THIRD NATIONAL COMMUNICATION OF THE KINGDOM OF SAUDI ARABIA

submitted to :
THE UNITED NATIONS FRAMEWORK CONVENTION ON CLIMATE CHANGE
(UNFCCC)
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Foreword

The Third National Communication (TNC) has been prepared by the Designated National Authority (DNA) in coordination and cooperation with all the relevant ministries, organizations and academic and research institutions, especially in partnership with the General Authority of Meteorology and Environmental Protection (GAMEP), the environmental agency of the Kingdom and Ministry of Energy, Industry and Mineral Resources (MEIMR). The main objective of this report is to fulfill the Kingdom's commitment under Article 12 of the United Nations Framework Convention on Climate Change (UNFCCC) and in accordance with the relevant Decisions of the Conference of Parties (COP) under the United Nations Framework Convention on Climate Change (UNFCCC) and to provide UNFCCC and the international community accurate and up-to-date information regarding the 2010 GHG emissions data and the policy initiatives, plans and programs that the government of the Kingdom of Saudi Arabia has taken to respond to the challenges posed by the Climate Change.

The 2010 GHG Emission Inventory section reports the total carbon dioxide emissions in the Kingdom, based on the revised 1996 IPCC guidelines and emission factors, estimated to be 472,186 Gg and sinks of 9,049 Gg, methane emissions of 2,067 Gg and nitrous oxide emissions 34.47 Gg in the year 2010.

Pursuant to decision 24/CP.18 of the UNFCCC, the Kingdom puts forward its national climate change efforts under a framework, which clearly recognizes the broader imperatives of sustainable development and economic diversification. The Kingdom has been striving to develop and implement policies, plans and programs in pursuit of economic diversification which have co-benefits in the form of emission reductions, adaptation to the impacts of climate change and response measures. The Kingdom of Saudi Arabia submitted its Intended Nationally Determined Contributions (INDCs) to the UNFCCC Secretariat in November 2015. The submission outlined the actions and plans to achieve mitigation co-benefits through contributions to economic diversification and adaptation.

The economic diversification efforts have started showing results as indicated by the increasing share of the non-oil sectors to the national gross domestic product. Few of the major policy initiative taken in this direction are making power and desalination plants more energy efficient, development and deployment of technologies relating to Renewable Energy Resources (RES) especially solar energy and Rationale Use of Energy (RUE). The government is also encouraging the reuse of the treated wastewater to reduce dependence on the energy intensive desalination plants and to conserve a valuable resource.

The Kingdom has made substantial progress in the field of Energy Efficiency by developing and enforcing regulations and guidelines for buildings, transportation, industry and urban planning and district cooling for efficient use and conservation of energy. Energy intensive industries are also improving their energy intensity to reduce energy demand.

The other key area the Kingdom is working on is Carbon Capture, Storage and Utilization (CCSU). The Kingdom has been engaged in the cooperative research initiatives with other countries to explore the potential of large scale commercialization and deployment of CCSU technologies. The Kingdom has planned to build the world's largest carbon capture and utilization plant and few other projects are under way.

The report also highlights some of the implications of climate change response measures and frames the climate change issue within the broader sustainable development context. The report further discusses the effects of climate change in Saudi Arabia using regional climate model called the PRECIS, which adds high-resolution information to large-scale projections of a global climate model. The regional model has been used to generate more accurate climate scenarios for Saudi Arabia projecting changes in temperature, relative humidity and precipitation for fifty (50) years from 2030 to 2079 in a regional scale setting. Scenario outputs were then used to assess the vulnerability of Saudi Arabia in the fields of water resources, desertification, agriculture and food security, and human health. Some of the inherent uncertainties in model projections have been minimized by using "Quantifying Uncertainty in Models Projections (QUMP)".

It is worth to remark that this National Communication has been prepared ensuring highest scientific standards and professionalism and by tireless efforts of DNA and a team of national and international experts, academicians, scientists and consultants. Information and data gaps as well as capacity constraints identified in the course of preparing this report would be addressed during the process of preparation of subsequent national reports.

I would also like to extend my appreciation to the team of experts, scientists, academicians and consultants who have participated in producing this report through relentless efforts and positive passionate attitudes. The members of the national committee of DNA are also thanked for their cooperation in providing data and information and timely inputs. The support of United Nations Environment Programme (UNEP) and Global Environment Facility (GEF) are also thankfully acknowledged. The scientific support of "Hadley Center for Climate Prediction and Research, U.K." is also highly appreciated.

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We also thankfully acknowledge the support of United Nations Environment Programme (UNEP) and Global Environment Facility (GEF). The assistance of Hadley Center for Climate Prediction and Research, U.K. is also acknowledged and appreciated.

Executive Summary

The Third National Communication (TNC) has been prepared by the Designated National Authority (DNA) in partnership with the General Authority of Meteorology and Environmental Protection (GAMEP), the environmental agency of the Kingdom, Ministry of Energy, Industry and Mineral Resources (MEIMR) and in cooperation and coordination with the relevant ministries, organizations and academic and research institutions. The report is comprised of ten chapters namely National Circumstances; GHG Inventory; Steps to Mitigation and renewable energy; Economic Diversification, Development and Transfer of Technology; Analysis of Socioeconomic Impacts of Annex 1 Response Measures; Climate Change Scenarios; Vulnerability Assessment and Adaptation Measures covering Water Resources; Desertification; Health; Agriculture and Food Security. Renewable energy, technology transfer, health, agriculture and food security issues have been included in this report for the first time.

Extreme heat and aridity are characteristic of most parts of Saudi Arabia. The average summer temperature range (in July) is 27° to 43°C (81° to 109°F) in Riyadh and 27° to 38°C (80°F to 100°F) in Jeddah. In winter, frost or snow can occur in the interior parts and on the higher mountains, although this occurs only once or twice in a decade. The lowest recorded temperature is -12.0°C (10.4°F), at Turaif. The average winter temperature ranges from 8° to 20°C (47° to 68°F) in January in interior cities such as Riyadh and 19° to 29°C (66° to 83°F) in Jeddah on the Red Sea coast. The annual rainfall in Riyadh averages 100 mm (4 inches) and falls almost exclusively between January and May; the average in Jeddah is 54 mm (2.1 inches) and occurs between November and January.

In the last few decades, Saudi Arabia witnessed tangible economic prosperity and progress in all domains of socio-economic development which produced sustainable improvement in all human development indicators such as standard of living, health and education, environmental conditions as well as potentials of comprehensive development.

In 2010 census, the population of the KSA was 27.2 million whereas it has been estimated to be 31,015,999 in 2015. During the past three decades, Saudi Arabia has made marked achievements in the field of education. Adult literacy rates stood at 94 percent in 2013.

The electricity generation capacity in the country in 2012 was 55,028 MW. The peak load of electricity in 2015 was 62,260 MW. During 2014, the total water export from the SWCC's plants amounted to one billion, one hundred and seven million and six hundred thousand cubic meters (1,107,600,000 m^3). Around 550.1 million cubic meters amounting to 49.7% was exported from the eastern coast plants feeding the eastern coast governorates, Riyadh, Qassim, Sudair, and Al-Washim regions; about 557.5 million cubic meters amounting to (50.3%) was exported from the western coast plants, feeding the Holy city of Makkah, Jeddah, Madinah, Tabuk, Al-Baha, Asir and Jizan regions. Regarding electric power generation from SWCC desalination plants as by-product, during the fiscal year 2014 amounted to 29,690,432 MWh, an increase of 19.3% as compared to the previous year. It is estimated that 70% of the required drinking water as well as 5% of the electricity demands in the Kingdom are met by the desalination plants.

The 2010 national inventory of anthropogenic greenhouse gas emissions and removals by sinks for the Kingdom of Saudi Arabia has been prepared according to the Revised 1996 Guidelines of the Intergovernmental Panel for Climate Change (IPCC, 1997). The three direct greenhouse gases, namely, carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) were addressed in this inventory. It covered the emissions from five sectors; namely, energy, industrial processes, agriculture, land-use change and forestry, and waste. Each sector included various sub-sectors or activities that emit CO_2, CH_4, and N_2O.

The total estimated CO_2 emissions in Saudi Arabia in 2010 were 472,186 Gg and CO_2 sinks were 9,049 Gg. The total estimated CH_4 emissions were 2,067 Gg whereas the total N_2O emissions were estimated to be 34.47 Gg. The energy sector contributed 89.7% of the total CO_2 emissions, followed by the industrial processes sector (10.1%) and the agriculture sector (0.2%).

The major source categories contributing to these CO_2 emissions (contributions ≥ 2% of the total emissions) were electricity generation (31%), road transport (21%), desalination (12%), petroleum refining (8%), petrochemical industry (7%), cement production (5%), iron and steel production (4%), fuel combustion in cement industry (3%), agriculture (2%), and fertilizer industry (2%). The waste sector contributed 52.7% of the total CH_4 emissions followed by the energy (42%), agriculture (3.6%), and the industrial processes (1.7%) sectors. The agriculture sector was the major contributor to N_2O emissions with 82.4%, followed by the waste (10.9%) and energy (6.7%) sectors.

The steps taken by the Kingdom to address Article 12.1(b) within the framework of this chapter include: (i) economic diversification initiatives with mitigation co-benefits; (ii) climate change adaptation initiatives with mitigation co-benefits; (iii) R&D activities on climate change; and (iv) efforts to reduce impacts of international climate change policy responses.

The Saudi Arabian economy will undoubtedly be impacted by climate change response-measures and policies since these actions will be implemented as policy measures to reduce primarily CO_2 emissions. This will reduce oil demand and affect negatively global oil prices. The implication of this for Saudi Arabia would be a reduction in crude oil exports and a decline in its oil export revenues which comprise a large portion of its GDP. However, Saudi Arabia will be working hard adapt to these response measures and policies by diversifying its economy sufficiently away from crude oil exports.

Pursuant to decision 24/CP.18 of the UNFCCC, the Kingdom puts forward its national climate change efforts under a framework, which clearly recognizes the broader imperatives of sustainable development and economic diversification. The Kingdom has been striving to develop and implement policies, plans and programs in pursuit of economic diversification which have co-benefits in the form of emission reductions, adaptation to the impacts of climate change and response measures. The Kingdom of Saudi Arabia submitted its Intended Nationally Determined Contributions (INDCs) to the UNFCCC Secretariat in November 2015.

Within the framework of the Paris Agreement, the Kingdom will make efforts to meet its INDC contributions while pursuing economic diversification within the context of sustainable development and the exploitation of its indigenous resources. Currently, Saudi Arabia is embarking on enormous efforts and large investments to foster economic diversification, including the establishment of economic cities, the investment in infrastructure, the development and use of gas, and the modernization of the power sector.

The report has also covered the analysis of historical climate trends (1978-2013) and future climate change scenarios. The historical (baseline) analysis puts special emphasis on extreme weather events namely heat wave, extreme wind, torrential rain flooding and dust/sand storm spatial and temporal distributions, recurrences and trends were analyzed for selected nine stations representing various climatic regions of the Kingdom. Examination of changes of temperature and rainfall trends for the period 2004-2013 (as compared with 1978-2003) has also been carried out for the selected nine stations.

In order to obtain more reliable models for producing future climate change scenarios, sub-ensemble of eight GCM models (out of twenty one ensemble members) has been recommended by Hadley Center to be examined for their performance in driving the RCM model (PRECIS-2) over Saudi Arabia. Two models have simulated successfully the outstanding synoptic-climate features used in the testing and hence, adopted to produce the future climate scenarios in terms of temperature, precipitation and relative humidity for the Kingdom over a selected 50 years period (2030- 2079). The spatial distribution of the projected annual mean temperatures, precipitation and humidity has been exhibited in maps for the above mentioned nine stations.

The possible effects of global warming on water resources in Saudi Arabia between 2030 and 2080 are investigated. Data for 28,000 grids covering Saudi Arabia (Latitude: 16.4°N to 32.2°N; Longitude: 34.6°E to 55.7°E) were retrieved from the PRECIS-RCM prediction model. The projection results indicate that by 2080 (a) wind speed and direction will vary spatially and temporally throughout the Kingdom; (b) changes in relative humidity will be significant in many parts of the Kingdom; and (c) temperature will increase across the Kingdom by -0.6°C to 5°C. Relative humidity appears to change from -12% in spring or fall to 22% in winter. Precipitation will decrease during the entire year in most parts of the Kingdom except Abha and Jizan regions in the south where there will be slight increase in precipitation during the summer.

Changes in the evapo-transpiration rate were estimated to vary from 3.5 to 15 mm/day during the modeling period. Usually, the highest evapotranspiration appears in the southeast and the lowest in the northwest and the southwest parts of the Kingdom. The yearly estimate shows that evapotranspiration may cause a significant decrease of the water table in the aquifers and may cause depletion in the quality of freshwater resources. It is likely that a water-table drop will affect hydrologic cycles, flow directions, and salinity conditions, which will ultimately affect the amount and quality of water stored in shallow and deep aquifers, resulting in a serious shortage of water.

Climate change impacts as represented by a temperature increase have been projected to elevate the levels of reference evapotranspiration by about 1% to 4.5% at a 1°C increase, and by about 6% to 19.5% at a 5°C increase in most regions. Crop irrigation water demands would annually rise by about 602 million cubic meters (MCM) with 1°C rise in temperature and 3,122 MCM at a 5°C rise in temperature. Climate change would also increase annual domestic and industrial water demands by about 75 MCM with a 1ºC rise and 390 MCM with a 5ºC rise in temperature.

This will lead to more challenges in satisfying the increasing domestic, industrial and agricultural water demands.

Using retrieved data from the PRECIS prediction model and estimating the evapotranspiration rate, the aridity index for all 28,000 grids was calculated based on the equation provided by the United Nations Environment Programme (UNEP). The results indicate that the aridity indices distributions are usually very low (less than 0.05) in most areas of the Kingdom, with slight seasonal changes. Such a low value, according to the definition of aridity, means that these areas are hyper-arid. Usually the highest vulnerability to desertification occurs in winter or fall in the southeast (Ash Sharqiyah region) and in summer in most of the central and northern areas. Vulnerability to desertification in over 90% of the grids is somehow not aggravated in the future according to the model projection. The desertification situation in some regions in the southwest (central Al Baha, southwest Asir, and Jizan) is not so critical. Nevertheless, vulnerability to desertification in the Kingdom is still very high. The overall trend of desertification vulnerability in 50 years is in the range of zero to 0.04%. The trend in the southwest corner can be up to 2%, leading to a high resistance to desertification. By 2080, vulnerability to desertification will increase in the northwest and will significantly reduce in the southwest. The change in vulnerability in the other areas will be insignificant.

Rapid population growth, insufficient recharge of fresh water, increased agricultural activity, and the implications of global warming have increased the pressure on natural water systems and the food security. The precipitation and evapo-transpiration modelling results were used to assess KSA's food security situation. An increase in temperature will threaten the production of winter wheat. As the wheat crop is very sensitive to temperature change, its temperature tolerance limit may be exceeded, seriously affecting crop yield. Approximately 30 percent of the crops and vegetables produced across KSA come from greenhouse cultivation; the remaining 70 percent will be affected by an increase in temperature, reduced precipitation, higher evapotranspiration, and low water reserves. An increased frequency in droughts and floods will also negatively affect crop yields and livestock. Farmers may be able to partially adjust by changing cultivars and/or planting dates for annual crops and by adopting other strategies. The potential for higher water needs should be considered in the design of new irrigation supply systems and in the rehabilitation of old systems. In general, measures to combat water scarcity, such as employment of latest irrigation techniques to minimize water consumption and the use of treated wastewater for agriculture, need to be carefully managed in order to avoid negative impacts on occupational health and food safety.

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National Circumstances

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Section 1: National Circumstances

1.1 National Circumstances

Saudi Arabia consists of a variety of habitats such as sandy and rocky deserts, mountains, valleys ('wadis'), meadows ('raudhas') salt-pans ('sabkhas'), lava-areas ('harrats'), etc.

It includes most types of terrain which can be generally divided into two distinct groups of rocks; the Arabian shield and the Arabian Platform. The Arabian shield is formed of igneous and metamorphic rocks of Precambrian age, that have been uplifted on the entire western sides and the Arabian Platform, situated in the Central and Eastern parts of the Kingdom, is composed of unaltered, younger sedimentary rocks. The latter group of rocks consists of escarpments, ridges, buttes, rocky and sandy deserts, etc.

1.1.1 Climatic Profile

Saudi Arabia has a semi arid to hyper arid climate, characterized by very low rainfall (annual average of 150mm (Abderrahman, 2001) and extremely high evapo-transpiration. However, the average annual precipitation in the southern western mountainous areas of Asir region has been recorded as high as 600 mm. For the rest of the country, rainfall is very low and erratic. The entire year's rainfall may consist of one or two local, heavy cloudbursts or Thunder storms. Saudi Arabia’s climate is principally determined by the southerly shift in wind patterns during the winter months, which brings rain and cool weather. The two main differences in the climate of Saudi Arabia can be felt between the coastal areas and the interior.

The migrating cyclones and anti-cyclones of middle latitudes westerlies have only little influence on its weather and climate, except to some extent, on the north and mid-western parts of the Kingdom. Charts of the average pressure at sea level, demonstrate that seasonal climate patters across the Arabian Peninsula and particularly in the Jeddah area, are governed by relatively stationary pressure patterns extending from the surrounding regions, in an alternating fashion from one season to another.

The temperatures in summer reach as high as 50ºC, but range from 27ºC to 43ºC in inland areas while it ranges between 27ºC to 38ºC in coastal areas. In winter, the temperatures range between 8ºC to 20ºC in the interior parts of Saudi Arabia while higher temperatures have been recorded in the coastal areas of Red Sea (19ºC-29ºC). Some areas such as Turaif recorded temperatures below zero degrees Celsius. Night time temperatures in the central deserts can be chilly even in summer, as the sand loses daytime heat rapidly once the sun sets.

The average annual rainfall has been low and recorded in the range of 100 mm in most regions. Flash floods can occur in many locations in the Kingdom after heavy torrential rains. All “wadis (valleys)” are considered floodplains and vulnerable to flooding after severe rainstorm. Jeddah gets its rains mainly between November and January.

1.2 Population

In 2010 census, the population of the Kingdom was 27.2 million, however, the population was estimated to be 29.9 million in 2013 and 31.02 million in 2015.

1.3 Health

The Ministry of Health (MOH) in the Kingdom of Saudi Arabia is committed to providing the latest health statistics and information for all partners in the health sector, including decision-makers and health care service providers. The MOH is the major governmental agency entrusted with the provision of preventive, curative and rehabilitative health care for the Kingdom's population. The MOH provides Primary Health Care (PHC) services through a network of health care centers.

1.4 Education

The government of the Kingdom of Saudi Arabia has devoted significant attention and resources to the development of human resources and the production of manpower skills. It has therefore taken concerted measures in its successive national development planning processes to address its goal of enhancing educational achievement at all levels giving the Ministry of Education the role of supervising all general education; and emphasizing the effective implementation of educational strategies. Another equally important measure has been to enhance the role of the private sector in the provision and planning of educational facilities. However, the public sector remains the main provider of educational services, with a share of 89.9 percent of the total enrolment in primary schooling and 88.5 percent of the total enrolment in all stages of public education in 2010 (KACST, 2014).

During the past three decades, Saudi Arabia has made marked achievements in making education available for all. Adult literacy rates stood at 94 percent in 2013.

As regards Higher Education, in 1434/35H (2013G), the number of government universities was 25 and distributed all over the regions of the Kingdom.

1.5 National Economy and National Development Priorities

In the last few decades, Saudi Arabia witnessed tangible economic prosperity and progress in all domains of socio-economic development which produced sustainable improvement in all human development indicators such as standard of living, health and educational services, environmental conditions as well as potentials of comprehensive development. Socio-economic indicators reflect this progress.

1.5.1 Directions of Development

The Kingdom adopts the development planning approach in mapping out its development process and defining its socio-economic policies and programs within the framework of comprehensive five-year plans that involve two basic complementary roles: directive role concerned about state institutions and the public sector and an indicative role concerned about the private sector. In this regard, the Ninth Development Plan (2010-2014), set the directions for all aspects of the country's socio-economic development for the plan period. The plan also addresses expected major challenges, along with the policies, programs and resources required to meet these challenges and to achieve development goals and objectives. The Plan marks a new stage in the process of development planning, which extends over the past four decades and constitutes the second phase in the strategic path of the national economy up to 2025. The Millennium Development Goals (MDGs) are part and parcel of the goals of this strategic path.

1.5.2 National Development Priorities

The following issues hold a strategic position in the Kingdom's development process:

Raising Standard of Living and Improving Quality of Life

As of the beginning of its development planning approach, the Kingdom succeeded in increasing its income many-folds, with per capita income growing at an average annual rate of 5.26% over the period 1990–2013. This income growth was accompanied by a similar improvement in human development indicators, thus ranking the Kingdom on the 11th place among "Countries with the fastest progress" in human development and 57 among 186 countries in the global human development index.

Diversification of Economic Base

Ever since the start of development planning, diversification of the economic base has been a principal objective of economic and social development. The development process placed emphasis on enhancing the role of non-oil sectors in the national economy. Nevertheless, developing the non-oil sectors to raise their share in production activities as well as in exports remains one of the main development challenges. It should be noted that diversification of the economic base is one of the main directions of the Ninth and Tenth Development Plans.

Enhancing Non-Oil Revenues

Oil revenues have been the main engine of development. Despite expansion and diversification of the economic base, oil revenues remain the main source of state budget that finance investment and operational expenditures. However, as oil resources are non-renewable, increasing focus has been given, through the development plans, to enhance diversification of the economic base as well as non-oil public resources.

Balanced Regional Development

Efforts made under the country's successive development plans have succeeded, to a great extent, in making tangible progress in reducing regional disparities, in light of the approved programs and projects which aim at developing infrastructure, public services and other necessary public facilities, along with a drive to build a production base, in each province, that primarily draws on individual region's particular development resources and stimulating investment in least developed regions (UNDP, 2013).

Move to a Knowledge-based Economy

The Kingdom of Saudi Arabia has intensified its efforts, particularly during the Seventh and Eighth Development Plans to develop its technological and knowledge capacities with a view, to lay the foundations of and advanced internationally competitive and knowledge-based economy that can keep pace with the accelerating global advancements of knowledge and technology. These efforts aspire to domestically generate, spread and utilize the said advances. In this regard, several key developments took place during the recent years.

- Initiation of implementation of the "Expanded Five Year Plan for the National Science and Technology Policy"
- Approval of the "National ICT Plan"
- "National Industrial Strategy"
- Setting up its implementation mechanisms

- Starting implementation of the “Strategy for Supporting Talent, Creativity and Innovation”
- Initiation of construction of the Economic Knowledge City in Medina”
- Inauguration of King Abdullah University of Science and Technology (KAUST)
- Approval to construct the Dammam Technology Zone”
- Approval of the Future University Education Plan of the Kingdom (AFAQ) 1450H.

Enhancing Competitiveness

Saudi Arabia is endowed with several resources and capabilities that constitute promising input for development of competitive advantages in production of many goods and services. This is backed up by persistent national efforts aimed at institutional and administrative development; creation of a business-friendly environment; improving the investment climate; upgrading the performance efficiency of government agencies and enhancing the drive towards a knowledge-based economy. These efforts have borne fruits, leading to improved ranking of Saudi Arabia in international reports. For example, the Kingdom ranked 26th among 189 countries with respect to ease of doing business (2014) and the Global Competitiveness Report (2013-2014) ranked Saudi Arabia 20th among 148 countries. Such efforts were adopted and pursued as key directions of the Ninth Development Plan.

