compared to conventional deep-water disposal (DWD), it has the potential to eliminate 300,000 tonnes of CO2 annually.

Figure 5-2: Major sustainable energy projects in Oman. Top: solar for schools initiative; Middle: Miraah solar project; Bottom: Nimr Reed Beds Water treatment project

Oman has also been active in reducing emissions in the gas natural gas sector. Petroleum Development Oman (PDO) efforts have continued to promote energy efficiency via cogeneration, waste heat recovery in steam generation activities, and reducing non-routine flaring activities to levels As Low As Reasonably Practicable (ALARP). Across all company operations, the GHG emission intensity significantly fell by 44% in 2016 to 0.14 tonne of CO2e per tonne of production compared to 0.25 in 2015 (see Figure 5-3).

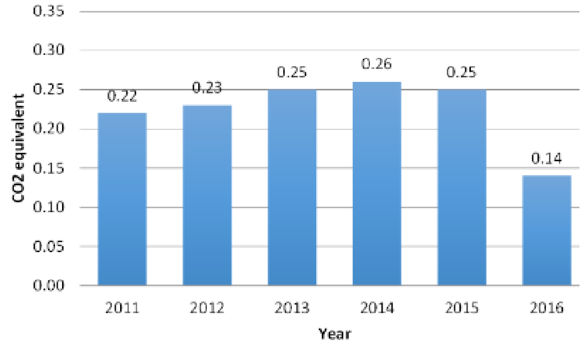


Figure 5-3: Greenhouse gas intensity ratio (CO_2 equivalent per tonne of production) (source: Petroleum Development Oman, 2019)

5.3. List of References

- National Strategy for Adaptation and Mitigation to Climate Change: 2020-2040
- Sultanate of Oman, 2015. Intended Nationally Determined Contribution.
- SoO, 2019. National Strategy for Adaptation and Mitigation to Climate Change, 2020-2040. Ministry of Environment and Climate Affairs.