Development and Productive Employment of Human Resources

Human resources development realized tangible progress over the past two decades due to the considerable investments targeted to developing the education and training sector. However, demand for labour surpassed Saudi labour supply in many professions, necessitating recruitment of large numbers of expatriate labour to meet the demand. This has created a situation that poses a key challenge for Saudization of jobs.

However, the need to match outputs of education and training with the skills and modern specializations required to meet development requirements has gained increasing significance over the past few years, as the mismatch has given rise to structural unemployment among Saudis. The Ninth and Tenth Development Plans have placed considerable attention to human resources development, through improved enrolment ratios in various educational stages; development of the education system to ensure quantitative and qualitative response to development requirements and new challenges and through expansion, development and wide-scale set up of vocational training programs in all regions of the Kingdom.

Sustainability of Natural Resources

Scarcity of water resources constitute a vital issue for the Kingdom, due to the fact that the largest share of water consumed for agricultural, municipal and industrial purposes comes from non-renewable resources. Accordingly, requirements of sustainable development urge for rationalization of water consumption and more reliance on conventional renewable water resources etc. On the other hand, conservation of agricultural land and protection against degradation or desertification is a major challenge facing sustainable development. The same applies to conservation, development and protection of the environment.

1.5.3 Economic and Industrial Cities

The oil industry, directly or indirectly plays a key role for the economy, both in the parts of the KSA where the oil extraction takes place and in other parts of the country. Because of the oil industry in the Eastern part of the KSA and because of the export incomes this generates to the national economy, there is room for a large trade and service sector all over the country. It is seen that the GDP contributions from mining and quarrying, including petroleum and gas and from petroleum refining, increased between 2001 and 2011, whereas all other components decreased over this period. It is also seen that agriculture, forestry and fishing decreased from 5% of GDP in the KSA to only 2% during the 10-year period.

The two industrial cities of Jubail and Yanbu are also expanding.

Economic Cities

The Kingdom of Saudi Arabia has announced the launch of six economic cities namely (i) King Abdullah Economic City, Rabigh (ii) Prince Abdulaziz bin Musaid Economic City in Hail (iii) Knowledge Economic City in Madinah (iv) Jazan Economic City (v) Economic city of Tabuk in the north and (vi) the industrial developments in the eastern province including Dammam and Dhahran techno parks and the Energy Intensive Industry complex of Ras AlKhair.

The objective of the economic cities is to grow the national economy and raise the standard of living for Saudis through:

- Enhancing the competitiveness of the Saudi economy
- Creating new jobs
- Improving Saudis' skill levels
- Developing the regions
- Diversifying the Economy

To ensure success, the economic cities will be developed according to six key design principles:

- Each city will be developed around at least one globally competitive cluster or industry, which will serve as an anchor and a growth engine for the city, around which other businesses will locate.
- The cities will utilize their Greenfield opportunity to adopt state-of-the-art technology solutions to make them truly competitive.
- Each city will be developed by the private sector and will therefore generate major private investment opportunities in infrastructure, real estate and industry.
- By Identifying and attracting core investors, core jobs will be created which will then spur other supporting services jobs.
- To achieve our high aspirations in terms of job creation and investment volume, the cities need to offer an attractive lifestyle to grow beyond a mere industrial free zone.
- The cities will enjoy a business friendly regulatory environment which is competitive to other free zones globally.

1.6 Natural Resources and Management

1.6.1 Energy Resources

Oil and Gas Resources

The Kingdom of Saudi Arabia is one the largest oil exporting country and is a member of Organization of Petroleum Exporting Countries (OPEC).

1.6.2 Mineral Resources

Saudi Arabian Mining Company "Ma'aden" was established in 1417H, corresponding to 1997, as a Saudi Arabian joint stock company. Ma'aden is one of the main companies for the development of the mining sector in the Kingdom.

1.6.3 Renewable Energy Resources

As a result of the ever increasing demand of primary energy resources in the Kingdom of Saudi Arabia such as electricity, transportation, water and the industrial sectors, measures have been taken to control the escalating internal demand for the primary energy resources and also various measures have been taken to address this demand including by developing and deploying renewable energy sources in addition to other measures.

Developing and deploying renewable energy have been considered among the most sustainable and reliable sources of energy in the Kingdom to meet the increased internal demand for the primary energy, thus, minimize the opportunity cost of lost export revenues.

The Kingdom is among the first nations in the world that initiated unique programs on solar energy applications and utilizations, including, the SOLERAS, a Saudi Arabia-USA joint program on solar energy applications, initiated in 1977 and HYSOLAR, a Saudi Arabia-German joint program on solar hydrogen production and utilization, initiated 1986.

Renewable energy sources have tremendous advantages, including the potential to provide energy services in a sustainable manner, particularly, in mitigating climate change, availability of a wide range of renewable energy technologies that can meet the full need from energy services with little or zero CO_2 emissions depending on the level of technical maturity and commercial scale of renewable energy technologies, an equitable and sustainable economic development, secure energy supply, energy access and environmental and health benefits.

The ambitious future energy mix is strategically important to the Kingdom to attain long-term prosperity, energy security and leading position in the global energy market. Building on some commercial and economical potential of renewable energy technologies, solar photovoltaic energy, concentrated solar energy and wind energy are envisaged as the most potential renewable energy sources in the Kingdom compared to the other technologies.

Private sector plays a critical role in the achievement of the sustainable economic and social development objectives. The participation of private sector in developing reliable renewable energy sources in the Kingdom could be promoted through implementing some multi-level economic frameworks that could be selected on the basis of technologies, applications and goals of development process.

1.6.4 Electricity Generation and Consumption

Currently, the Kingdom has a single vertically integrated electricity company, Saudi Electricity Company (SEC), which owns all the three verticals of the power industry, including most of the generation, complete transmission and virtually all distribution capacities, with an exception in the industrial city of Yanbu, where Marafiq (a private integrated utility company) is responsible for generation, transmission and distribution of electricity. However, there are a considerable number of other private generators and Independent Power Producers (IPPs) that produce power and sell all of their generation to SEC or supply to isolated loads (not connected to the grid). Quite a few Industrial consumers, which are having large demand, also have internal generation (captive generation), which is used to feed a substantial portion of their own load.

The government has been very considerate to open the electricity market for restructuring. This decision to restructure the market and open it for competition primarily in the generation space would help the Kingdom in bridging gap between supply and ever increasing demand. Also, with several IPPs coming up, alternative means of power generation would gain more importance. Electricity and Cogeneration Regulatory Authority (ECRA) of the Kingdom has prepared a detailed restructuring plan under the banner of Electricity Industry Restructuring Plan (EIRP). ERIP is primarily divided into three major milestones detailed as follows:

- Unbundling SEC from being a vertically integrated monopoly in creating a market for open generation and distribution
- Create a separate transmission company, which would operate independently of the generation, distribution and retail businesses
- To encourage the concept of the “Parallel Market” where large consumers can directly procure electricity from suppliers of their choice at a mutually agreed price and conditions

The residential sector consumes about half of the electricity supply, closely followed by the industrial, commercial/trade and government facilities at 19%, 15% and 13%, respectively. Saudi Arabia is facing a sharp rise in the demand for power, driven primarily by population growth, rapid expansion of the industrial sector, higher cooling demand during the summer and low end-user prices. Kingdom’s leadership has been instrumental in pointing out the urgency to expand the current installed capacity and look for alternatives, in terms of fuel mix for power generation.

1.6.5 Water Resources

The water resources in the Kingdom can be classified into four categories namely surface water, groundwater, desalinated seawater and reclaimed wastewater. Conventional water resources including groundwater and surface water are the major sources of water supply while the non-conventional water resources, including treated wastewater and desalinated seawater only contributes a small percentage of water supply. In last three decades, groundwater resources have been the most reliable water resource in the Kingdom to support its comprehensive agricultural, industrial and socio-economic development (Ouda, 2013).

Surface Water

To facilitate storage of surface water runoff and also to prevent flash floods, a great amount of dams have been constructed throughout the Kingdom by the Ministry of Water and Electricity (MOWE), presently Ministry of Environment, Water and Agriculture (MEW). The use of constructed dams for storing runoff water reduces surface water evaporation while increases infiltration for recharging groundwater resources (Tuinhof & Heederik, 2002). It is estimated that approximately 1.4 BCM of surface water runoff is stored annually through a total of 302 dams across the Kingdom (MOEP, 2010). Among those dams, 275 dams are used for groundwater recharge and controlled recharging approximately 992.7 MCM/year of water. A total of 25 dams are used to store 303.5 MCM/year of water annually for drinking water supply while 2 dams are used to store 51.5 MCM/year for agricultural irrigation (Chowdhury & Al-Zahrani, 2013).

Ground Water

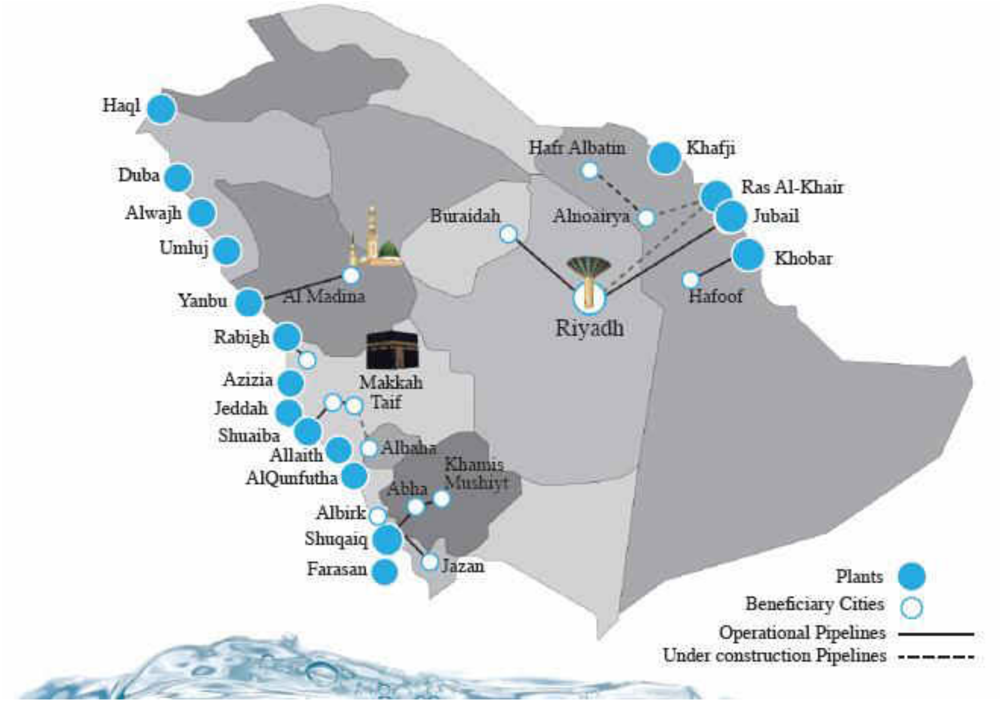
Groundwater is the most reliable water source in the Kingdom and it provided over 84% of the Kingdom's water supply since 1985. In the Kingdom, groundwater resources exist in two main sources: the shallow alluvial and deep rock aquifers. The shallow alluvial aquifers are the main sources of renewable groundwater resources and these aquifers located mostly in the western and southwestern parts of the Kingdom. These renewable groundwater resources are stored in basalt layers of varying thickness and width and usually exist under major valleys within the coastal mountains. Groundwater in those unconfined alluvial aquifers can be replenished more frequently and rapidly than the deep sedimentary, mostly confined aquifers. Those renewable groundwater resources are utilized for domestic and agriculture purposes and even drinking in some rural areas. It is worthy to mention that those aquifers are sensitive to human activities especially when the aquifers are located in the vicinity of major cities and towns with high population (Ouda, 2013). The aquifer is estimated to store 84 BCM with an average annual recharge of 1196 MCM. However, those estimates were mostly based on the investigations carried out over fifteen years ago and shall be updated with more recent studies (Ouda, 2013). The groundwater recharge is important for sustainable groundwater management and planning, especially for water-scarce regions in the Kingdom.

The main source of water for Saudi Arabia is non-renewable fossil groundwater in the sedimentary aquifers. The aquifer water is generally brackish and confined in sand and limestone formations of a thickness of approximate 300 m at a depth from 150 -1500m (Chowdhury& Al-Zahrani, 2013). The sedimentary aquifers can be classified as either primary or secondary, based on their areal extent, groundwater volume, water quality and development potential. The principal aquifers include Saq, Wajid, Tabuk, Minjur, Dhruma, Biyadh, Wasia, Dammam, Umm ErRadhuma and Neogene (Chowdhury& Al-Zahrani, 2013). The secondary aquifers include Al-Jauf, Al-Khuff, Al-Jilh, the upper Jurassic, Sakaka, the lower Cretaceous, Aruma, Basalts and Wadi Sediments (Ouda, 2013).

Desalination of Seawater

Under scarcity of conventional water resources and high water consumption rates, seawater desalination has become a strategic approach to the Kingdom of Saudi Arabia to meet the growing demand for water. Saline Water Conversion Corporation (SWCC) has made Saudi Arabia the world's leading producer of desalinated seawater by virtue of its tremendous desalination projects. During 2014, the total water export from the SWCC's plants amounted to one billion, one hundred and seven million and six hundred thousand cubic meters (1,107,600,000 m^3), an increase of 10% as compared to the previous year. Around 550.1 million cubic meters amounting to 49.7% were exported from the Eastern Coast plants, feeding the Eastern Coast governorates, Riyadh, Qassim, Sudair and Al Washim regions; about 557.5 million cubic meters amounting to (50.3%) were also exported from the Western Coast plants, feeding the holy city of Makkah, Jeddah, Madinah, Tabuk, Al Baha, Asir and Jazan regions. Additionally, the initial operation of Ras AlKhair plant, as the first section, with a production capacity of 307,500 cubic meters/day commenced in April 2014, based on RO technology.

Figure 1.1: Desalination Plants on The Eastern and Western Coasts with Beneficiary Cities, Operational Pipelines and Under Construction Pipelines



Regarding electric power production from SWCC desalination plants as by-product, during the fiscal year 2014 amounted to 29,690,432 MWh, an increase of 19.3% as compared to the previous year. It is estimated that 70% of the required drinking water as well as 5% of the electricity demands in the Kingdom are met by the desalination plants.

Wastewater

In Saudi Arabia, a small fraction of wastewater is reclaimed for agricultural, landscaping and industrial uses. The wastewater is treated in around 70 sewage treatment plants in the Kingdom (Chowdhury & Al-Zahrani, 2013). Wastewater collection and treatment systems currently cover 42% of the Kingdom's urban area and is expected to increase to 60% of the urban area by 2014 (Ouda, 2013). There is continuous effort by the government to bring the remaining parts of the Kingdom under the network cover. Septic tanks and cesspits are used for wastewater disposal in areas without wastewater infrastructures, which cause environmental issues such as water table rise and possible pollution of groundwater.

About 1,460 MCM of wastewater is generated in the country, of which about 671 MCM (46%) are collected and treated. The treated wastewater has been extensively reused in many cities (e.g., Riyadh, Jeddah, Jubail, Yanbu etc.) for municipal park irrigation and urban area landscaping which is estimated to be 240 MCM which is about 38% of the treated wastewater (Ouda, 2013).

1.7 Tourism

Tourism has a huge potential for the Kingdom both as a field of employment and a source of income. The total number of international tourists to the KSA in 2011 was 17.5 million and domestic tourists amounted to 22.5 million (Tourism Information and Research Centre, 2012). The total expenditure of tourists was 85 billion SAR, which generated a value addition of 65.7 billion SAR (3% of GNP) and an employment of an estimated 670,000 (Tourism Information and Research Centre, 2012). Both indicators are growing faster than the average economic growth.

The holy city of Makkah takes a good share of the tourism industry. 55% of hotels and 18% of furnished apartments for tourists are in this province (Tourism Information and Research Centre, 2012). The majority of international tourists visited KSA for religious purposes, but pilgrims often transfer directly from the Airport terminal onto buses for Makkah or Medina. Jeddah is the only city in the KSA with a preserved historic downtown area. It possesses valuable and attractive historic assets such as the old town of Jeddah (Al Balad), which has been listed for consideration as a UNESCO World Heritage Site.

The surrounding areas have a number of highly desirable natural attractions, such as the coastline itself and the marine life as well as the unique and internationally recognized coral reefs. There are plenty of opportunities available for ecotourism and leisure visitors. Along the coastline, people have picnics at the beaches and go leisure fishing, kiting and undertake other recreational activities. Sailing and leisure fishing take place along the entire coastline and in particular close to existing marinas or ports. Scuba diving and snorkeling is undertaken at several places along the coast. Plenty of dive spots are located off Durat Al Arus in Jeddah and around the coral reefs of Eliza Shoals, north of Jeddah. There is thus a broad range of activities, but there is also a huge potential for more tourism along the Red Sea.

1.8 Agriculture

Over the past decades, the agricultural development in the Kingdom has significantly witnessed changes with new policies, aiming towards food security. Although the Kingdom's primary land area is a desert, it has regions where the climate supports agriculture. The government, in particular, has aided with this process by converting large areas of desert into agricultural fields. This was possible by implementing major irrigation projects and adopting large-scale mechanization.

Presently, agriculture in Saudi Arabia is focused on the production of wheat, dates, fish, poultry, etc. and exporting some of these volumes to neighboring countries and also to global players. The government has implemented many policies to ensure constant development. The Ministry of Agriculture's (MOAs), currently Ministry of Environment, Water and Agriculture (MEWA) primary goal is to frame agricultural policies, which will help both foreign and local suppliers. The Kingdom's other agencies include the Saudi Arabian Agricultural Bank (SAAB) – disbursement of subsidies and granting of interest free loans and the Grain Silos and Flour Mills Organization (GSFMO), who are responsible for purchase and storage of wheat, construction of flourmills and animal feed production. The government offers land distribution, reclamation programs and fund research projects. The private sector has played a major role in the Kingdom's agricultural development. This is primarily due to the government programs that offered long term, interest free loans, technical and support services and incentives, such as free seeds and fertilizers, low-cost water, fuel, electricity and duty free imports of raw materials and machinery. Foreign joint-venture partners of the Kingdom's individuals or companies have been exempt from paying taxes up to 10 years.

Saudi Arabia has allocated substantial financial resources for improving roads, linking producing areas with consumer markets. Such programs encouraged the participation of private players in the market. Water is a key resource for agriculture. The Kingdom had successfully implemented a multifaceted program to provide the vast supply of water necessary to achieve the tremendous growth of the agricultural sector. This was possible by constructing dams in strategic location to utilize the seasonal flood for irrigation. However, the scarcity of water has been increasing for the past few years, which thereby impacted the production of few crops.

1.9 Institutional Arrangement for National Communication

The focal point of the UNFCCC in the KSA is based at the Ministry of Energy, Industry and Mineral Resources (MEIMR) and the focal point for the preparation of the Third National Communication (TNC) is the "Designated National Authority (DNA)".

The Designated National Agency (DNA) serves as the implementing entity. The project is implemented in close coordination and cooperation of a number of institutions stakeholders. The institutional framework is composed of a set of institutions and their roles, the cooperative mechanism amongst them and a dedicated team of support staff from the Designated National Agency (DNA). DNA has hosted the Project Management Unit (PMU) and is fully responsible for the implementation of the project.

1.9.1 Structure of the DNA

The National Committee for the Clean Development Mechanism (CDM) is the Designated National Authority (DNA) for CDM supervised by National Climate Change Committee (NCCC) in KSA. The National Committee is chaired by a representative of the Ministry of Energy, Industry and Mineral Resources (MEIMR). Other members of DNA belong to the following Ministries and entities:

i. Ministry of Municipal and Rural Affairs

ii. Ministry of Commerce and Investment

iii. Ministry of Health

iv. Ministry of Environment, Water and Agriculture

v. General Authority of Meteorology and Environmental Protection (GAMEP)

vi. Royal Commission for Jubail and Yanbu (RCJY)

vii. Saline Water Conversation Corporation (SWCC)

viii. Saudi Aramco

ix. Saudi Arabian Basic Industries Corporation (SABIC)

x. Saudi Electricity Company (SEC)

xi. King Abdulaziz City for Science and Technology (KACST)

xii. King Abdullah City for Atomic and Renewable Energy (KACARE)

The National Committee is supported by a Secretariat based at the Ministry of Energy, Industry and Mineral Resources which reports to the Chairman of the Committee.

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SECTION – 2

National Inventory of Anthropogenic Greenhouse Gas Emissions by Sources and Removals by Sinks for the Year 2010

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Section 2: National Inventory of Anthropogenic Greenhouse Gas Emissions by Sources and Removals by Sinks for the Year 2010

2.1 Introduction

This section presents the "*National inventory of anthropogenic emissions by sources and removals by sinks of greenhouse gases not controlled by the Montreal Protocol*" for the year 2010. This inventory has been prepared in response to the Kingdom's commitment to the United Nations Framework Convention on Climate Change (UNFCCC) to submit its third National communication which would include national inventory of anthropogenic emissions and removals by sinks of greenhouse gases for Saudi Arabia according to the Revised 1996 Guidelines of the Intergovernmental Panel for Climate Change (IPCC, 1997).

The Kingdom of Saudi Arabia ratified the United Nations Framework Convention on Climate Change in December 1994. This convention aims to stabilize the greenhouse gas concentrations in the atmosphere at a level that would prevent significant potential changes to the global climate. One effective option that has been adopted by various developed countries to obtain this objective is the stabilization of greenhouse gas emissions by the year 2000 at their 1990 levels. Being a signatory to the UNFCCC, Saudi Arabia has agreed to develop a national inventory of greenhouse gas emissions and sinks as part of its National Communication. Accordingly, the Kingdom submitted its First and Second National Communications in 2005 (PME, 2005) and 2011 (PME, 2011), respectively.

The 2010 national inventory of anthropogenic emissions of greenhouse gases by sources and removals by sinks for the Kingdom of Saudi Arabia was developed according to the Revised 1996 IPCC Guidelines. The major findings including a brief description of the inventory development process are presented in the following sections.

2.2 Objectives

As mentioned above the main objective of this section was to present a national inventory of anthropogenic emissions of greenhouse gases by sources and removal by sinks for Saudi Arabia for 2010 addressing the three direct greenhouse gases (i.e., CO_2, CH_4 and N_2O) as an integral part of the Kingdom's Third National communication to the UNFCCC.

2.3 Inventory Development Process

The inventory development process included the following major steps:

- Identification of the types of data to be collected from each emission source category and sub-sectors (under each category) as proposed in the Revised 1996 IPCC Guidelines;
- Preparation of a list of government ministries and other governmental, semi-governmental and private organizations that would be contacted to collect the required information (identification of the inventory data input sources);
- Development of questionnaires or forms to collect the required information from the selected ministries and organizations (development of questionnaires);

- Collection of inventory data from all the selected ministries and organizations (collection of information);
- Tabulation of the collected data in the IPCC prescribed format;
- Estimation of greenhouse gas emissions/sinks based on methodologies recommended by the Revised 1996 IPCC Guidelines; and
- Development of the national inventory report and summary of total anthropogenic emissions of greenhouse gases and their removals by sinks.

2.4 Data Collection, Emission Factors and Methodologies

2.4.1 Preparation of Questionnaires

The Revised 1996 IPCC Guidelines were utilized in the preparation of questionnaires. These Guidelines are in three volumes. Volume 1 consists of general reporting instructions and identifies sectors, sub-sectors and categories of activities that are considered in developing a greenhouse inventory of sources and sinks. The methodologies for estimating emissions are discussed in Volume 2 (Workbook) and Volume 3 (Reference Manual) elaborates on the scientific bases of the methodologies and default factors that are used in the calculations of greenhouse gas emissions.

The Revised 1996 IPCC Guidelines for preparing the greenhouse inventory were reviewed thoroughly to identify inventory input data requirements for each of the activities given in the documents. The workbook accompanying the Revised 1996 IPCC Guidelines was also checked thoroughly for additional and/or auxiliary information that may be required for calculating emissions of greenhouse gases. Custom-made questionnaires were developed for each targeted organization/company and forwarded to them for their input.

2.4.2 Selection of Target Organizations/Companies

Based on the input data requirements for calculating greenhouse emissions for each sector and sub-sector given in the Revised 1996 IPCC Guidelines, a list of potential government departments, private organizations and industrial companies, from which such information should be available, was prepared. All relevant information sources were consulted in preparation of this list.

2.4.3 Input Data Sources

The basic information sources prepared during the development of the First (PME, 2005) and the Second (PME, 2011) National Communications for the Kingdom of Saudi Arabia were updated for selection of target organizations to obtain necessary data pertinent to direct greenhouse gas emission sources in the Kingdom. The custom-made questionnaires were prepared and mailed to each of the targeted organizations/companies. The inputs from these organizations/companies were carefully reviewed and analyzed for utilization in the calculations of greenhouse gas emissions. In addition to the questionnaires, various other sources of information were consulted.

2.4.4 Input Data Collection and Tabulation

The data collected through questionnaires and from other accessible sources were sorted for individual activities for which direct greenhouse gas emissions were to be calculated.

Information obtained from different sources for a specific activity was combined, as appropriate. Some of the information requested in the questionnaires was not provided by the respondents. In such cases, appropriate assumptions were made to estimate the missing data.

2.4.5 Selection of Emission Factors and Calculation Methodologies

In addition to the basic inventory input data, emission factors were needed to calculate greenhouse gas emissions. These emission factors were adopted from the Revised 1996 IPCC Guidelines. Additionally, available more accurate (than the default emission factors suggested in IPCC Guidelines) country-specific information was also adopted in this study. Calculation methodologies in the Revised 1996 IPCC Guidelines were followed in estimating greenhouse gas emissions in this study.

2.4.6 Uncertainties in Emissions Estimation

Due to the unavailability of certain source specific input data including emission factors, uncertainties are unavoidable when any estimate of national emissions or removals is made. It is therefore important to establish and express uncertainties quantitatively and/or with the acceptable confidence interval or range. The Revised 1996 IPCC Guidelines provide a general table for relative uncertainties associated with emission factors and activity data, which is limited to CO_2 and CH_4 emissions only.

Uncertainties in emissions estimation basically come from three major sources: input data, the assumptions used in selecting the emission factors and adopting extrapolated and/or averaged values in calculations.

Uncertainties related to input data depend mainly on the size and quality of data collection and record keeping. Uncertainties involved in selection of emission factors come from the fact that the default values provided in the Revised IPCC Guidelines (1997) were established for a certain group of activities that comprises a number of processes. The nature of a group of activities in a particular country may differ from the generalized nature of the group considered in derivation/establishment of the default emission factors. Similar analogy applies to the variation in source and/or sink characteristics in different countries. Therefore, the default emission factors may not exactly represent and characterize the actual conditions of source/sink activities. In such cases, using these factors to calculate the greenhouse gas emissions would result in high uncertainties.

Uncertainties also appear when the unavailability of input data compels the use of extrapolated and/or averaged values for a particular set of data. Uncertainty of extrapolated or averaged data cannot be quantified precisely because the uncertainties associated with the interpolation and/or averaging procedures also depend on the quality of the relevant data including accuracy.

Input Data

The raw data provided by the government organizations were considered to be accurate while the raw data supplied by the private sectors were considered to be accurate in some cases and the uncertainty of raw data were considered to vary within 5% to 10% in others. As mentioned above, the uncertainties involved in estimation of missing data were not quantified since it was not possible to establish uncertainty levels associated with the extrapolated and/or averaged values adopted in emissions calculations.

Emission Factors

The uncertainties associated with the emission factors used in this study were taken from the IPCC Guidelines (1997) and ranged between 7 and 55%.

Overall Emissions Estimation

The overall uncertainty of CO_2 and CH_4 emissions were estimated according to the Revised IPCC Guidelines (1997). Uncertainties in emission estimates for N_2O were not determined due to the unavailability of relevant data and/or methodology in the IPCC Guidelines.

2.5 Summary of Overall Greenhouse Gas Emissions and sinks

2.5.1 Overview of 2010 National Greenhouse Gas Emissions and Sinks

The 2010 greenhouse gas emission inventory for Saudi Arabia is summarized in Table 2.1. The details of estimated greenhouse gas emissions from various activities associated with sub-sectors in each sector are presented in Table 2.2. The inventory included the direct greenhouse gases; namely, carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). Emissions of these gases were calculated for the energy, industrial processes, agriculture, land-use change and forestry and waste sectors in the Kingdom. Greenhouse gas emissions from the various uses of paints and solvents have not been recommended by the Revised 1996 IPCC Guidelines, thus, they were not included in this report. The major findings pertaining to individual greenhouse gases are summarized below.

- CO_2 emissions in Saudi Arabia in 2010 were 472,186 Gg and CO_2 sinks were 9,049 Gg. As shown in Table 2.1, the energy sector contributed 89.7% of the total CO_2 emissions, followed by the industrial processes sector (10.1%) and the agriculture sector (0.2%). The major source categories (Figure 2.1) contributing to these CO_2 emissions (contributions $\geq$ 2% of the total emissions) were electricity generation (31%), road transport (21%), desalination (12%), petroleum refining (8%), petrochemical industry (7%), cement production (5%), iron and steel production (4%), fuel combustion in cement industry (3%), agriculture (2%) and fertilizer industry (2%).

Table 2.1: Summary of 2010 Direct Greenhouse Gas Emissions Inventory for Saudi Arabia

Source Sector	Quantity Emitted (Gg)		
	CO_2	CH_4	N_2O
Energy*	423,713.8 (89.7)**	868.17 (42.01)	2.32 (6.7)
Industrial Processes	47,532.6 (10.1)	35.70 (1.7)	
Agriculture	939.2 (0.2)	74.06 (3.6)	28.39 (82.4)
Land-use Change and Forestry	-9,049.4*** (1.9)		
Waste		1,088.79 (52.7)	3.75 (10.9)
Total Emissions	**472,186**	**2,067**	**34.47**
Net Emissions******	**463,136**	**2,067**	**34.47**

** As per the IPCC Guidelines, emissions from International Aviation and Navigation Bunkers were not included in Total Emissions; ** Numerals in brackets are percentages of Total Emissions; *** Minus sign indicates sink; **** Total emissions minus sinks.*

Table 2.2: Overview of 2010 National Direct Greenhouse Gas Emissions Inventory for Saudi Arabia

SOURCE AND SINK CATEGORIES	CO_2 (Gg)	CH_4 (tons)	N_2O (tons)
Total National Emissions	**472,186**	**2,066,725**	**34,466**
Net National Emissions	**463,136**	**2,066,725**	**34,466**
1. Energy*	**423,713.8**	**868,167.8**	**2,321.7**
A. Fuel combustion	419,948.2	31,956.5	2,321.7
1. Energy industries	186,610.8	5,735.0	1,016.2
2. Manufacturing industries and construction	60,178.7	4,942.2	154.2
3. Transport	105,302.3	19,257.8	907.3
4. Other Sub-sectors	67,856.3	2,021.5	244.1
B. Fugitive emissions from fuels	3,765.6	836,211.2	
2. Industrial processes	**47,532.6**	**35,699.9**	**0.0**
A. Mineral products	25,281.0		
B. Chemical industry	4,331.6	35,699.9	
C. Iron and steel production	17,920.0		
3. Solvent and other product use**			
4. Agriculture	**939.2**	**74,063.8**	**28,392.0**
A. Enteric fermentation		59,270.6	
B. Manure management		13,085.6	8,590.1
C. Agricultural soils			19,772.8
D. Field burning of agricultural residues	939.2	1,707.7	29.1
5. Land-use change and forestry	**-9,049.4**	**0.0**	**0.0**
A. Changes in forest and other woody biomass stocks	-8,902.6		
B. Forest and grassland conversion	-105.9		
C. Abandonment of managed lands***			
D. CO_2 emissions and removal from soil	-40.9		
6. Waste		**1,088,793.9**	**3,752.7**
A. Solid waste disposal on land		714,578.0	
B. Wastewater handling		13,197.5	
C. Human sewage			3,752.7
D. Industrial wastewater		361,018.4	

** As per the IPCC Guidelines, emissions from international aviation and navigation bunkers were not included in energy total;*
*** Estimation of greenhouse gas emissions from the various uses of paints and solvents have not been recommended by the Revised 1996 IPCC Guidelines.*
**** No abandonment of managed lands in Saudi Arabia was assumed.*

Figure 2.1: Relative Contributions of Major Source Categories to 2010 CO_2 Emissions of 472,186 Gg (Data from Table 2.3)

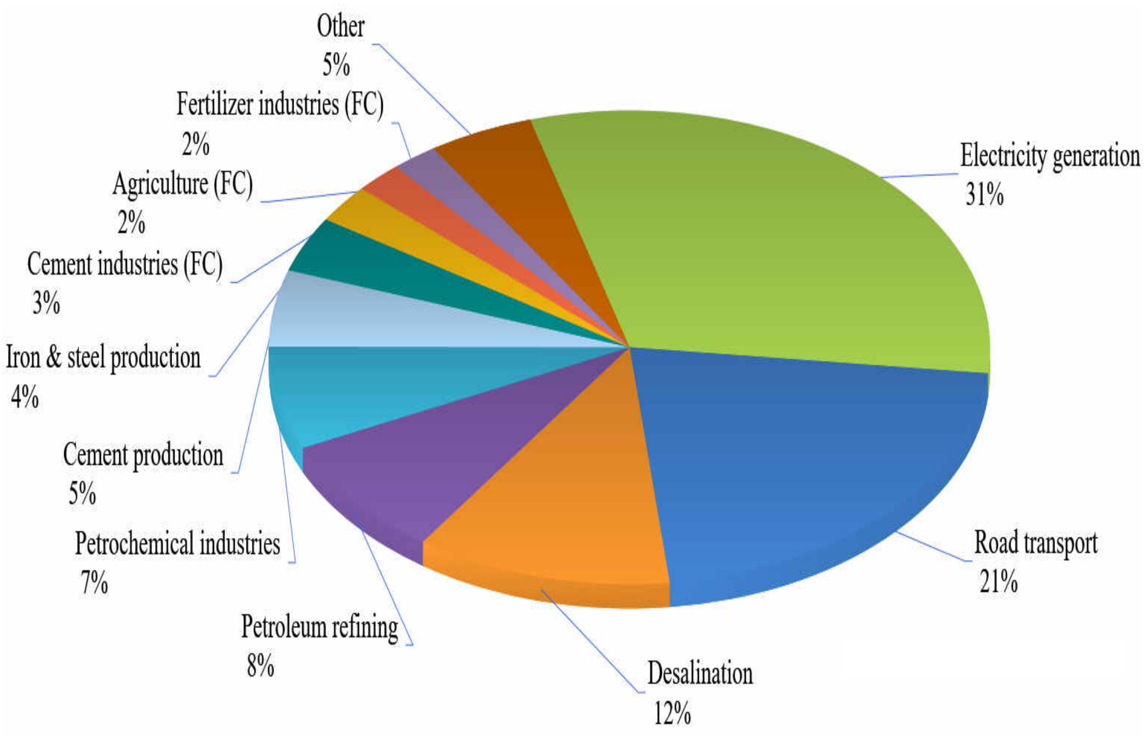


Table 2.3: 2010 Carbon Dioxide (CO_2) Emissions from Major Source Categories

Source Categories	CO_2 (Gg)	Percent of Total
Electricity Generation	147,331.8	31
Road Transport	101,334.1	21
Desalination	54,192.3	12
Petroleum Refining	39,279.1	8
Petrochemical Industries	33,178.7	7
Cement Production	24,713.3	5
Iron & Steel Production	17,920.0	4
Cement Industries (FC*)	12,325.8	3
Agriculture (FC)	9,995.9	2
Fertilizer Industries (FC)	9,700.1	2
Others **	22,214.4	5
Total	**472,186**	**100**

* Fuel Combustion

** Others include the following source categories:

Iron and steel (FC)(4,572.8 Gg)	*Limestone production and uses(464.1 Gg)*
Ammonia production(4,331.6 Gg)	*Other industries (FC)(401.2 Gg)*
Residential(3,668.1 Gg)	*Oil refining (FE)(231.3 Gg)*
Navigation(2,231.4 Gg)	*Soda ash uses(103.6 Gg)*
*Oil and gas production (FE***)(1,804.9 Gg)*	*Railways(85.7 Gg)*
Aviation(1,651.1 Gg)	*Oil and gas exploration (FE)(69.7 Gg)*
Gas processing (FE)(1,643.2 Gg)	*Oil and gas transportation (FE)(16.4 Gg)*
Field burning of crop residues(939.2 Gg)	

*** Fugitive Emissions

- CH_4 emissions were 2,067 Gg as shown in Table 2.1. The waste sector contributed 52.7% of the total CH_4 emissions followed by the energy (42%), agriculture (3.6%) and the industrial processes (1.7%) sectors. The major source categories contributing to CH_4 emissions (≥2% of the total emissions) are shown in Figure 2.2.

Figure 2.2: Relative Contributions of Major Source Categories to 2010 CH_4 Emissions of 2,067 Gg (Data from Table 2.4)

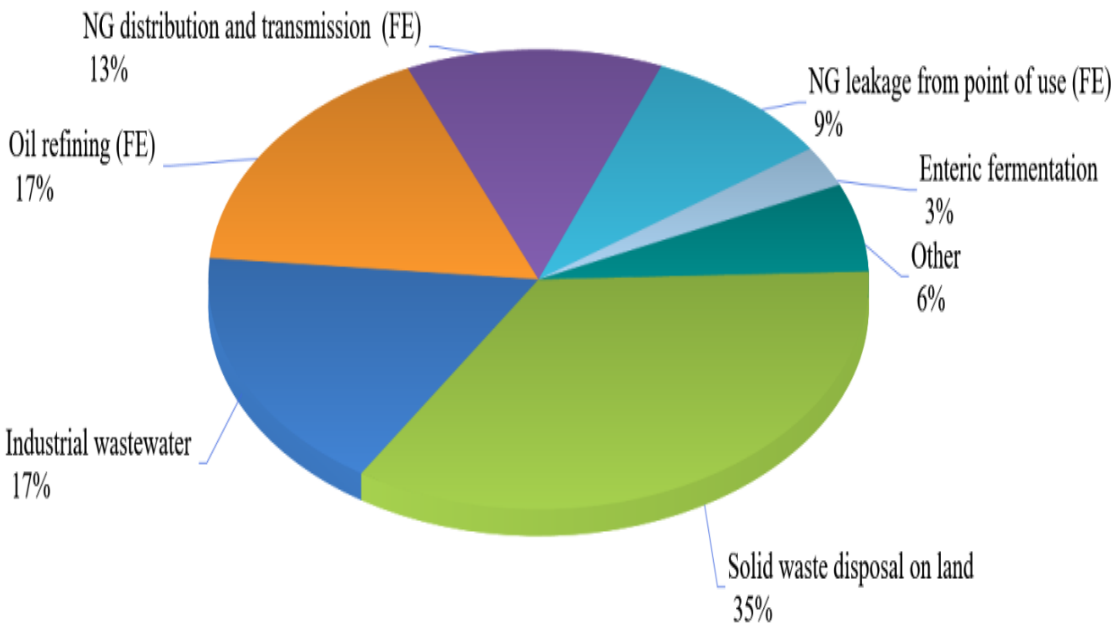


Table 2.4: 2010 Methane (CH_4) Emissions from Major Source Categories

Source Categories	CH_4 (ton)	Percent of Total
Solid waste disposal on land	714,578.0	35
Industrial wastewater	361,018.4	17
Oil refining (FE*)	351,993.4	17
NG distribution and transmission (FE)	259,358.3	13
NG leakage from point of use (FE)	192,320.8	9
Enteric fermentation	59,270.6	3
Others**	128,185.9	6
Total	**2,066,725**	**100**

* Fugitive emission

** Others include the following source categories:

Chemicals production(35,699.9 tons)

Road transport(19,065 tons)

Oil and gas production (FE)(14,356.4 tons)

Wastewater handling(13,197.5 tons)

Manure management(13,085.6 tons)

Gas processing (FE)(12,700.5 tons)

Electricity generation (5,088.5 tons)

Oil and gas transportation (FE)(4,666.4 tons)

*Petrochemical (FC***)(2,972.0 tons)*

Field burning of crop residues(1,707.7 tons)

Agriculture (FC)(1,363.2 tons)

Fertilizer industries (FC)(868.9 tons)

Oil and gas exploration (FE)(815.5 tons)

Cement industries (FC)(681.0 tons)

Petroleum refining(646.4 tons)

Iron and steel (FC)(409.6 tons)

Desalination(366.0 tons)

Residential(292.3 tons)

Navigation(145.7 tons)

Aviation(41.3 tons)

Other industries (FC)(10.7 tons)

Railways(5.8 tons)

*** Fuel Combustion

- N_2O emissions were 34.47 Gg as shown in Table 2.1. The agriculture sector was the major contributor with 82.4%, followed by the waste (10.9%) and energy (6.7%) sectors. Major source categories contributing to N_2O emissions (≥2% of the total emissions) are shown in Figure 2.3.

Figure 2.3: Relative Contributions of Major Source Categories to 2010 N_2O Emissions of 34.47 Gg (Data from Table 2.5)

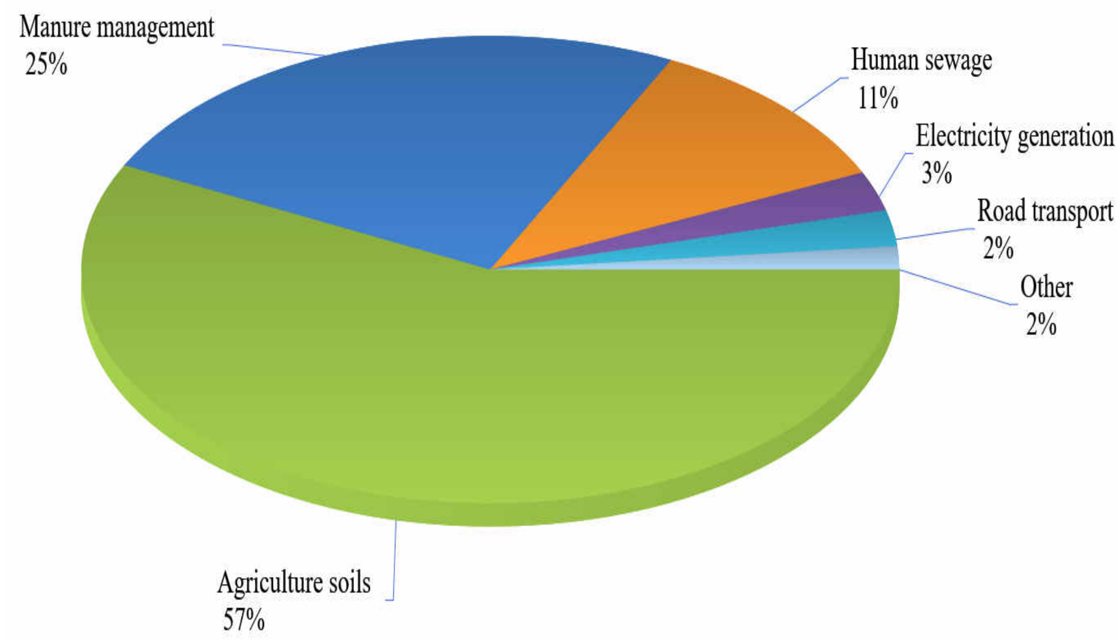


Table 2.5: 2010 Nitrous Oxide (N_2O) Emissions from Major Source Categories

Source Categories	N_2O (ton)	Percent of Total
Agriculture Soils	19,772.8	57
Manure Management	8,590.1	25
Human sewage	3,752.7	11
Electricity generation	943.4	3
Road transport	859.8	2
Others*	547.5	2
Total	**34,466**	**100**

* Others include the following source categories:

Desalination(156.4 tons)

*Agriculture (FC**)(81.8 tons)*

Petroleum refining(72.7 tons)

Cement industries (FC)(65.9 tons)

Petrochemical (FC)(59.4 tons)

Aviation(29.3 tons)

Field burning of crop residues(29.1 tons)

Navigation(17.5 tons)

Fertilizer industries (FC)(17.4 tons)

Iron and steel (FC)(8.2 tons)

Residential(5.8 tons)

Other industries (FC)(3.2 tons)

Railways(0.7 tons)

** Fuel Combustion

2.5.2 Uncertainties in Greenhouse Gas Emission Estimations

In this study, the raw data provided by the government organizations were considered to be accurate. The data reported by the well-known international organizations, which were verified were also considered to be accurate. However, the uncertainty of the raw data supplied by the private sectors assumed to vary within 10%. The activity data used for estimation of more than 80% of the total greenhouse gas emissions were considered to be reasonably accurate. The overall uncertainties of CO_2 and CH_4 emissions were estimated to be in the range of 7-15% and 25-60%, respectively (as per the IPCC Guidelines). Uncertainties in emission estimates for N_2O could not be determined due to the unavailability of methodology and/or the emission factors in the Revised 1996 IPCC Guidelines. Uncertainties involved in using extrapolated values, yearly averaged values, or both were not established. Uncertainties due to exclusion of some sources were also not assessed.

2.6 Contributions of Major Sectoral Activities to 2010 Greenhouse Gas Emissions

The contributions of major activities associated with the energy, industrial processes, agriculture, land-use change and forestry and waste sectors in the Kingdom to the 2010 greenhouse gas emission inventory for Saudi Arabia is presented in Table 2.2. The main findings pertaining to individual greenhouse gases are summarized below.

2.6.1 Energy Sector

The energy sector is the most important contributor to greenhouse gas emissions, especially to carbon dioxide (CO_2) emissions. Different activities considered in the energy sector are presented in Figure 2.4.

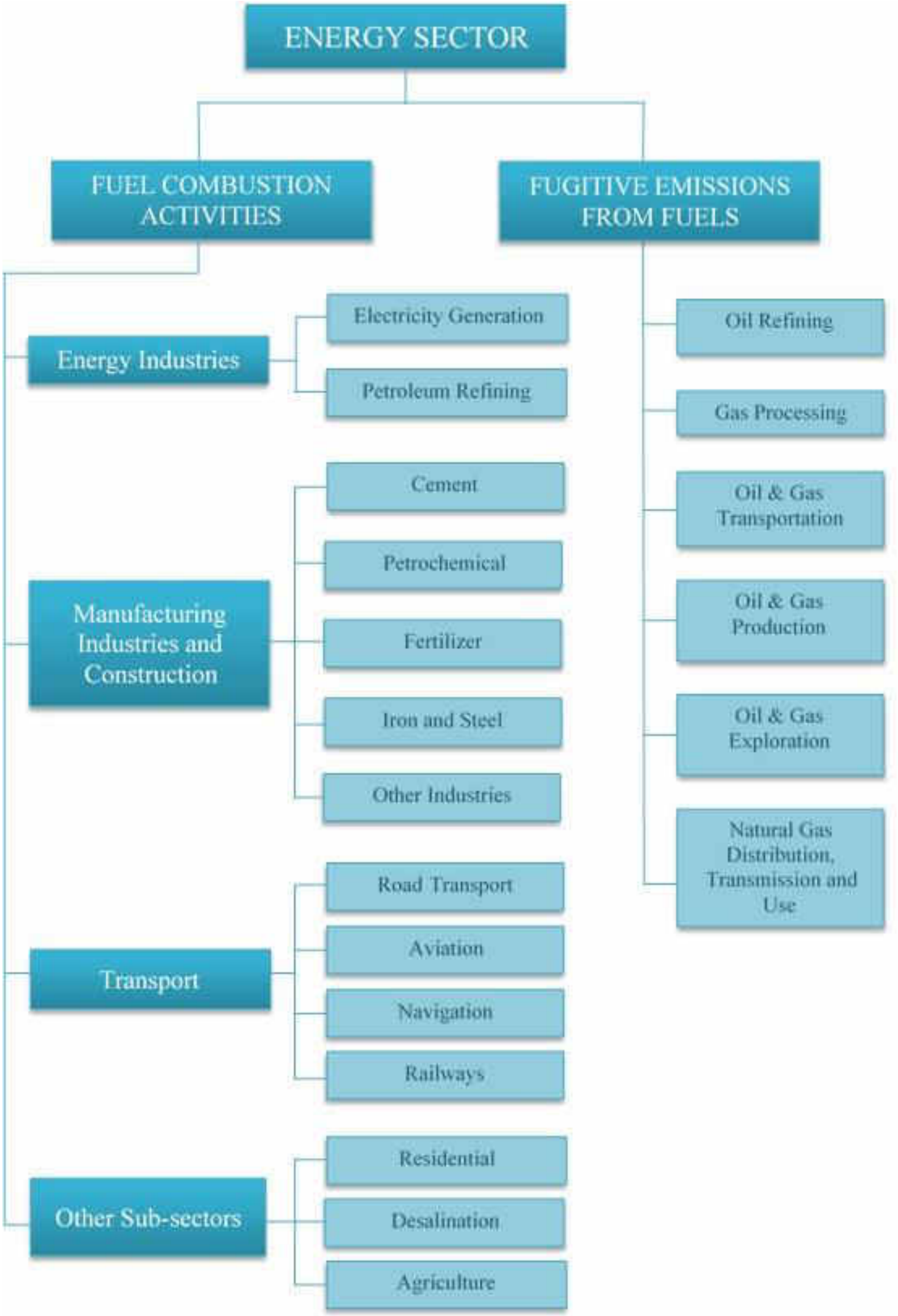
Greenhouse gas emissions from energy-related stationary and mobile combustion source categories were considered in this sector. These sources included electricity generation, petroleum refining, manufacturing industries and construction and transportation (road transport, civil aviation, navigation and railways). Residential, desalination, agriculture and fisheries and waste management activities were also accounted for. In addition to the combustion sources, fugitive emissions from fuels in the oil and gas industry and other usage, including venting and flaring, were considered.

The emissions of CO_2, CH_4 and N_2O from various activities in this sector were estimated and are summarized in Table 2.2. The total CO_2, CH_4 and N_2O emissions from this sector were 423,714 Gg, 868.17 Gg and 2.32 Gg, respectively.

Emissions from Fuel Combustion

- Emissions from the **electricity generation** category were 147,332 Gg CO_2, 5.09 Gg CH_4 and 0.94 Gg N_2O. Crude oil combustion accounted for 43% of CO_2 emissions, followed by natural gas (28%), diesel oil (24%) and residual fuel oil (5%). Combustion of crude oil, diesel oil, natural gas and residual fuel oil contributed 52%, 28%, 15% and 5% of CH_4 emissions, respectively. About 56% of N_2O emissions were contributed by the combustion of crude oil, followed by the combustion of diesel oil (30%), natural gas (8%) and residual fuel oil (6%).

Figure 2.4: Activities Considered in the Energy Sector



- The **Petroleum Refining** category encompasses activities related to oil refining, gas processing, oil and gas production, oil and gas transportation and oil and gas exploration. Emissions from petroleum refining were 39,279 Gg CO_2, 0.65 Gg CH_4 and 0.07 Gg N_2O. Fuel combustion associated with gas processing activities was the major contributor to CO_2 emissions, followed by those generated by the fuel combusted in the oil refining activities. The emissions of CH_4 and N_2O from different activities of petroleum refining category followed the similar trends to those of CO_2 emissions.
- The **Manufacturing Industries and Construction** category consists of activities related to the cement industry, petrochemicals manufacturing, fertilizer industry, iron and steel industry and other industries. Total emissions from fuel combustion in these activities were 60,179 Gg, CO_2, 4.94 Gg CH_4 and 0.15 Gg N_2O. Activities related to the petrochemical, cement and fertilizer industries were the largest contributors to CO_2 and CH_4 emissions in this category. The cement industry was the major contributor to N_2O emissions from the manufacturing industries and construction category followed by petrochemical and fertilizer.
- The **Road Transportation** category was one of the major sources of greenhouse gas emissions. Automobiles emitted 101,334 Gg CO_2, 19.1 Gg CH_4 and 0.86 Gg N_2O. Gasoline combustion was the major contributor to the emissions of three direct greenhouse gases.
- The **Aviation** category was divided into national and international aviation combustion sources. The greenhouse gas emissions from national aviation combustion sources were 1,651 Gg CO_2, 0.04 Gg CH_4 and 0.03 Gg N_2O. The emissions from international aviation combustion sources were 4,030 Gg CO_2, 0.03 Gg CH_4 and 0.13 Gg N_2O. The emissions from the combustion for international aviation category were not included in the 2010 greenhouse gas emissions inventory as per the Revised 1996 IPCC Guidelines.
- The **Navigation** category was divided into national and international bunker combustion sources. The emissions from national bunker combustion sources (including fisheries activities) were 2,231 Gg CO_2, 0.15 Gg CH_4 and 0.02 Gg N_2O. The emissions from international bunker combustion sources were 8,246 Gg CO_2, 0.54 Gg CH_4 and 0.06 Gg N_2O. The emissions from the international combustion for navigation category were not included in the 2010 greenhouse gas emissions inventory as per the Revised 1996 IPCC Guidelines.
- The **Railways Activities** relate to the combustion of diesel oil. Emissions from fuel combustion in the railways activities category were 86 Gg CO_2 and very small quantities (<0.01 Gg) of CH_4 and N_2O.
- The **Residential Activities** relate to the combustion of liquefied petroleum gas. Emissions from fuel combustion in the residential activities category were 3,668 Gg CO_2, 0.29 Gg CH_4 and <0.01 Gg N_2O.
- The **Desalination** plants combust heavy fuel oil, crude oil, diesel oil and natural gas. Emissions from fuel combustion in the desalination plants category were 54,192 Gg CO_2, 0.37 Gg CH_4 and 0.16 Gg N_2O.
- In the **Agricultural** category, off-road vehicles (such as tractors, bulldozers, etc.), irrigation and the activities related to poultry and dairy farms were considered (from fuel combustion only). Emissions from the agricultural category were 9,996 Gg CO_2, 1.36 Gg CH_4 and 0.08 Gg N_2O.

Fugitive Emissions from Fuels

The fugitive emissions (non-combustion and non-productive combustion emissions) were the major source of CH_4 in the energy sector (96%) and accounted for about 836 Gg CH_4. Oil refining, gas processing, oil and gas production, transportation, exploration, venting and flaring and leakage from distribution, transmission and point of use were considered in the above estimate. Approximately 52% of CH_4 emissions in this sector were generated from leakage of natural gas during distribution, transmission and use. Oil and gas related activities (i.e., exploration, production, transportation, processing, oil refining activities, flaring and venting) accounted for 44% of CH_4 emissions. All other activities accounted for about 4% of CH_4 emissions. Gas flaring from oil and gas related activities emitted 3,766 Gg of CO_2.

The relative contributions of the major activities (emitting ≥ 2% of the sectoral total) to CO_2, CH_4 and N_2O emissions in the energy sector are presented in Figures 2.5, 2.6 and 2.7, respectively.

Figure 2.5: Relative Contributions of Major Activities to 2010 CO_2 Emissions from Energy Sector

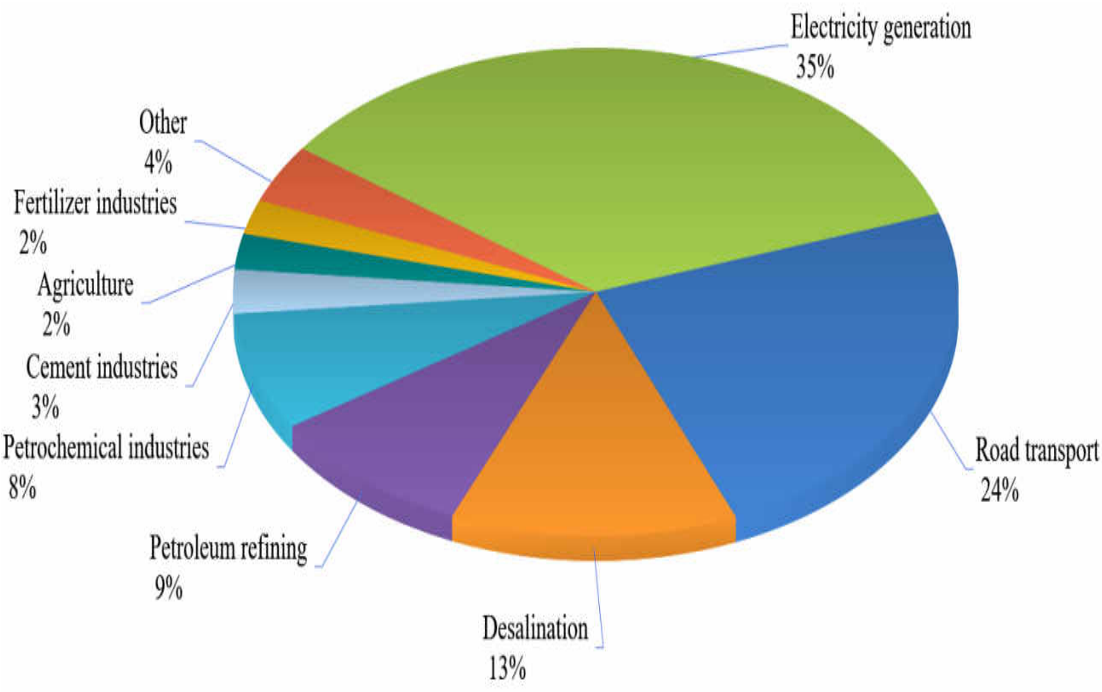


Figure 2.6: Relative Contributions of Major Activities to 2010 CH_4 Emissions from Energy Sector

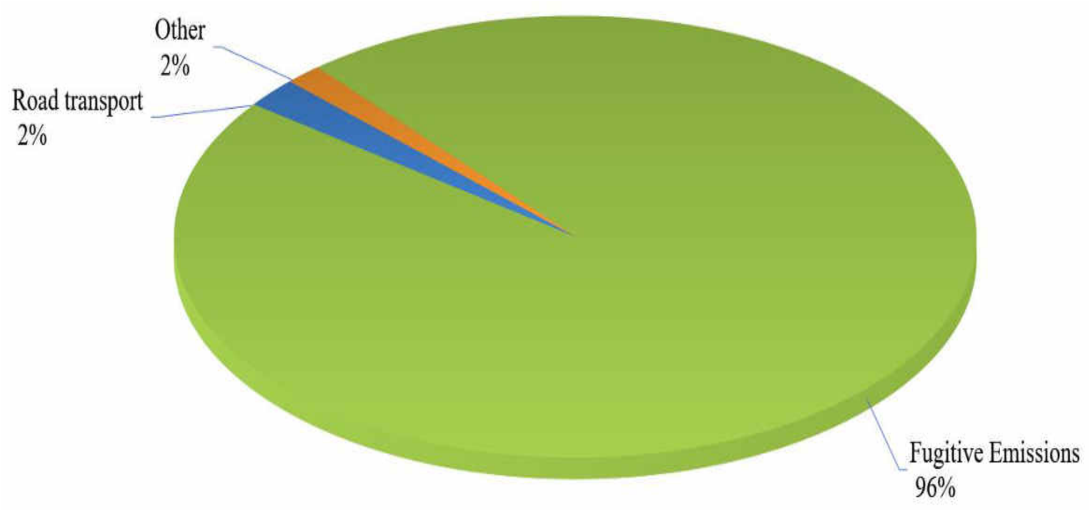
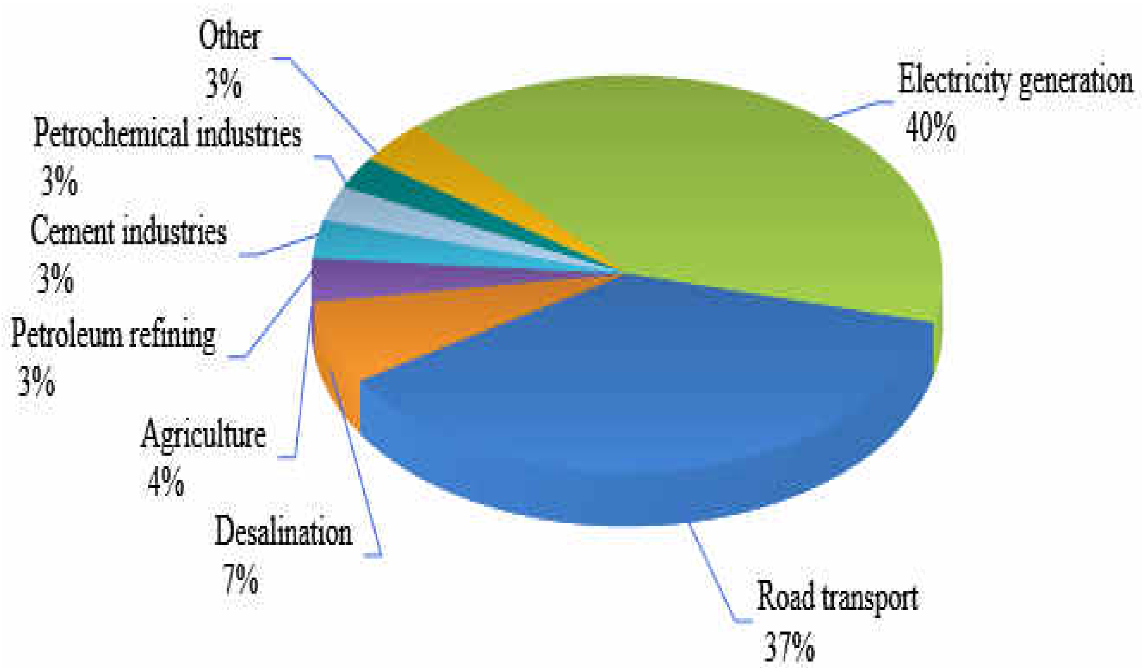


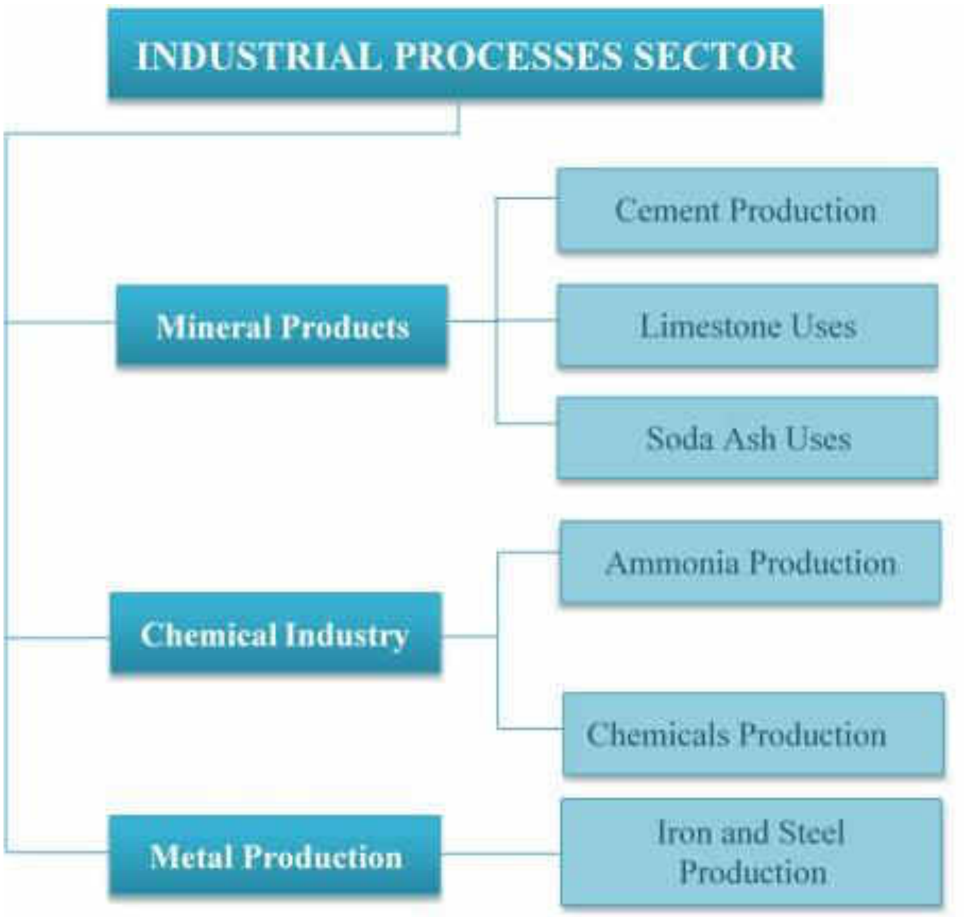
Figure 2.7. Relative Contributions of Major Activities to 2010 N_2O Emissions from Energy Sector



2.6.2 Industrial Processes Sector

Greenhouse gas emissions are produced from a variety of industrial activities which are not related to energy use. The main emission sources are industrial production processes, which chemically or physically transform materials to greenhouse gases. Cement production, limestone uses, soda ash uses, ammonia production, chemicals production and iron and steel manufacturing are some of the important activities of the Saudi industrial sector that are considered in this section. The major source categories in industrial processes from which greenhouse gas emissions have been estimated are presented in Figure 2.8.

Figure 2.8 Activities Considered in the Industrial Processes Sector

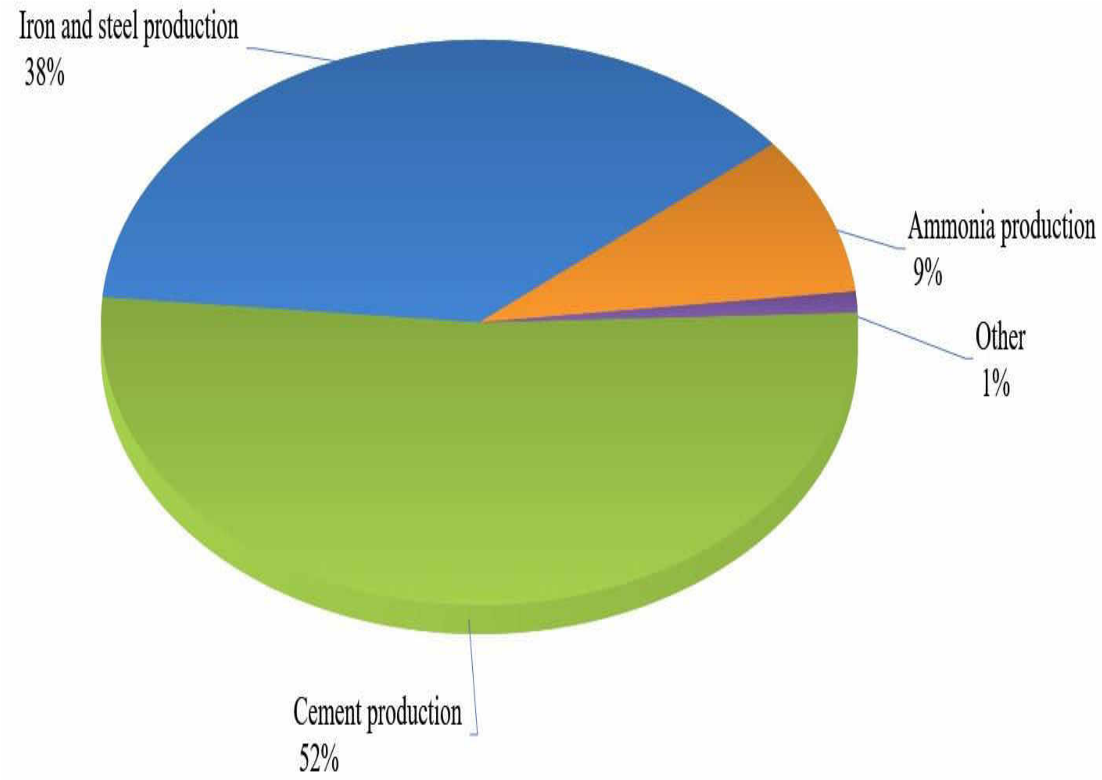


The emissions of CO_2, CH_4 and N_2O from various industrial processes were estimated and are summarized in Table 2.2. A total of 47,533 Gg of CO_2 were emitted from mineral products (53%), metal production (38%) and chemical industry (9%). Cement production emitted the highest amount of CO_2 (52%) followed by iron and steel production (38%) and ammonia production (9%).

The chemicals production was the sole contributor to a total of 35.7 Gg of CH_4 emissions in this sector. No N_2O was emitted from this sector.

The relative contributions of the major activities (emitting $\geq$ 2% of the sectoral total) to CO_2 emission in the industrial processes sector is presented in Figure 2.9.

Figure 2.9: Relative Contributions of Major Activities to 2010 CO_2 Emissions from Industrial Processes Sector



2.6.3 Agriculture Sector

Saudi Arabia is a desert country where irrigation-based agriculture is neither well developed nor extensive. Shortage of good quality irrigation water is the foremost limitation. The Revised 1996 IPCC Guidelines recommended agricultural activities for use in estimating greenhouse gas emissions is presented in Figure 2.10.

Greenhouse gas emissions from livestock (enteric fermentation and manure management), soils and field burning of agricultural residues are considered in this section. Cattle, sheep, goats, camels and poultry constituted the livestock population in Saudi Arabia. CH_4 and N_2O emissions were the most important greenhouse gases emitted by the activities related to livestock.

The estimated greenhouse gas emissions from the agricultural sectors are presented in Table 2.2. The total CO_2, CH_4 and N_2O emissions from various activities of the agriculture sector were 939 Gg, 74.1 Gg and 28.4 Gg, respectively.

The CH_4 emissions from enteric fermentation, manure management and field burning of crop residues were estimated at 59.3 Gg, 13.1 Gg and 1.71 Gg, respectively. The N_2O emissions from manure management, agricultural soils (direct and indirect) and field burning of crop residues were estimated at 8.59 Gg, 19.8 Gg and 0.03 Gg, respectively. Field burning of crop residues also emitted 939 Gg CO_2. For agricultural soils, as per the IPCC Guidelines, only N_2O emissions were estimated.

Enteric fermentation, manure management and field burning of crop residues contributed 80%, 18% and 2% to the total CH_4 emissions from the agriculture sector, respectively. Agricultural soils accounted for 70% of the total N_2O emissions in the agriculture sector followed by 30% from manure management. Field burning of crop residues was the sole source of CO_2 in the agriculture sector.

The relative contributions of the major activities (emitting ≥ 2% of the sectoral total) to CH_4 and N_2O emissions in the agriculture sector are presented in Figures 2.11 and 2.12 respectively.

Figure 2.10: Activities Considered in the Agriculture Sector

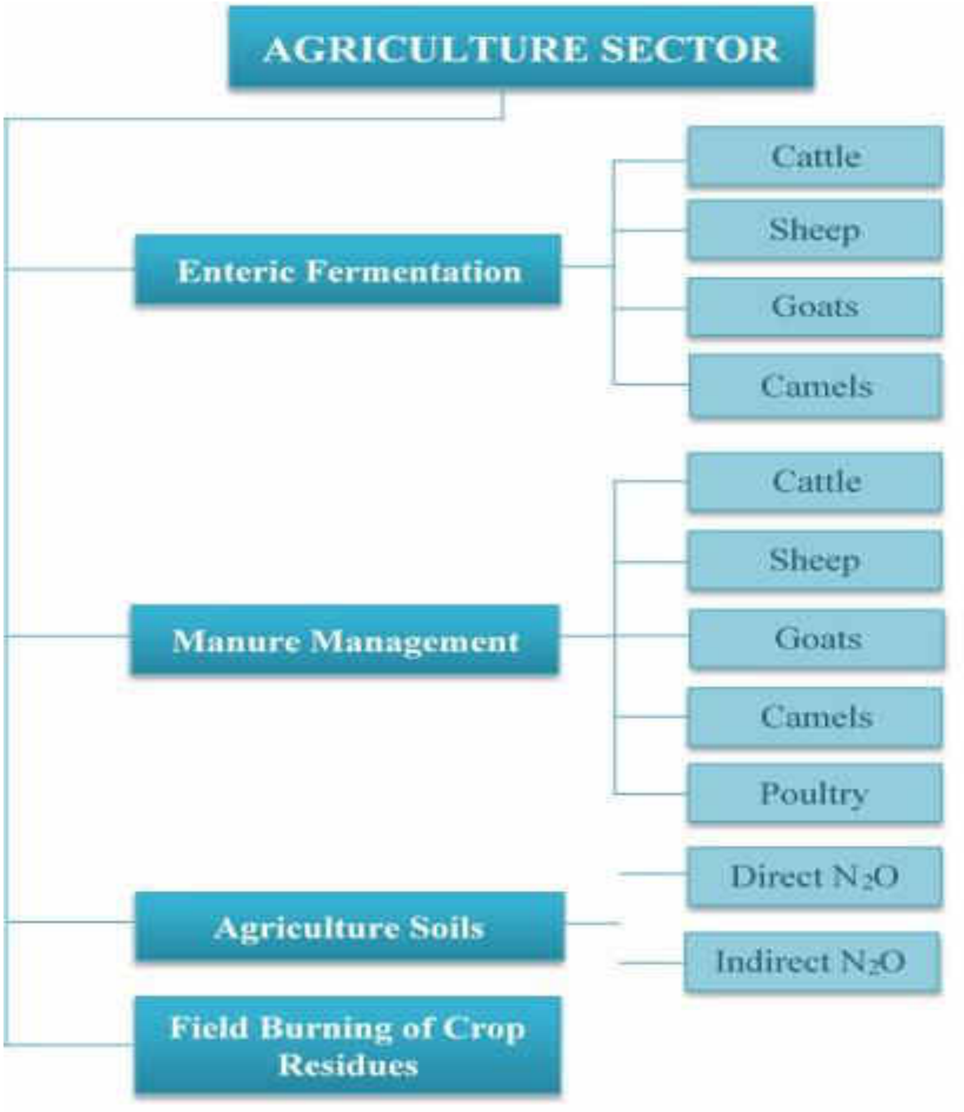


Figure 2.11: Relative Contributions of Major Activities to 2010 CH_4 Emissions from Agriculture Sector

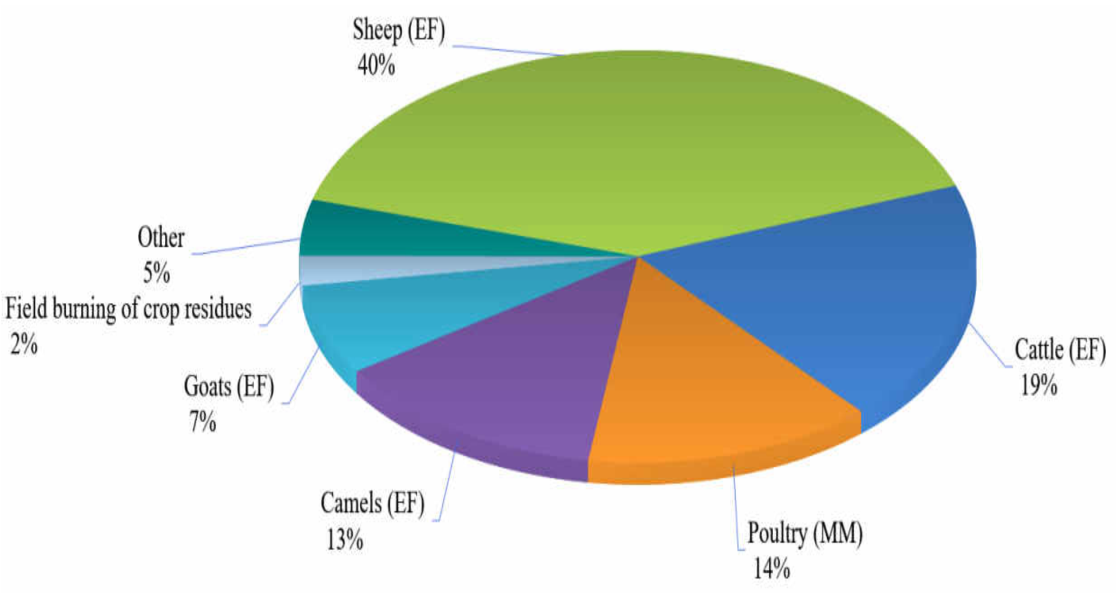
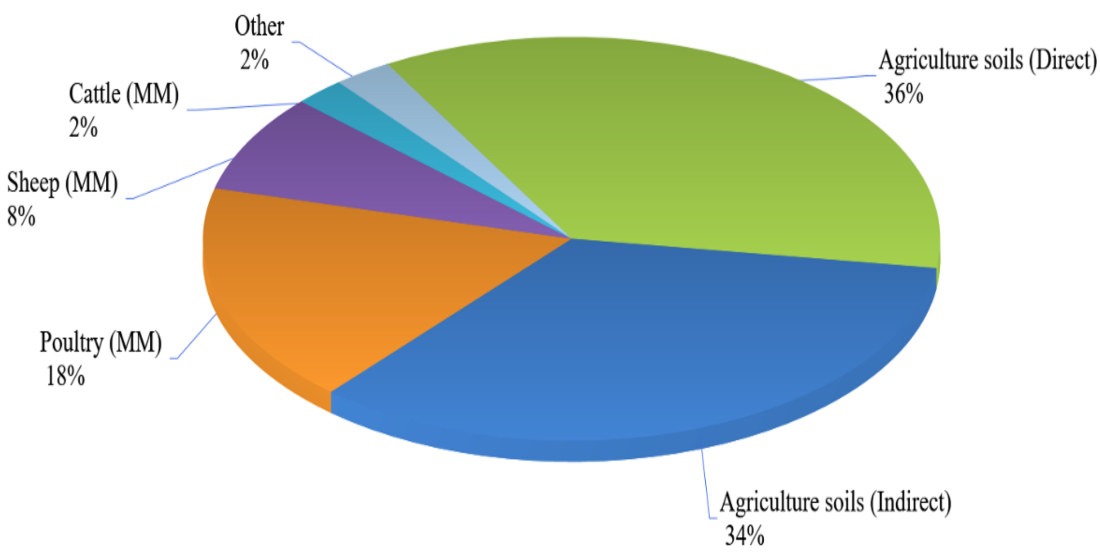


Figure 2.12: Relative Contributions of Major Activities to 2010 N_2O Emissions from Agriculture Sector



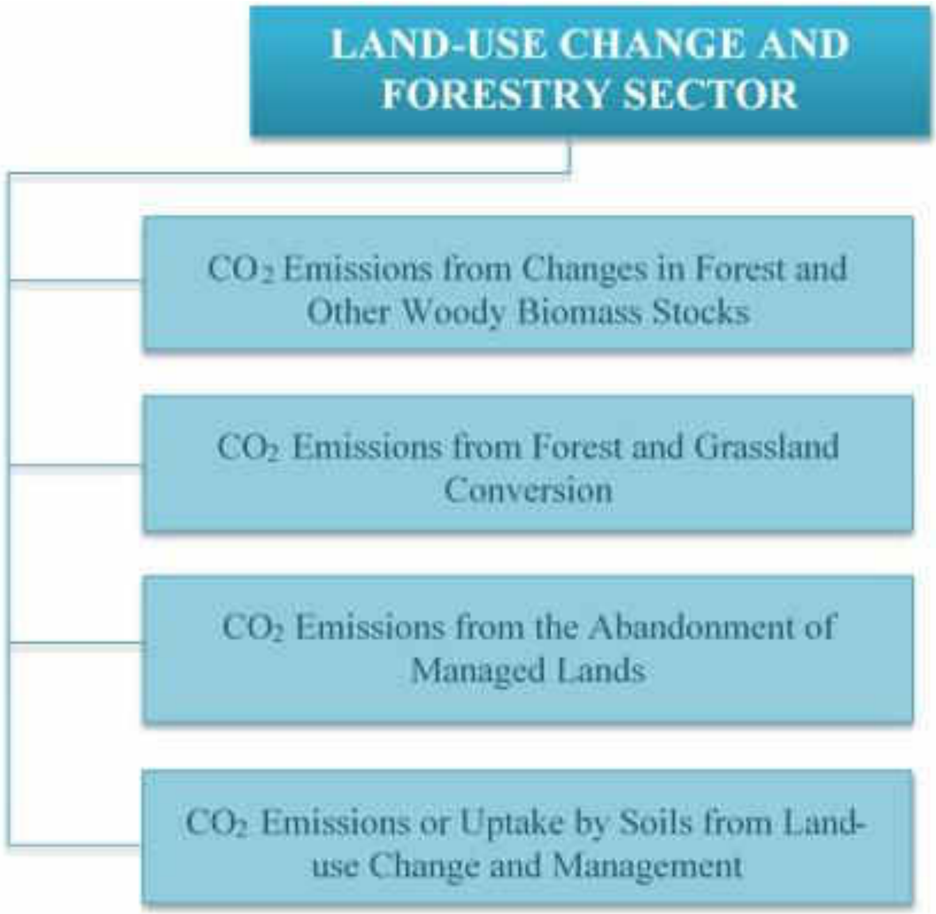
2.6.4 Land-use Change and Forestry Sector

Calculations of emissions from land-use change and forestry focus upon four activities (Figure 2.13) that are sources or sinks of CO_2. Activities considered in this section include changes in forests and other woody biomass stocks, forest and grassland conversion, abandonment of managed lands and uptake by soil from land-use change and management. The estimated greenhouse gas emissions from this sector are presented in Table 2.2. A total of 9,049 Gg of CO_2 sink was estimated from various activities related to this sector.

Sinks

- Changes in the forest and other woody biomass provided a sink for 9,049 Gg of CO_2.
- Forest and grassland conversion to other land uses converted 106 Gg of atmospheric CO_2 to plant material (acting as a sink for CO_2).
- Due to land-use changes, agricultural soils accumulated (acted as sinks) 41 Gg of atmospheric CO_2.
- The total sink from the land-use change and forestry sector was 8,902 Gg of CO_2.
- In general, CO_2 exchange (i.e., uptake or release) by oceans are not anthropogenic. Therefore, marine sinks (the Arabian Gulf and the Red Sea) were not included in this inventory.
- The possible intake of atmospheric CO_2 by the abandonment of managed land (due to decrease in total cultivated land area) is not considered due to the fact that the regrowth potential of these abandoned areas is expected to be a minimum, particularly under the prevailing harsh weather conditions in the Kingdom.

Figure 2.13: Activities Considered in the Land-Use Change and Forestry Sector

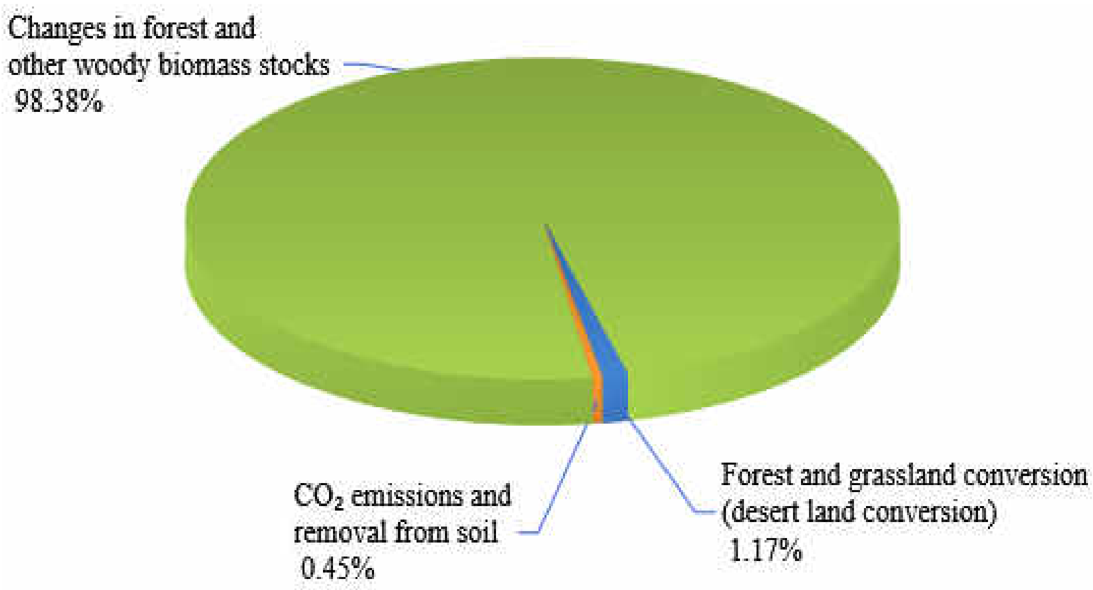


Emissions

- No significant emissions of CO_2 from the land-use change and forestry sector is expected in Saudi Arabia considering that wood is not generally burned for fuel in the Kingdom.

The relative contributions of the major CO_2 sinks in the land-use change and forestry sector are presented in Figure 2.14.

Figure 2.14: Relative Contributions of the Major Sinks to 2010 CO_2 Emissions from Land-Use Change and Forestry Sector



2.6.5 Waste Sector

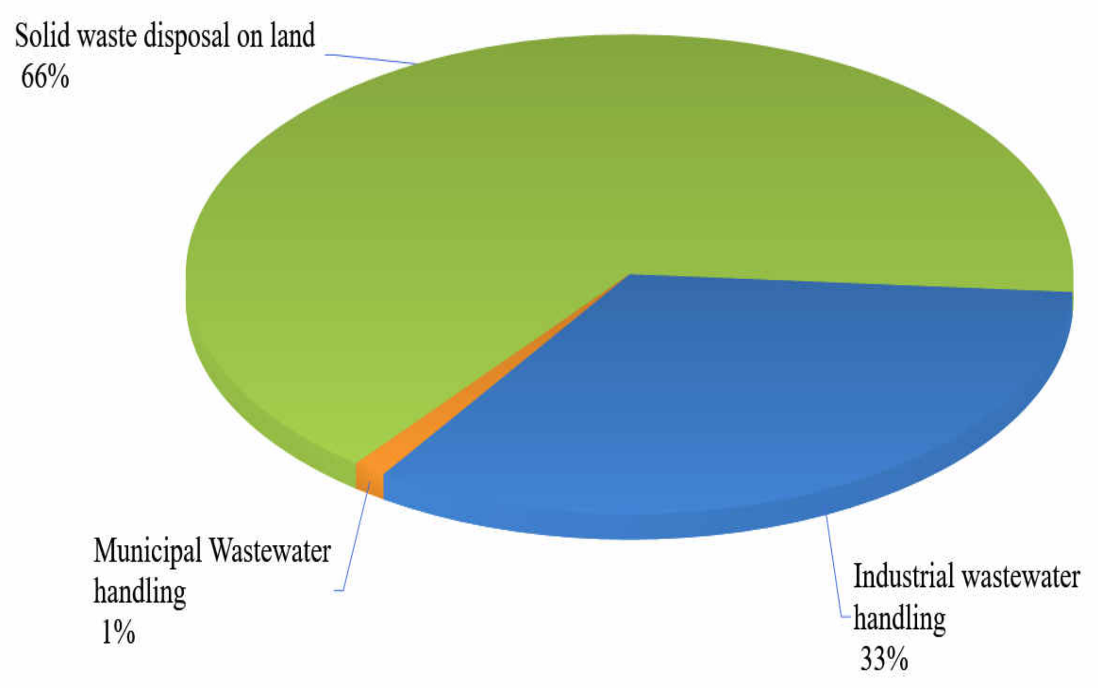
The Revised 1996 IPCC Guidelines recommend consideration of greenhouse gas emissions from landfilling of solid wastes, treatment of liquid wastes (wastewater) and waste incineration activities. Waste incineration activities in Saudi Arabia are prohibited by law and are not addressed. Solid wastes and wastewater disposal practices are considered in this section. The activities considered in the waste sector are shown in Figure 2.15. The emission estimations are summarized in Table 2.2. The total CH_4 and N_2O emissions from various activities of this sector were 1,088.8 Gg and 3.75 Gg, respectively.

Solid waste management practices emitted 714.6 Gg of CH_4. Municipal and industrial wastewater handling emitted 374.2 Gg of CH_4. N_2O emissions from human sewage were estimated to be 3.75 Gg. Solid waste disposal contributed 66% of total CH_4 in the waste sector followed by industrial wastewater handling (33%). The sole contributor to N_2O emission in the waste sector was human sewage.

The relative contributions of various activities to CH_4 emission in the waste sector are presented in Figure 2.16

Figure 2.15: Activities Considered in the Waste Sector

Figure 2.16: Relative Contributions of Various Activities to 2010 CH_4 Emissions from the Waste Sector



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2 IPCC (1997b). Greenhouse Gas Inventory Workbook. Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories. Volume 2, Ed. J. T. Houghton, L.G. Meira Filho, B. Lim, K. Treanton, I. Mamaty, Y. Bonduki, D.J. Griggs and B.A Callander. Intergovernmental Panel on Climatic Change, WGI Technical Support Unit, London, United Kingdom.

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SECTION – 3

Steps to be Taken to Address Article 12.1(b) of the United Nations Framework Convention on Climate Change (UNFCCC) and Renewable Energy

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3.1 Introduction

In line with the Kingdom's strong commitment to sustainable development, the public and private sector and even the general public of Saudi Arabia have been putting climate change issues on top of the list of their priorities. The Kingdom ratified the United Nations Framework Convention on Climate Change (UNFCCC) by accession on 28 December 1994. It also acceded to the Kyoto Protocol on 31 January 2005 (UNFCCC, 2005). Being a signatory to the UNFCCC, Saudi Arabia has taken steps to implement Article 12.1(b) of the UNFCCC.

Pursuant to decision 24/CP.18 of the UNFCCC, the Kingdom puts forward its national climate change efforts under a framework, which clearly recognizes the broader imperatives of sustainable development and economic diversification. The Kingdom has been striving to develop and implement policies, plans and programs in pursuit of economic diversification which have co-benefits in the form of emission reductions, adaptation to the impacts of climate change and response measures.

The steps taken by the Kingdom to address Article 12.1(b) within the framework of this chapter include: (i) economic diversification initiatives with mitigation co-benefits; (ii) climate change adaptation initiatives with mitigation co-benefits; (iii) R&D activities on climate change; and (iv) efforts to reduce impacts of international climate change policy responses.

The Kingdom has been actively participating in the development and deployment of technologies relating to Renewable Energy Sources (RES) and Rational Use of Energy (RUE). A process of environmental awakening is also observed in the Kingdom. It is expected that the use and development of RES and RUE can make a significant contribution to the improvement of environmental protection (Bertelsmann Foundation, 2002; Gelil and Kandil, 2004). The Kingdom adopted holistic approach by exerting its sincere effort in almost all the sectors which affect the environment, to ensure sustainable development for the present and the future generations. Among the general objectives and strategic principles for the Sixth Five-Year Development Plan (1415-1420H), the tenth strategic principle asks for environmental conservation, protection and enhancement as well as prevention of pollution.

3.2 National Economic Diversification Measures and Adaptation Actions with Mitigation Co-Benefits

3.2.1 National Energy Efficiency Plan

The National Energy Efficiency Plan (NEEP) of Saudi Arabia aims to curtail the growth in peak electricity demand. The NEEP is currently focusing on the design of the first energy conservation law and national and regional regulations, preparation of a new national database on energy supply and demand, capacity development of energy efficiency managers and public awareness. The NEEP has updated the energy efficiency standard (EER) for air-conditioners to be 8.5 (three stars on the label) for window type and 9 (four stars) for split type.

3.2.2 Energy Efficient Technologies and Energy Conservation Policies

The Saudi Energy Efficiency Center (SEEC) was established in October 2010. The Center focuses on the development of energy efficient technologies and energy conservation policies. It provides services including (i) development of appropriate criteria of using energy in all sectors following specified specifications and standards as well as diffusing awareness in the fields of energy conservation, (ii) spreading of the culture of energy rationalization in schools and other educational institutes and (iii) development of energy-efficiency databases in order to help electric-load management and further the study of appropriate methods and measurements to be applied through programs and technologies that are suitable for the Kingdom. The SEEC proposed demand-side management programs such as the replacement of low-efficiency AC units and mandatory thermal insulation for all new buildings (Saudi Building Code), remote control of AC units during peak times and curtailable load contracts and load tariffs. In accordance with the Royal Decree (No. 6927/MB) dated 22/09/1431H, the application of thermal insulation in all new residential and commercial buildings, or any facilities and other constructions like government buildings in major cities of the Kingdom is now mandatory. The SEEC has been working to enhance its mandate by including the collection of data, the setting of targets and their enforcement.

3.2.3 Electricity Tariff Restructuring

The Saudi Electricity Company (SEC) took steps aimed at restructuring the electricity tariffs. The tariff policy of Saudi Electricity Company was amended by the council of ministers on October 5, 2009, which granted the board of directors of the electricity and co-generation regulatory authority the right to review and adjust the non-residential (commercial, industrial and governmental) electricity tariff and approve them as long as the change does not exceed 26 Halala for each kilowatt per hour, taking into consideration, among other matters, the electrical consumption at peak times. This tariff was implemented from July 1, 2010 (SEC, 2014).

3.2.4 Saudi Arabian Standards Organization Initiatives

The Saudi Arabian Standards Organization (SASO) has taken initiatives to reduce energy demand by promoting and encouraging the use of insulating materials in design and construction of new buildings. It stopped issuing licenses to air-conditioners that do not meet the modified energy efficiency standards (8.5 or three stars on the label for window type and 9 or four stars for split type) since September 7, 2013. The Ministry of Commerce and Investment officials confiscated more than 50,000 air-conditioners from stores which do not comply with the Kingdom's energy saving requirements since the inspecting rounds started from the beginning of 2014. The board of SASO approved the technical regulations of Saudi Standard for fuel economy of light vehicles, which is effective from 2016 and remain valid until 2020.

3.2.5 Regulatory Framework for Energy Sources

In 2013, the Electricity and Cogeneration Regulatory Authority (ECRA) developed a national strategy for smart meters and smart grids in order to improve the reliability of the network and the quality of service, increase the efficiency of operation and realize better utilization of assets. The roadmap aims to (i) reduce complaints arising out of issuing the electricity bills, issue them in a timely manner and reduce the cost of reading more than seven million meters monthly, (ii) enable the renewable energy sources and facilitate their integration into the electricity system and (iii) provide additional services to consumers and increasing the efficiency and conservation of electricity consumption.

The *Electricity Distribution Code*, which is effective since 2008, provides the rules and regulations for distribution of energy throughout Saudi Arabia and mandates, including a provision stating that designated enterprises provide loading and generation output information to the government, as well as a layout of requirements for generators and a call for demand forecasting and operational efficiency (ECRA, 2008). This Code has been playing an important role in electricity demand management.

The ECRA has taken initiatives to develop regulatory framework for the promotion of clean and renewable sources of energy to generate power in the Kingdom. During a workshop of ECRA held in June 2009 in Riyadh, many stakeholders including policy makers, academicians, researchers, industrialists and government and non-government organizations discussed on the regulatory framework. In 2013, ECRA, in cooperation with KACARE conducted a study for developing a regulatory framework for the activities of electricity generation, cogeneration and water desalination production using atomic and renewable energy (ECRA, 2013). ECRA has been developing a comprehensive regulatory framework for the codes, procedures and license forms required for the electricity and water desalination projects that use atomic and renewable energy (ECRA, 2014a).

3.2.6 Ministry of Water and Electricity Initiatives

The Ministry of Water and Electricity (MOWE) (currently Ministry of Energy, Industry and Mineral Resources (MEIMR) has initiated several steps to implement energy conservation and to reduce peak load demand, which include the formation of an Energy Conservation and Awareness Department, imposing limits to the maximum power that can be delivered to the electricity consumers, establishing demand-side management actions and rationalizing the use of electricity (Al-Ajlan et al., 2006). The Ministry in collaboration with SEC has undertaken the following:

- Implementation of procedures enabling the commercial, governmental, agricultural and industrial sectors to reduce consumption and shift peak loads,
- Prohibition of irrigation during peak load times in the agricultural sector,
- Publication and distribution of the first edition of the Energy Conservation and Load Management Consumers' Guide,
- Organization of workshops and meetings to promote public awareness of energy conservation; and
- Arrangement of site visits to major consumers in the governmental sector to stress the importance of following energy conservation procedures and to introduce load reduction tools.

3.2.7 Energy Technology Research and Innovation

The King Abdulaziz City for Science and Technology (KACST) has developed an Energy Technology Program consisting of seven priority technical areas. These include, (i) renewable energy generation, (ii) conventional energy generation, (iii) electricity distribution and transmission, (iv) energy conservation and management, (v) energy storage, (vi) fuel cell and hydrogen and (vii) combustion. The program which will support the national economy by creating an energy technology system has goals including:

- Efficiently exploiting national energy resources.
- Supporting national self-dependence in critical energy technologies.
- Supporting the local energy industry to find technological solutions that facilitate new products development, improve production efficiency, price/value efficiency and environmental protection. This is being done in view of the rapidly rising demands for electrical and other forms of energy as a result of population growth, industrialization and globalization.
- Developing innovative technologies for special needs that cannot be satisfied efficiently or economically through existing systems.
- Transferring, adapting and developing technologies for local users and markets through business models that promote creation and maximization of employment and investment opportunities, as well as economic diversification and competitiveness.
- Supporting societal and cultural development towards optimal exploitation of technology and transformation from consuming to producing culture.
- Promoting the national image and stature in science and technology.

The King Abdullah Petroleum Studies and Research Center (KAPSARC) is striving to advance the knowledge, insight and understanding of energy challenges and opportunities. The Center is focusing on a number of research areas related to energy economics, policy, technology and the environment.

3.2.8 Clean Energy Roadmap Development

The King Abdullah City for Atomic and Renewable Energy (KACARE) was established in 2010. It aims to contribute to achieving sustainable development in the Kingdom through exploiting the science, research and industry of atomic and renewable energy for peaceful purposes. It released a series of documents detailing the revised National Energy Plan. The KACARE has already taken an important step by launching its online *Renewable Resource Atlas* which will provide developers of solar power (and later also wind power, geothermal heat and waste-to-energy) comprehensive, reliable data on which to base project bids (Hashem, 2014). KACARE has performed a comprehensive evaluation of sustainable energy resources and concluded that hydrocarbons will remain as prime elements of the possible energy mix in 2032. As part of the strategy, the country aims to attract $109 billion investments for creating a massive solar industry (Halonen et al., 2013).

The Kingdom's National Committee for the Clean Development Mechanism (CDM) is the Designated National Authority (DNA) and was established in June 2009 by the Council of Ministers decision no. 208 as required by the Kyoto Protocol for the CDM.

The DNA had promoted the development of CDM project activities as well as the Carbon Market of the Kyoto Protocol in the Kingdom. It is also mandated to serve as the implementation entity any future international agreement related to climate change. It has a number of new and emerging responsibilities which include:

- Preparing and submitting National Communications to the UNFCCC;
- Preparing and submitting Biennial Update Reports to the UNFCCC;
- Preparing and updating INDC/NDCs

The DNA has assisted in the development process of a number of CDM projects including, the Madinah Landfill Gas Capture Project, Jeddah Old Landfill, the Safaniyah Flare Gas Recovery and the Solar Power Project at North Park Building.

3.2.9 Carbon Sequestration Roadmap

The Kingdom has developed the comprehensive technology roadmap on CO_2 capture, sequestration and utilization in order to protect the market for liquid hydrocarbon fuels and simultaneously reduce greenhouse gas emissions. Some of the major initiatives in the field of carbon capture and storage include:

- The Uthmaniyah CO_2-Enhanced Oil Recovery demonstration project is planned to capture carbon dioxide for use in enhanced oil recovery at the world's largest oil field, Ghawar;
- The manufacturing of automobiles with carbon capture system;
- The increased capture and use of CO_2 in petrochemical plants; and
- The successful development of catalytic platforms to convert CO_2 into useful products such as polyols through collaborative research.

3.2.10 Intended Nationally Determined Contributions of Saudi Arabia

The Kingdom of Saudi Arabia submitted its Intended Nationally Determined Contributions (INDCs) to the UNFCCC Secretariat in November 2015. The submission outlined the actions and plans to achieve mitigation co-benefits of up to 130 million tons of CO_2 equivalent avoided by 2030 annually through contributions to economic diversification and adaptation (Saudi Arabia, 2015).

3.3 Major Energy Initiatives

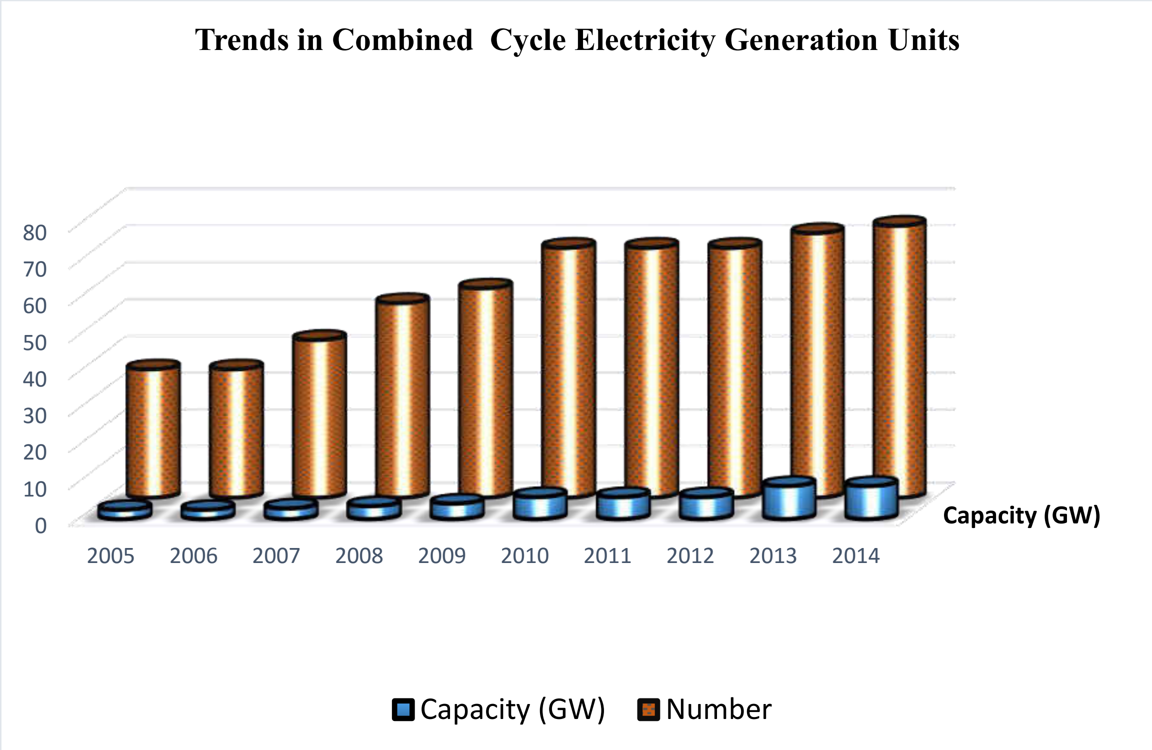
3.3.1 Rational Use of Energy Initiatives

Several organizations within the Kingdom have initiated a number of measures aimed at ensuring rational use of energy. They are intended to provide grant sufficient access to energy services while reducing energy consumption through efficiency, savings, conservation and smart energy use behavior.

Industrial Sector

The Kingdom has been investing substantial resources to increase overall efficiency of power plants by adopting combined-cycle operation. In this system, a heat recovery steam generator is employed to capture heat from high temperature exhaust gases to produce steam which is used in steam turbines to generate additional electricity. The reduction in fuel consumption is achieved through conversion of inefficient, single-cycle gas turbines to combined-cycle plants and by installing new combined-cycle plants (Matar et al., 2015). The deployment of combined-cycle electricity generation units has been increasing steadily in the Kingdom (Figure 3.1). The number of combined-cycle electricity generation units increased from 35 in 2005 to 74 in 2014. In the Kingdom, the production capacities of cogeneration entities in 2013 were 15,375 MW of electricity, 5,240,001 m3/day of water and 14,374 ton/hour of steam (ECRA, 2013).

Figure 3.1: Growth of Combined Cycle Electricity Generation Units in the Kingdom (ECRA, 2012 and 2014b)



Saudi Aramco has been maintaining its environmental stewardship by adopting a number of energy initiatives to ensure rational use of energy resources. In 2013, Saudi Aramco achieved a decrease in its energy demand intensity. The energy required to produce one barrel of oil equivalent product reduced by 4.56 percent compared to that of 2012 (Saudi Aramco, 2013). In 2014, the energy intensity decreased by 5.4% compared to 2013 (Saudi Aramco, 2014). Saudi Aramco also initiated its Energy Management Program in 2000. The cumulative energy conservation savings of this program was 112.81 thousand barrels of oil equivalent per day during 2000 to 2010. In 2013, Saudi Aramco's energy efficiency performance was enhanced by cogeneration facilities. It saved approximately 170 million cubic feet of gas per day compared to the national energy efficiency average.

Saudi Aramco is implementing zero discharge technology at onshore and offshore well-site operations in order to eliminate gas flaring and liquid hydrocarbon discharge. During 2013, Saudi Aramco minimized flaring from 0.89 percent to 0.72 percent of raw gas production at all upstream facilities. It adopted zero discharge technology at 432 well sites and as a result, 2.6 billion standard cubic feet of gas and more than 215,000 barrels of crude oil were recovered in 2014.

Saudi Aramco reduced refining energy intensity by 3% in 2014, primarily through energy conservation initiatives. The Company's energy conservation savings achieved in Company operations within 2002 to 2014 was 160.85 thousand barrels of oil equivalent per day (Saudi Aramco, 2014).

In 2014, Saudi Aramco reached roughly 90% self-sufficiency in power generation. It commissioned a 420-megawatt cogeneration plant at Manifa, which made the facility self-sufficient in power generation (Saudi Aramco, 2014). The Saudi Aramco has been implementing projects to reach the target of producing 1,075MW of electricity and 4.4 million lb/h of steam from the cogeneration facilities since 2002. The Company replaced incandescent lights by installing 500,000 LED light bulbs during 2014. This initiative saves 30 million kWh annually.

The Saudi Arabia Basic Industries Corporation (SABIC) signed an agreement with SEEC for activating the energy efficiency standards set by SEEC in all of the Company's factories in order to reduce the energy consumption. SABIC reduced 2% GHG emissions intensity, 5% energy consumption intensity, 5% water consumption intensity and 10% material loss intensity in 2013 compared to the base year 2010 (SABIC, 2013). In order to reduce GHG emissions and ensure improved efficiency, the process vent gas reutilization projects were executed by three Jubail affiliates of SABIC: (i) the benzene unit in Petrokemya, (ii) the polypropylene and HDPE units in Saudi Kayan and (iii) the styrene unit in Sadaf, which reduced emissions by 125,000 tons of GHG emissions and saved 784,000 GJ of energy annually (SABIC, 2011). An operational upgrade was completed in Al-Bayroni plant of SABIC in Jubail. The site completed a major retooling of their process boilers, which will result in 15% reduction in GHG emissions and more than 9% decrease in energy usage (SABIC, 2013). In March 2010, Yanbu National Petrochemicals Company (Yansab) established commercial operation. In this plant, a high pressure steam extraction reliability project resulted in 1,040,000 ton/year of additional steam, 99,000 ton/year of natural gas saving, 4,160,000 GJ/year of reduction in energy consumption and 229,000 ton CO_2 eq/year of GHG emissions reduction (SABIC, 2011).

The Valox iQ® resin of SABIC contains upcycled post-consumer polyethylene terephthalate (PET) from water bottles and offers molded-in color to avoid secondary painting. It delivers high electrical and mechanical performance and the resin has a carbon footprint of nearly 50% less than the traditional Polybutylene terephthalate (PBT). As recognition of SABIC's continuous efforts to maintain rational use of energy sources, the SABIC Plastics Applications Development Center (SPADC) at Riyadh Techno Valley of King Saud University received LEED Gold certification.

The Yanbu Cement Company (YCC) has signed a contract to set up a 34MW waste heat recovery (WHR) system which will be completed by the end of 2016 (Global Cement, March 05, 2015). Sinoma Energy Conservation Ltd, China will set up the WHR plant at a cost of US$61.8m. It is expected that the plant will reduce fuel consumption in power generation and reduce CO_2 emissions by more than 0.1 million ton per annum. As a continuous endeavor to ensure RUE Source Energy, a major Saudi energy company started to build an efficient power plant that will provide the King Road Tower with electricity and air conditioning services. This project uses absorption chillers to produce refrigeration by capturing the waste heat generated by the diesel power plant. It aims to reduce CO_2 emissions by about 10,000 tons per year.

3.3.2 Green Building Initiatives

The Saudi Green Building Council (SGBC) encourages the adoption of green building concept with the view to promoting the construction of energy efficient, resource efficient and environmentally responsible buildings. The Saudi Green Building Forum was launched at a workshop held in October 2010 to raise awareness and promote the concept of sustainability. It provided a crucial industry forum to debate best practices in design, construction and the built environment. The event focused on the role that the wider community has to play in achieving an environmentally sustainable future. The main objectives of the forum are to :

- Find laws and regulations that govern the path of development mechanism of building regulations and codes.
- Achieve technological Buildings Information Modeling ideal for green building.
- Develop the concepts of green building and identity in an environment of Saudi Arabia in the Gulf society and the preservation of urban heritage and modern developments.
- Build a culture of urban style to the generations to take care of inventory of cultural and educational advancement of the concept of green buildings in the rationalization of water and energy and uses environment friendly materials.

The Kingdom currently has more than 300 green building projects and the area occupied by the green buildings in the Kingdom exceeded 20 million square meters by the end of 2014 (Ventures Middle East, 2015). The investment associated with the green buildings is approximately Saudi Riyals 200 Billion. It is estimated that the Kingdom accounted for approximately 15 percent of the green building projects in the Middle East. The Kingdom is planning to build 90,000 eco-friendly mosques across the Kingdom through utilizing solar and other renewable sources of energy as part of a bid to put green building on the national stage. The initiative was agreed following a joint meeting between the Ministry of Islamic Affairs (currently Ministry of Islamic Affairs, Call and Guidance) and the Saudi Green Building Forum.

3.3.3 Afforestation Initiatives

In July 22, 2010 the Jeddah municipality started a project to plant 160,000 trees in Wadi Al-Asla. In the second phase, the forested area would be expanded further to eight million square meters and include planting 360,000 fragrant flowers and herbs. In Yanbu, the Huzam Al-Akhdar project is spread over an area of 9 kilometers along King Abdul Aziz Road and as many as 22,000 trees and 200,000 flowering plants have been planted in the area. It has greenery covering 70,000 square meters. In Yanbu, the Fairouz Garden was established covering an area of 72,300 square meters.

In January 6, 2010, the Deputy Minister of Municipal and Rural Affairs laid the foundation stone for various development projects around Jeddah which include a 2 million m2 forestation program near the sewage lake in east Jeddah and a garbage separation and recycling plant at the new landfill in Asla. On the same occasion, the Mayor of Jeddah also announced that about one of many potential greenery projects which would include a national park, a safari park and many other entertainment facilities. The project would cover an area of 100 million m2. The Green Jeddah Program is Saudi Arabia's first youth-led eco-friendly initiative. The students from all over Jeddah are involved in kicking off the green movement within the city of Jeddah. The core objective of Green Jeddah is to promote recycling and other green practices in the name of sustainable living within the region.

3.3.4 Transportation Related Initiatives

The SEEC plans to enforce the first phase of new rules for fuel-saving tires. It has planned to launch a campaign to reduce fuel consumption in the country targeting the drivers. It aims to rationalize energy consumption by choosing vehicles that consume less fuel and saving fuel by driving more efficiently. The Kingdom's fuel economy standard for incoming light duty vehicles (LDVs) (2016 – 2020) is defined at (i) 10.3 km/liter for passenger cars tested and (ii) 9.0 km/liter for light trucks tested as per the US EPA driving cycle (SASO, 2014). In 2016, the regulation became effective (SASO, 2016). Under the Saudi Energy Efficiency Program, multiple heavy duty vehicle (HDV) initiatives including anti-idling regulations, aerodynamic additives and retirement programs for old vehicles are currently under analysis. Both LDVs and HDVs will be subjected to rolling resistance and wet grip requirements.

In 2013, the carbon capture efficiency of the second prototype vehicle increased to 20 percent and the required size of the carbon capture unit is only one-eighth of the original size (Saudi Aramco, 2013).

Saudi Aramco established a fuel research center in Paris, France which conducts research on developing more efficient combustion engines using modified petroleum formulations (Al-Meshari et al., 2014). It also established a Mobility Center in Detroit, USA which provides a platform for demonstrations, deployment and engagement with United States automobile manufacturers to develop suitable technological solutions for reducing the carbon emissions from mobile sources (Al-Meshari et al., 2014).

Saudi Aramco has been conducting a number of research projects for developing a new frontier of capturing greenhouse gases in road transportation. Saudi Aramco presented a prototype vehicle (Figure 3.2) which captures 10 percent of its emissions through a carbon capture unit using absorbent materials from the exhaust system, a tank used for compression and storage and a unit that recycles the heat produced by the vehicle to run the carbon capture system.

Figure 3.2: Saudi Aramco Environment Friendly Automobile

3.3.5 Renewable Energy Sources Conversion Initiatives

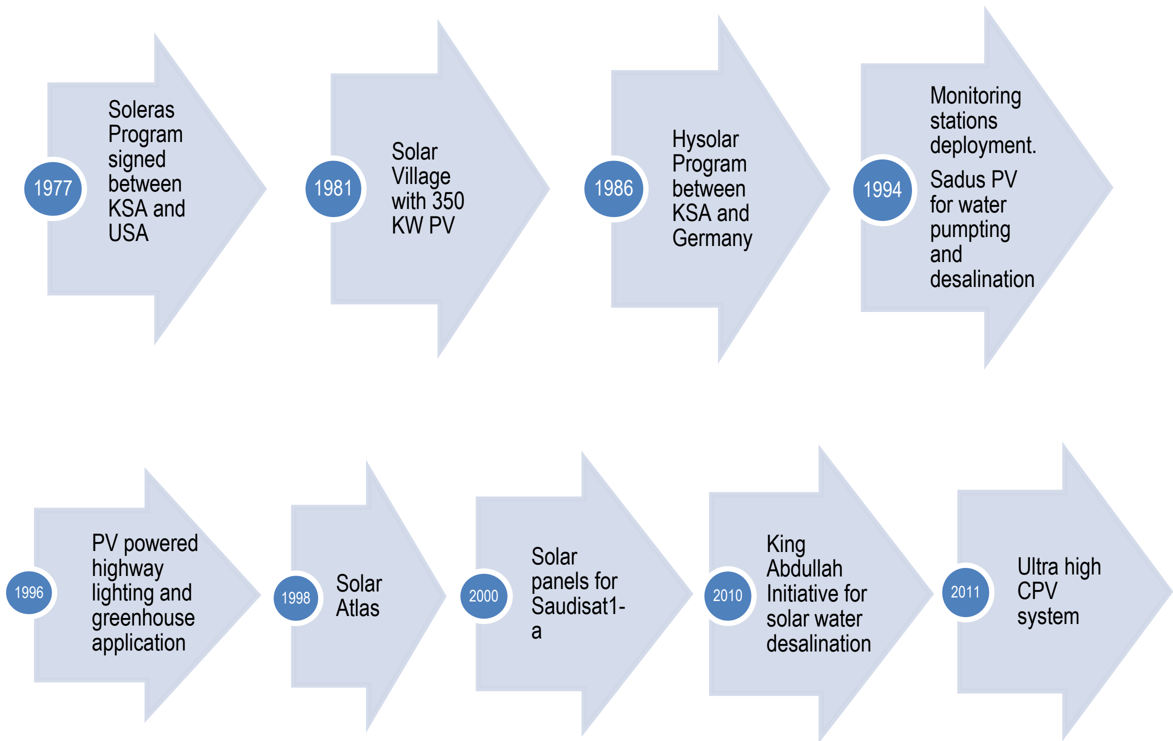
Solar Energy Conversion Initiatives

The Kingdom undertook and implemented integrated programs to develop solar energy based technologies to provide support for the industrial base of the country. The major solar energy conversion initiatives of the Kingdom are as follows:

KACST has been conducting major R&D activities in the field of solar energy on photovoltaic, solar thermal dishes, solar water heating, solar water pumping and desalination, solar hydrogen production and utilization, ultra-high concentration photo-voltaics (CPV) since late 1970s.

The Energy Research Institute (ERI) at KACST has conducted a number of international joint programs. The Renewable Energy Center of ERI is dedicated to continue research activities in the utilization and adaptation of renewable energy sources for the sustainable development of the Kingdom. The historical contributions of KACST in the field of solar energy are summarized in Figure 3.3 and described in the following few paragraphs.

Figure 3.3: Research and Development on Solar Energy at KACST



The ERI, along with the Former Ministry of Agriculture and Water (currently MEWA), conducted various research studies to develop efficient systems for drying dates using solar energy. They designed, installed and experimentally tested a number of solar dryers at the Al-Hassa and Qatif Agricultural experimental sites. The Institute has conducted a study on the development of solar water heating systems (SWHS). SWHS can be considered as one of the ways to reduce electricity consumption in water-heating sectors for different hot water applications (Alawaji, 2001).

The first solar-powered desalination plant with a capacity of 30,000 cubic meters would be built in Al Khafji to serve 100,000 people. In the second phase, a desalination plant with a capacity of 300,000 cubic meters/day of water will be established. In the third phase, several water desalination plants using solar energy will be installed in various locations of the Kingdom (KACST, 2016).

IBM and KACST have been collaborating to establish a water desalination plant powered by solar electricity, which could significantly reduce water and energy costs (LePree, 2010). The developed technologies through this joint research initiative include ultra-high concentrator photovoltaic (UHCPV) and desalination membrane module development. This technology is capable of operating a CPV system at a concentration > 1500 suns (LePree, 2010). KACST signed an agreement with the Advance Water Technology Company (AWTC) for planning the design and construction of solar water desalination plant in Al Khafji with a production capacity of 60,000 cubic meters per day (Oxford Business Group, 2015). KACST initiated the program which aims to promote collaborative research with industry by establishing Technology Innovation Centers (TICs) at universities. A research initiative of KFUPM concerning carbon capturing and carbon management was approved by KACST in early October 2010.

Saudi Aramco has been deploying a number of renewable energy sources mainly solar energy systems. The company commissioned a carpark mounted solar panel array in 2012 which generates 17.5 GWh/year (Figure 4). It is a CDM project and the annual average estimated reduction over the crediting period (up to 2019) is 10,834 tons of CO_2. It established KAUST solar park (rooftop mounted array) to generate 3,332 GWh/year in May 2010 (Figure 3.5). The power system includes premium components combining over 9,300 high-efficiency solar modules, occupying 11,577 square meters of roof space.

A ground mounted solar system was commissioned in 2013 at King Abdullah Petroleum Studies and Research Center (KAPSARC). It is to generate 5.8 GWh/year. Saudi Aramco commissioned a ground mounted solar system at KAPSARC Riyadh (KAPSARC II Project) to generate 3 GWh/year in 2014. Saudi Aramco is introducing solar powered streetlights in its compound and installed approximately 130 solar powered lighting bollards (Saudi Aramco, 2014).

Saudi Aramco initiated an evaluation program for emerging solar photovoltaic technologies in Dhahran from more than 30 technology vendors for testing, monitoring and understanding how different technologies perform under Saudi weather conditions. Figure 3.4. Saudi Aramco solar car park at Al-Midra office tower.

Many entities of the Kingdom have already established a number of solar energy source systems including the Princess Noura Bint Abdul Rahman University, General Authority of Civil Aviation (GACA), King Abdullah University of Science and Technology (KAUST) and Saudi Electricity Company (SEC).

Figure 3.4: Saudi Aramco Solar Car Park

Figure 3.5: KAUST Solar Park

A polysilicon production plant is already planned in order to meet the growing solar energy demand. The major solar energy initiatives are discussed below.

The KACARE aims to (i) develop and issue performance and reliability standards for Saudi conditions for PV, CPV and CSP solar technologies and (ii) establish world-class PV/CPV and CSP testing facilities within the next few years.

The Princess Noura Bint Abdul Rahman University established a solar thermal plant of 25 MWh in Riyadh in April 2012. The plant provides 900,000 liters of hot water storage. It utilizes 36,305 square meters of solar panels to provide solar energy into a district heating grid for 40,000 students. The plant approximately saves 16.35 tons of CO_2 emissions annually (estimated).

The GACA established ground mounted solar system to generate 9.3 GWh/year in June 2013. The plant approximately saves 6,082 tons of CO_2 emissions annually (estimated).

The SEC and Showa Shell Sekiyu commissioned a pilot project of ground mounted solar array to generate 864 MWh/year in 2011 at Farasan Island, Jazan. The plant approximately saves 565.1 tons of CO2 emissions annually (estimated).

The KAUST commissioned a solar rooftop mounted array in King Abdullah Financial District Project, Riyadh in 2012 to generate 330 MWh/year. It annually saves around 180 tons of CO_2 emissions.

In 2018, Saudi Arabia will commission a utility-scale solar plant in Makkah to generate 385 GWh/year. It will annually save approximately 251 thousand tons of CO_2 emissions (estimated).

The center for Clean Water and Clean Energy is established as a collaboration by Massachusetts Institute of Technology (MIT) and KFUPM to conduct research on the technologies related to the production of fresh water and low-carbon energy. The research areas of the Center for Clean Water and Clean Energy at MIT and KFUPM include: (i) photovoltaic power including silicon and polymer devices and systems; (ii) desalination of seawater by advanced membranes and by thermal and solar power; (iii) applications of nanotechnology to solar and thermoelectric energy conversion; (iv) design and manufacturing of solar power systems and desalination systems; (v) advanced sensors for leak detection in water distribution networks; (vi) technologies for carbon capture; and (vii) remediation of water from oil and gas production.

The Ministry of Higher Education has also established the Center of Research Excellence in Renewable Energy at KFUPM in 2007. The Center aims to further enhance the scientific/technological development in all the major areas of renewable energy. The Center has developed four main research programs on (i) solar cell, (ii) solar cooling and heating, (iii) photovoltaics and (iv) energy storage and conversion. The Center has already established a research collaboration with Fraunhofer Institute of Solar Energy, Germany in the area of PV module and system reliability and performance, Stuttgart University, Germany in the area of solar absorption cooling and Umm-Al Qura University in the area of concentrated solar power. A research team of KFUPM manufactured a solar vehicle and the team participated in the World Solar Challenge 2011 in Australia. The cruising speed of the vehicle was 80 km/h and the maximum speed was 140 km/h.

The Solar and Photovoltaic Engineering Research Center at KAUST aims to provide the foundation for innovation in efficient and low-cost disruptive PV foundational technologies. The KAUST and the University of California at Berkeley are jointly conducting a research project on solar hydrogen production by photocatalytic water splitting using highly crystalline oxide and non-oxide materials.

Some important future initiatives of the Kingdom in the area of solar energy include:

- Developing novel photoanodes and photosensitizer dyes for efficient dye sensitized solar cells.
- Developing efficient third generation polymer and quantum dot photovoltaics.
- Developing efficient perovskite solar cells.
- Efficient perovskite solar cells using a nanostructured WO_3–TiO_2 core–shell electron transporting material.
- Developing new self-assembled, nanowire network electrodes for depleted bulk heterojunction solar cells.
- Developing efficient advanced energy storage system to store electrical or thermal energy generated by renewable energy sources including solar energy.
- Developing desalination system including humidification desalination system using thermal, solar and hybrid systems.
- Evaluation of photovoltaic panels subjected to uniform cooling.
- Thermodynamic optimization of solar thermal power tower systems with thermal storage.
- Evaluation of solar energy driven combined power and cooling thermodynamic cycle.
- Feasibility study of photovoltaic-thermal hybrid solar collector system in the Kingdom.
- Evaluation of solar assisted organic Rankine Cycle-Ejector-Absorption refrigeration system for power production and air conditioning.
- Development and assessment of single and multi-stage humidifier operated through solar thermal energy for applications in desalination.
- Solar harvesting of surface modified lead chalcogenide heterostructures.
- Designing new configuration of hybrid solar cell incorporating Zn nanorods and Ag nanorods and polymer blend for excitons generation.
- Designing a-Si based solar cells using CNTs and mc-Nanostructures.
- Evaluation of photovoltaic solar-powered vapour compression air conditioning or refrigeration system.

Wind Energy Conversion Initiatives

The rapid development in manufacturing and applications for the wind energy industry has increased the benefits of wind energy exploitation. The first Saudi Arabian Wind Energy Atlas was produced in 1987 by a research team from KACST and KFUPM based on the data collected from 20 meteorological stations for the period 1970-1982 (Al-Ansari et al, 1986). KACARE developed the renewable resource atlas of Saudi Arabia which provides newly collected and historical wind resource monitoring data and satellite-based modeled data for developers, researchers, government institutions and policy-makers (KACARE, 2016). The following paragraphs include the major initiatives related to the wind energy resources development and deployment.

Under the "Wind Energy Resources Measurement Project", KACARE has identified forty (40) sites throughout the Kingdom, which will serve as future wind farms. The City has embarked on the erection of three (3) towers on different sites and the installation process is moving ahead progressively in a huge number of sites throughout the Kingdom. The height of the wind measurement poles tower is about 100 meters so that they get accurate readings at different heights. Upon the completion of the Project, the Kingdom shall have such an integrated map that will measure wind resources thoroughly and accurately.

The Kingdom plans a first round wind tender of 650MW and a second round of 1.05GW. The KACARE is running the program. It would examine possible locations with a view to building a blade and turbine test facility by 2016. It added that as much as 9GW of future capacity would be installed along the Red Sea coast and the Arabian Gulf. This would primarily be used by desalination plants (McKenna, 2013).

Saudi Aramco conducted feasibility studies for potential wind project developments within the whole country starting from 2012. It received some encouraging data from the wind towers in Shedgum and the Gulf of Aqaba. The study is still going on. The company is planning to initiate 300 MW of solar photovoltaic and wind power projects at 10 remote locations across the Saudi Arabia (Saudi Aramco, 2014). Saudi Aramco planned to install a 3.3 MW wind turbine at Turaif bulk plant (Saudi Aramco, 2014). Saudi Aramco installed two wind turbines each of 6 kW at two different remote locations to generate power for the communication towers.

Global Wind Energy has contributed in data collection with the King Saud University and it has performed a feasibility study for a private project of 20 MW to be built on the Red Sea shore.

Wind energy research activities in the Kingdom cover the following:

- Wind power meteorology data collection,
- Wind resource assessment,
- Prediction of wind resources,
- Site selection for wind turbines,
- Wind turbine modeling,
- Wind energy conversion system development,
- Grid integration of wind power and
- Environmental impacts of wind turbines.

Other Renewable Energy Conversion Initiatives

The adoption of energy efficient technologies and renewable energy sources supported by energy conservation policies plays an important role in maintaining sustainable development of the Kingdom (Belloumi and Alshehry, 2015). The Kingdom embarked on a massive agricultural experiment that can help in the assessment of the potential of the utilization of biomass as a source of energy (Aljarboua, 2009). The major organizations of the Kingdom along with the Government have been taking wide range of initiatives related to renewable energy conversion initiatives (such as geothermal hybrid system development, geothermal energy system development).

The use of geothermal energy system is now recognized as a cost effective standard for energy conservation. The geothermal resources encountered in Saudi Arabia are mainly of three categories: (i) low enthalpy resources represented by deep-seated aquifers that can be accessed only by deep oil wells, (ii) medium enthalpy resources (hot springs) encountered along the western and southwestern coastal parts and (iii) high enthalpy resources (Harrats) that are represented mainly by lava fields with fumarolic activity - Harrat Khaybar (Lashin et al., 2015).

The geothermal energy sources along the western shield margin are represented by hydrothermal and hot dry rock sources (Chandrasekharam et al., 2015a). The western part of Saudi Arabia is a region with high potential for geothermal energy development due to the high heat flow associated with the tectonic spreading of the Red Sea (Missimer et al, 2014). Lashin et al. (2014) described the entire western Arabian shield as the domain of both hydrothermal and enhanced geothermal systems associated and the most prominent sites of hydrothermal systems are located around Al-Lith and Jazan. According to Chandrasekharam et al. (2015b), Jazan geothermal province is characterized by high heat flow and high geothermal gradient and hosts several thermal and warm springs. It is estimated that the province may generate electricity of the order of 134×10^6 kW h (Chandrasekharam et al., 2015b).

Sharqawy et al. (2009) conducted a study which describes the in situ experimental determination of the thermal properties of the underground soil for use in the design of Borehole Heat Exchangers (BHE) which has been installed for the first time in Saudi Arabia. Al-Khouba geothermal resource at the Jazan province contains a geothermal potential of 17.847 MWt (Lashin and Al Arifi, 2014). The Wadi Al-Lith is considered one of the most promising geothermal targets with estimated heat energy of 1.713×1017 J (rock and fluid) and a geothermal reserve potential of 26.99 MWt (Hussein et al., 2013).

The SEC planned to build a 550 MW natural gas-fired power plant integrated with an additional 50 MW solar combined cycle facility. The project is expected to be completed by the end of 2017 (Willliams, 2015). According to the planned SEC upgrades, approximately 14 GW renewables will be integrated in the grid by 2020. Research on geothermal energy development has been gathering significant momentum in recent years. The principal focus areas for future research include:

- Determination of high potential locations for the development of geothermal systems,
- Assessment of technological challenges in the design, construction and operation of geothermal energy systems,
- Assessment of technologies to minimize costs and maximize efficiencies in geothermal energy system development and
- Environmental assessment of geothermal energy systems.

3.3.6 Energy Efficiency Initiatives

The first National Energy Efficiency Program (NEEP), launched in 2003 as a three-year temporary program to improve the management and the efficiency of electricity generation and consumption in the Kingdom ended in 2006. Building on the experiences gained between the period of 2003-2006 and seeking to sustain and unify energy efficiency efforts, the Saudi Energy Efficiency Center (SEEC) was established in 2010 by a Council of Ministers' Decree. The Center is managed by a Board of Directors composed of more than 26 entities from ministries, government departments and the private sector. Its main tasks were to:

- Develop a national energy efficiency (EE) program
- Promote awareness about energy efficiency
- Participate, as needed, in the implementation of pilot projects
- Propose energy efficiency policies and regulations and monitor their implementation

In 2012, SEEC, the custodian of demand-side energy efficiency in the Kingdom, launched the Saudi Energy Efficiency Program (SEEP) and hereinafter called 'the Program', with the objective of improving the Kingdom's energy efficiency by designing and implementing initiatives and their enablers. An Executive Committee was established by SEEC's Board, chaired by H.R.H. Prince Abdulaziz bin Salman, Vice Minister of Petroleum and Mineral Resources (now the Ministry of Energy, Industry and Natural Resources) and composed of members from 14 government and semi-government entities, to establish the Program. The Executive Committee targeted more than 90% of the Kingdom's energy consumption by creating specialized teams that focused on the buildings, transportation and industrial sectors and enablers.

Objectives, Legal and Institutional Framework of SEEP

The Saudi Energy Efficiency Program has two main objectives namely to:

a. Improve energy efficiency in the Kingdom through initiatives based on the capabilities of its local market.

b. Involve all relevant stakeholders in developing the Program, which range from public sector to private sector and general public.

The Program involves all stakeholders at all levels and leverages the current mandates of the government entities working in areas related to the mandate of SEEP.

Execution Methodology and Planning

The Program has developed and consolidated over the years a solid ecosystem. This ecosystem is the basis of its modus operandi (Figure 3.6)

Figure 3.6: Modus Operandi of SEEP

The Program is organized into specialized work-streams that use the same fact-based bottom-up approach to define the strategy, initiatives, enablers and implementation plan as follows:

a. Energy demand data collection and analysis consisting of:

(i) Data collection and analysis of energy demand by end-use sectors in the Kingdom.
(ii) Identification of key energy consumption drivers for each sector
(iii) Prioritization of sectors and drivers.

b. Establishment of technical teams and mobilization of stakeholders consisting of:

(i) Identification of government, semi-government and private sector stakeholders for each sector.
(ii) Creation of a technical team for each sector with stakeholders' representatives and technical experts.
(iii) Liaison with international organizations and experts and establishment of partnerships

c. Design and planning of initiatives and enablers consisting of:

(i) Benchmarking of energy efficiency initiatives globally and assessment of applicability in the Kingdom.
(ii) Proposal of energy efficiency initiatives to the Executive Committee (monthly meetings)
(iii) Selection of energy efficiency initiatives by the Executive Committee
(iv) Design and implementation plan for selected energy efficiency initiatives

d. Implementation of energy efficiency initiatives and enablers consisting of:

- **(i)** Ensuring that enablers are in place. These include, budget and manpower for government entities, private sector infrastructure (e.g. testing laboratories, Energy Service Companies) and Regulations & Standards.
- **(ii)** Handing over the energy efficiency initiatives to the relevant entities for implementation.
- **(iii)** Monitoring of implementation and evaluation of impact on energy consumption/ efficiency.

Role of Stakeholders

All relevant stakeholders, including government agencies, private, or public entities, are continuously involved in the development of the Program through:

- **a.** Weekly team meetings to discuss and tackle different issues in each work-stream
- **b.** Monthly meetings with the Executive Committee to share progress and highlight any challenges requiring the committee's assistance
- **c.** Workshops to discuss the initiative design and implementation mechanism to ensure feasibility and early buy-in from the stakeholders

Key Initiatives

The Program has more than 60 initiatives (either directly related to energy savings or related to enablers) which are either in feasibility, design or execution phase. A non-exhaustive list of some key initiatives undertaken by the program include:

Buildings

In the Building sector, the following initiatives have been undertaken.

- **a.** Established a baseline of energy efficiency standards, regulations and their enforcement in the Kingdom for products within the scope of the Program (air conditioners, white goods, insulation materials, lighting products etc.).
- **b.** Developed comprehensive benchmarks of similar standards and derived key success factors for standards in the Kingdom.
- **c.** Developed the energy efficiency standards jointly with the international and local players to ensure consensus and minimize impact on the market and consumers.
- **d.** Worked with government entities on the execution mechanisms including "what if" scenarios for handling non-compliant products.

Transport

In the Transport sector, the following initiatives have been undertaken.

- **a.** Improving the energy intensity in the transport sector was addressed through setting:
  - **(i)** A Corporate Average Fuel Economy (CAFE) standard to improve the efficiency of the new incoming Light-Duty-Vehicles (LDVs)
  - **(ii)** Minimum fuel economy requirements to improve the efficiency of used incoming LDVs

- **(iii)** Maximum rolling resistance limits requirements for all new tires, imported, produced or sold in the Kingdom for LDVs and Heavy-Duty-Vehicles (HDVs)
- **(iv)** Fuel Economy label for all incoming LDVs in order to raise awareness amongst consumers on the importance of fuel economy

b. The fuel economy performance requirements previously referred to in 1 & 2 above will be set for all incoming LDVs to the Kingdom starting January 2016:

- **(i)** CAFE standard is mandated on a manufacturer fleet level while ensuring technology neutrality, equitable competitiveness and sustainable progressive targets.
- **(ii)** Minimum fuel economy requirements are mandated on an importer level. All used vehicles imported with a fuel economy value lower than the threshold will be banned from entering the Kingdom

c. The maximum rolling resistance limits requirements, previously referred to in 3 above, will depend on the type of tires and will be enforced in two separate phases:

- **(i)** Phase I extends from November 2015 until October 2019
- **(ii)** Phase II extends November 2019 onwards

Industry

In the Industrial sector, the following initiatives have been undertaken.

a. Improving the energy intensity in the industry sector was addressed along two dimensions:

- **(i)** Energy intensity requirements as targets to improve the efficiency of existing plants and design standards to ensure the efficiency of new plants.
- **(ii)** Minimum energy performance standards for the most energy intensive equipment commonly found in industrial plants such as electric motors.

b. Consequently, existing plants need to reach the average energy performance of their respective international energy intensity benchmark by 2019.

c. New plants can only be built if they are designed to reach the top performance of their respective international energy intensity benchmark. The plant's energy intensity will have to be confirmed upon commissioning.

d. Plants not compliant with their energy intensity targets will not be able to obtain nor renew the various licenses and permits required to operate in the Kingdom.

Testing, Inspection and Certification

a. Developed comprehensive global benchmarks of product control mechanisms and derived key insights applicable to the Kingdom.

b. Developed a generic product control mechanism based on border, production line and in market monitoring.

c. Tailored the control process based on the different products.

d. Worked with the reference laboratory /private laboratories to send samples for verification.

e. Estimated the required budgetary, work force and systems requirements in order to facilitate smooth execution of the program.

f. Monitored impact on prices of products in the markets, as well as evolution of availability of energy efficient products with the support of the technical teams.

Urban Planning and District Cooling

In the area of Urban Planning and District Cooling, the following initiatives have been undertaken.

a. Energy Efficiency guidelines were developed in partnership with key government and private stakeholders responsible for Urban Planning.

b. Conducted a study which served as the basis for establishing the need for a Regulator and why the Electricity and Cogeneration Regulatory Authority (ECRA) is best suited to take on this role.

c. Conducted a detailed study that outlined the benefits of District Cooling and the types of regulations required. Identified the salient aspects of legal, licensing, economic and technical regulations.

d. Identified the critical parameters and associated values that need to be met in order to designate an area as a District Cooling zone.

e. For enforcement (when economically attractive) of district cooling in the government sector, developed threshold criteria and the outline of a feasibility study. Also, developed case studies to demonstrate the economic attractiveness of District Cooling for three projects of varying cooling requirements.

Funding

a. Defined a "funding methodology" to guide the funding decision-making process for Energy Efficiency initiatives:

(i) Energy Efficiency initiatives shall be implemented using laws and decrees that all constituents of the Kingdom - businesses, households and government – shall be mandated to follow.

(ii) On a case-by-case basis, it will be agreed to put in place specific financial instruments, incentives or facilities to support the implementation of Energy Efficiency initiatives. Non-regulatory EE initiatives shall only be considered for funding if:

a. Initiative is beneficial for the Kingdom, based on a Benefit-to-Cost analysis

b. Initiative payback for end-user at current energy market prices is higher than 5 years

(iii) In addition, special consideration shall be given to low-income households. In accordance with this funding methodology, about 10 identified funding initiatives that meet the requirements will be supported. These initiatives include:

- **a.** In the buildings sector, initiatives for new “highly efficient” air conditioners and early-retirement of inefficient air conditioners
- **b.** In the transport sector, initiatives to accelerate the adoption of fuel efficient vehicles and the early retirement of old inefficient vehicles
- **c.** In the industry sector, soft loans to encourage industrial plant retrofits

The detailed implementation mechanisms for these initiatives are currently in the design stage.

(iv) In 2013 and 2014, the Program worked with government entities to obtain their budget requirements to carry out their mandates related to the implementation of Energy Efficiency initiatives and their enablers designed by the technical teams in the Program. These consolidated requirements including justification for each requirement and secured the funding through the Ministry of Finance. The total budgetary funding for Energy Efficiency for 2013 and 2014 was about 70 million Saudi Riyals.

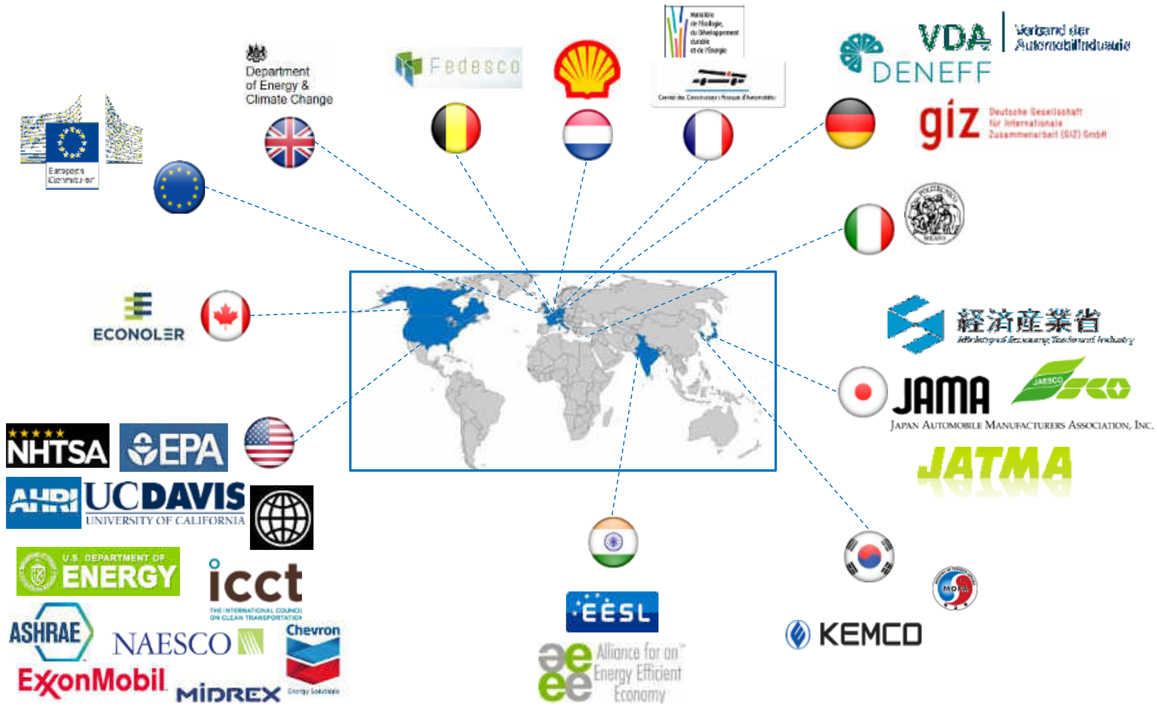
Energy Services Company (ESCO)

- **a.** Identified the barriers to the development of the ESCO industry in the Kingdom and analyzed several potential industry structures, with the role of the government ranging from low involvement to moderate involvement.
- **b.** Defined an ESCO industry structure, which includes the establishment of a government owned “Super-ESCO”, a commercial enterprise with the primary mandate to fund and manage government building retrofits. The Super-ESCO will work with the private sector to implement retrofit projects and will be a catalyst for the development of the local industry.
- **c.** Developed the Super-ESCO business case, from initial concept through to a technical and financial feasibility study.

Role of International Community

The Program leverages extensively the experience and the expertise of other countries, including successes and failures. For that purpose, broad collaboration frameworks were set with various international organizations and foreign governments.

Figure 3.7: International organizations that collaborated with the SEEP Team



Major achievements:

Some of the key achievements of the Program since its conception include:

Air Conditioner Energy Efficiency

Cooling of buildings roughly accounts for half of the electricity consumed in the Kingdom. A comprehensive and consensus–driven approach was adopted in order to raise the minimum energy performance standard (MEPS) and implement a product control mechanism. Split AC MEPS were raised from the original 7.5 Energy Efficiency Rating (EER) to 9.5 in 2014 and then to 11.5 in 2015, yielding about 35% electricity savings for cooling compared to the business-as-usual scenario. To date, more than 900,000 non-compliant AC units were re-exported, dismantled for spare parts, or revamped to meet new MEPS, which translates into savings of almost 1,800 GWh in 2014 alone. Overall, this initiative is expected to save about 553,300 GWh between the period from 2014-2030 cumulatively, which translates into about 1,020 million barrels of oil equivalent of savings at the wellhead.

Building Thermal Insulation

The Kingdom had many challenges with thermal insulation as more than 70% of the buildings in the Kingdom are not thermally insulated, leading to a loss of about 250 million barrels of oil equivalent over the past 5 years. Hence the Program team worked with public and private stakeholders to update the thermal insulation material standards and ensure that only compliant materials are produced, imported and used. Moreover, a comprehensive enforcement framework was developed covering the design, inspection and construction of new buildings, so that utilities such as water and electricity are not provided to non-compliant new buildings. Subsequently, upwards of 100,000 market surveillance visits to almost 52,000 buildings under construction were conducted. Cumulative energy savings are expected to exceed 1,000 million barrels of oil equivalent by 2030. Also, up-to-date 8 non-compliant thermal insulation production lines were shut down.

Awareness and Education Programs and Capacity Building

The Program has evaluated local and international best practices of awareness campaigns and have engaged the inputs of many focus groups to develop its 3 year awareness plan that is customized to the Saudi culture. The awareness plan has a number of planned campaigns covering new standards and regulations that are scheduled to take place with full collaboration of the technical teams and stakeholders. Awareness campaigns encourage target groups and participants to review and possibly change their values, behaviors, consumer habits or even lifestyles. The campaign cycle involves the following stages: (i) analyzing the issue, (ii) developing messages, (iii) defining target audiences, (iv) planning the campaign, (v) campaign delivery and (vi) monitoring and evaluation.

Campaigns projects and activities include:

a. ***Campaigns clips***: produced clips that were customized to each campaign. Clips should be attractive to deliver our messages easily to the target audience.

b. ***Creative Work***: it is the ads design for each message. Clarity, simplicity and attractiveness are taken into account at the design.

c. ***Media Buying***: hire international media buying companies to publish all our messages, designs and clips on TV, Radio, Newspapers, Outdoor and Digital Media to reach all our target audiences.

d. ***Sponsorship:*** engage private sector practitioners to participate on sponsoring campaigns.

e. ***Performance Measurement:*** conduct pre-assessment and post-assessment surveys to understand the awareness level for all consumers and to evaluate and enhance future campaigns.

f. ***Media Monitoring:*** monitor each ad to ensure maximum awareness.

g. ***Press:*** educating reporters and opinion leaders is one of the most important key to reach consumers and target audiences through them. Also, publishing press releases and reports that have rich information about energy efficiency is another way to share energy efficiency information.

h. ***TV & Radio:*** TV and Radio interviews are another access to share the knowledge with all targeted audiences.

i. ***Exhibits & Events***: many exhibits and events are associated with campaigns launching in many cities. They focus on giving energy consumers easy tips for avoiding unnecessary energy use and energy costs by changing some of habitual consumption patterns.

j. ***New Media***: Managing Social Media Campaigns through Twitter, Instagram and YouTube to provide two ways communication methods to reach and interact with audiences for a full engagement with them. Mobile campaign is another method to maximize the engagement. Also, Website that host rich content about energy efficiency so people can refer to it anytime for more information.

Lessons learnt

A number of important lessons were learnt during the development of the Program and they include:

a. *Technical Expertise and Approach*: The team should use a fact-based systematic methodological approach in the design and implementation of the Program to avoid conflicts of opinions and give confidence to the stakeholders that decisions are rational and unbiased.

b. *Stakeholder Engagement*: The team should engage with the government and private sector stakeholders from the inception of the Program to ensure practical initiative design and buy-in for smooth implementation.

c. *Leadership Commitment:* The team should have the continuous support of the government leadership, to alleviate the hurdles which are bound to present themselves for the Program, as the interest of the Kingdom might conflict with the status quo.

d. *Coordinated Enforcement*: Enforcement of the regulations and standards ought to be optimized by developing a unified enforcement approach and coordinating with the various government entities' enforcement efforts, in order to ensure high levels of compliance.

Conclusions and Recommendations

The Program has been an unprecedented inter-governmental entities effort in the Kingdom with two main impacts namely (i) saving energy for future generations and (ii) encouraging institutions and individuals to act and think with a "one government, one team" mentality.

Going forward, the Program should continue to reinforce its ecosystem and ensure that it is sustained over the long run.

3.3.7 Other Environmentally Friendly Energy Sources

The Kingdom has taken a number of research initiatives in order to ensure increased shares of clean fuel in national fuel varieties. A number of projects are already conducted focusing on fuel cell technology, high octane compound production and biofuel production. Researchers at KFUPM have actively participated in fuel cell research since the 1980s and their current efforts are directed to develop a Proton Exchange Membrane (PEM) fuel cell system emphasizing three different aspects such as developing novel low cost proton conducting membranes, developing multifunctional catalyst system and development of hydrocarbon based fuel processing systems. The researchers of Saudi Aramco investigated different candidate fuels for hydrogen generation using autothermal-partial oxidation reforming and water-shift reaction technologies.

KACST is funding a project titled "Saudi Arabia Bioefinery from Algae" to screen lipid hyper-producers species in Saudi Arabia coastal waters. These species will be used for algal biofuel production (Zafar, 2014). The Kingdom planned to set up a biodiesel facility with the capacity of 40,000 metric ton per year that will use fats from meat rendering as feedstock. The feedstock will be locally produced.

After successfully acquiring 'in-house' know-how for developing half-cells, mono-cells and 100- and 250-W stacks a 1 kW PAFC stack was demonstrated at the ERI, KACST. The experience led to an improved design and fabrication of the 1 kW PAFC stack. These lessons will ultimately contribute in scaling-up the power-generating modules for power utility applications in remote areas. In one of the projects of ERI, KACST, locally available internal combustion engines and ceramic mantle gas lamps, have been modified to use hydrogen as a fuel for small-scale demonstration purposes (Alawaji, 2001). In ERI, a commercial thermoelectric power generator, supposed to be fueled by methane or propane, has been modified to operate using hydrogen.

The national R&D trends in clean fuel production place emphasize the following areas:

- Production of high octane compounds.
- Transformation of heavy fuel oil to high-quality hydrocarbons.
- Development of catalysts for refining processes, clean fuel additives and the desulfurization of crude oil.
- Development of fuel cell technologies using nano carbon tubes.
- Improvement of clean fuel production using biotechnology.
- Development of efficient anode support and electrolyte layer for micro-tubular solid oxide fuel cells.
- Investigation of the effects of polymer binder in electrolyte slurries and application for micro-tubular solid oxide fuel cells.
- Development of miniaturized solid oxide fuel cells with pulsed laser deposition.
- Synthesis and characterization of materials for solid oxide fuel cells.
- Development of system for operating solid oxide fuel cell generator on diesel fuel.
- Development of novel composite membranes for medium temperature fuel cell.
- Development of efficient membrane materials for polymer electrolyte membrane fuel cells (PEMFC).

Carbon Capture and Management Initiatives

In the Kingdom, a number of research and development initiatives have been conducted to capture and store carbon dioxide emitted from industrial sources and other human-induced activities in an attempt to reduce the increasing rates of carbon dioxide emissions. Saudi Arabia was one of four countries signed up to the “Four Kingdoms” initiative which aims to explore the environmental viability of carbon capture and storage (CCS) technology. The Kingdom’s initiatives have been investigating the potential of isolating carbon dioxide at production, transportation and storage facilities and studies the possible geological formations to determine the most suitable geological sites for carbon storage. The initiatives are contributing to enhance the national capacity in the following areas:

- Identification, quantification and monitoring of the sources of CO_2.
- Minimization of CO_2 formation.
- Reduction of CO_2 emission.
- Transportation and storage system development.
- Identification of sequestration locations.

- Development of sequestration technologies for depleted oil reservoir.
- Development of carbon separation technologies using metal-organic frameworks (MOFs).
- Developments of carbon capture technologies using biological process and chemical-looping combustion.
- Utilization of CO_2 to produce polycarbonates and polyurethanes.
- Utilization of CO_2 for enhanced oil recovery.
- Conversion of CO_2 into useful products.

In line with the corporate commitment and part of its environmental stewardship program, Saudi Aramco is participating in a number of research and technology programs with leading national and international organizations to reduce greenhouse gas emissions by improving combustion efficiency, reducing carbon dioxide emissions and implementing Carbon Management (CM). The company developed a CM technology roadmap which aims toward enhancing petroleum presence in global CM technological development, leveraging petroleum industry resources and know-how and enhancing the value created from the carbon cycle.

Saudi Aramco plans to inject carbon dioxide into the world's biggest oilfield by 2012. It is intended to inject 40 million standard cubic feet per day (cfd) of CO_2 into the field. This effort will contribute in trapping emissions and enhancing oil recovery from the field. Saudi Aramco arranged the first regional symposium on CM titled “Carbon management challenges and opportunities for the petroleum industry”. It was held in Dhahran in May, 2006. Saudi Aramco was one of the sponsors of the IEA GHG Weyburn–Midale CO_2 monitoring and storage research project (Whittaker et al., 2011). Saudi Aramco and Korean Advanced Institute of Science and Technology (KAIST) are going to establish a CO_2 research center to pursue innovative and cost-effective technological solutions for managing emissions from both stationary and mobile sources.

SABIC is going to build the world's largest plant for capturing and using carbon dioxide. According to the plan, the plant will capture around 1,500 tons a day of carbon dioxide from ethylene plants and purify it for use in petrochemical plants in the industrial city of Jubail (Reuters, 2013).

The researchers of KAUST and the University of South Florida (USF) discovered and developed metal-organic framework (MOF) material for carbon capture and separation, as a part of a KAUST-sponsored faculty-initiated collaboration grant. The Advanced Membranes and Porous Materials Center (AMPMC) at KAUST developed membranes and porous materials for separations in many fields including carbon capture and the production of potable as well as industrial water. The Clean Combustion Research Center (CCRC) at KAUST aims to improve less conventional processes such as hydrocarbon fuels gasification in order to obtain hydrogen or hydrogen-rich fuels, while capturing the carbon for sequestration or use in high value-added materials. It also exerts efforts for developing simple, cost-effective processes for supplying clean energy by combustion, partial oxidation, or other means relying on chemical energy conversion.

A research team of KFUPM has been working in microalgae cultivation emphasizing on the potential applications in carbon dioxide bio-fixation, wastewater treatment and biofuel production. Razzak et al. (2015) studied the hydrodynamics of a photo-bioreactor focusing on the gas-holdups and mass transfer from gas to liquid phase in a tubular photo-bioreactor at various superficial liquid velocities. They also estimated the overall mass transfer coefficient.

The KACST initiated a program to promote collaborative research with industry establishing Technology Innovation Centers (TICs) at universities. A research proposal of KFUPM related to carbon capturing and carbon management for establishing TIC was approved by KACST (Rahman and Khondaker, 2012). The center already developed several technologies on carbon-free gas turbine, carbon-free fire-tube boiler and oxygen transport reactor based oven. The KAPSARC initiated a project on CCS implementation strategies aiming to prepare a comprehensive strategy (KAPSARC, 2011).

The national research and development projects and technology transfer of carbon capture and storage include: (i) development of carbon capture technologies using biological process, (ii) utilization of CO_2 to produce syngas (dry reforming project), (iii) utilization of CO_2 as regenerative agent in order to increase the commercial potential of methane dry reforming, (iv) utilization of CO_2 to produce oxygenates and hydrocarbons, (v) development of novel CO_2 adsorbent materials in the form of thin-film membranes, (vi) development of O_2 carrier for chemical-looping combustion for liquid fuel based power plants and (vii) development of efficient nanocomposite membranes for gas separation in steam at high temperatures.

Utilization of Natural Gas

The primary ingredient of natural gas is methane (CH_4), which has a higher energy content compared to other fuels (such as coal, diesel oil, gasoline, propane) and thus, it has a relatively lower CO_2-to-energy content (EIA, 2015). The Kingdom has been encouraging investments for natural gas exploration and production and adopting measures to increase the share of natural gas in the national energy mix. The national natural gas consumption increased by 73% and 86% between 1990 and 2000 and between 2000 and 2010 respectively.

Methane Recovery and Flare Minimization

The Kingdom adopted the initiative to measure methane emissions from oil and gas operating facilities using the Solar Occultation Flux technique to minimize methane emissions. It is also implementing Lead Detection and Repair (LDAR) protocol and program for oil and gas operation activities. It is piloting flare monitoring satellite technologies in order to control flaring activities and reduce methane emissions. The oil and gas facilities are installing flare gas recovery systems to limit gas flaring.

Saudi Aramco operates the world's largest single gas collection system (Master Gas Collection System) that reduced the flaring emission from oil gas production activities by more than 99% during the period between 1997 and 2000. The flaring is minimized from 0.89 percent to 0.72 percent of raw gas production at all upstream facilities during 2013. The adopted zero discharge technology at 432 well sites resulted in recovery of 2.6 billion standard cubic feet of gas in 2014 and more than 215,363 barrels of crude oil was recovered in 2014. Saudi Aramco installed a flare gas recovery system to recover gas from the flare headers of Safaniyah Onshore Plant and avoids the flaring of this gas into the atmosphere. It annually saves approximately 25,363 tons of CO_2 equivalent emissions at the flares.

Solid Waste Management Initiatives

A number of initiatives have been taken in the Kingdom to reduce greenhouse gas emissions in solid waste management which include landfill gas collection and flaring system development and transforming waste materials to organic fuels. A few relevant major projects are discussed below.

The Madinah Landfill Gas Capture Project consists of the installation of a network of gas extraction wells and pipes on the landfill with the purpose of collecting and draining the gas to a newly installed flaring system to avoid atmospheric release of the landfill gas. This project is expected to reduce approximately, 141,266 tons of CO_2 equivalent annually from 2011 to 2017 (UNFCCC, 2016a). The Jeddah Old Landfill (JOLF) and Jeddah New Landfill (JNLF) Landfill Gas Recovery Bundled Project activities include installation of landfill gas (LFG) recovery and flaring systems at two landfill sites within or close to the City of Jeddah in order to capture and flare the landfill gas. This project is expected to reduce approximately, 362,668 tons of CO_2-equivalent annually from 2012 to 2021 (UNFCCC, 2016b).

Jeddah Municipality has launched a recycling initiative that would see it transform waste into organic fuel, fertilizer and other raw materials. The municipality established a new landfill location of over 5.2 million square meters where six units would be processing 1,440 tons of waste a day.

Saudi Aramco recycled approximately, 960 tons of paper and carton by the end of 2013 (Saudi Aramco, 2013).

As of December 2012, the Kingdom had more than 40 recycling companies working at different levels and with different types of waste (Alameer, 2014). In 2012, Exitcom concluded a contract with International Computer Company (ICC) to build the first e-scrap recycling plant in Saudi Arabia. The strategic plans of the major cities are getting inspired by the concept of waste minimization. For example, the strategic plan of Jeddah which was initiated in 2005 emphasized the programs concerning waste management in order to reduce landfill requirements by waste reduction technologies including composting.

Sustainable Urban Development and Public Transport Initiatives

The Kingdom has been implementing a number of projects aiming to build a sustainable transportation system focusing on mass transit.

The Kingdom established the Public Transport Authority (PTA) in October 2012 and allocated 200 Billion Saudi Riyals for public transport projects and for regulating the public transport services within and between cities. The Kingdom is currently implementing King Abdulaziz Project for Riyadh Public Transport which includes (i) 756 metro cars, 85 stations, 6 metro lines and a 176-km network; and (ii) 3,853 bus stops and stations, 24 bus routes, 1,150 km network and 956 buses. The budget of this project is $22.5 billion. The Al-Mashaaer Al-Mugaddassah Metro Line project in Makkah involves the construction of a 20 km long metro line. It connects the holy cities of Mecca, Arafat, Muzdalifa and Mina. The metro line started functioning during the Hajj pilgrimage in 2010 (UITP, 2014).

In 2015, the Mayor of Jeddah announced that 24 tunnel projects were completed in the past four and a half years and a public transportation system is expected to be completed in the next several years. The implementation of the Haramain High Speed Railway project linking the holy cities of Makkah and Madinah via Jeddah and King Abdullah Economic City is going on (Saudi Railways Organization, 2015). The railway line between Madinah and Rabigh and between Makkah and Jeddah is expected to be operational in 2016.

The railroads are considered more environmentally friendly than cars, trucks or airplanes. The Kingdom initiated the North-South Railway (NSR) project which is the world's largest railway construction and the longest route to adopt the European train control system (ETCS) to date. It is a 2,400 km passenger and freight rail line originating in the capital city Riyadh to Al Haditha, near the border with Jordan. The ongoing “Saudi Land Bridge” project aimed to construct a 950 km new railway line between Riyadh and Jeddah and a 115 km new railway line between Dammam and Jubail as shown in Figure 3.8 (Saudi Railways Organization, 2016).

Figure 3.8: Saudi Land Bridge Project

The National Spatial Strategy (NSS) provides principles and guidance on ways to support development and address the social and environmental consequences of growth, including ways to integrate low-emissions approaches to urban planning. The Kingdom established urban observatories network in order to develop a knowledge base which is required to develop sustainable urban policies and monitoring human settlement dynamics. The National Urban Observatory Center is responsible for collecting, analyzing and developing urban indicators at all levels. The Center intends to ensure sustainable urban development planning. The network of urban observatories consists of thirteen regions and the City of Jeddah. The UNDP supported the Municipality of Al Madinah Al Munawarah Region to establish Al-Madinah Urban Observatory Network (MOUN) during the period 2003-2008. The urban observatories are also established for Makkah, Taif, Abha, Uhod Refaidah, Khamis Mushayt, Buraidah, Baha, Qurrayyat, Al Hassa and Najran. The main objective of building an urban observatory is to use available data to effectively and efficiently disseminate a city’s most current urban indicators, statistics, conditions and profiles.

Growth Management Initiatives

Different organizations in the Kingdom have initiated various studies on potential growth management alternatives and strategies to ensure protection of the natural environment while promising sustainable development. The Kingdom has initiated establishment of mass transit systems for the major cities. In order to achieve successful mass transit systems the Kingdom is also exerting sincere efforts in transit-oriented development. As a result the growth has been increasing in the urban centers which have good infrastructure, accessibility, job opportunities and community services.

Water Conservation and Recycling Initiatives

KSA has been facing a challenging water scarcity problem where water demand exceeds the sustainable yields of natural resources (Ouda, 2013). The Kingdom's long-term water resources are desalinated water, brackish ground water and reclaimed waste water. In the Kingdom, the total quantity of reclaimed waste water was 166 million m^3 in 2006. In the Royal Commission of Jubail and Yanbu jurisdictions, the reuse of water is 168,000 m^3/day. The reclaimed water used for irrigation is 78,000 m^3/day.

Saudi Aramco has been developing and implementing a number of strategies to reduce water demand and increase the use of treated waste water in its facilities. The Company established its Water Conservation Strategy to reduce the Company's projected fresh water consumption by 70 percent in 2022. Saudi Aramco investigated, along with the National Water Company, using treated sanitary waste water generated from the major cities for various applications inside the Company. In the Company, 49% of irrigation needs were met by recycled sanitary waste water generated by its communities and facilities (Saudi Aramco, 2013). Approximately 70 percent of the sanitary waste water generated by Saudi Aramco facilities is treated and re-used for landscape irrigation. In order to facilitate identification of water conservation opportunities in 2013, Saudi Aramco installed flow meters in facilities company-wide. Currently in Saudi Aramco, 85 percent of the produced water is injected into oil reservoirs for maintaining pressure level. There was no increase in the quantity of fresh water withdrawn or consumed by oil and gas operations from 2012 levels in Saudi Aramco (Saudi Aramco, 2013).

In SABIC, the majority of the water used in manufacturing operations is recycled multiple times and operational practices are followed to minimize usage. The water intensity of SABIC was reduced by 5% in 2013, as compared to the base year 2010 (SABIC, 2013).

The research entities have been conducting a number to research projects to develop the sustainable future water supply roadmap of the Kingdom. The Saline Water Desalination Research Institute (SWDRI) of SWCC has conducted more than 400 scientific studies. It has already developed a patent for a desalination method which uses both nano-filtration membranes and thermal or reverse osmosis units. In 2012, the SWCC signed a memorandum of understanding with Dow Chemical for collaborative research.

From studies in KFUPM and MIT laboratories, a new carrier gas extraction technology has been developed. It employs a continuous, atmospheric pressure, ambient temperature desalination technique that uses a carrier gas to extract fresh water (< 100 ppm salinity) from high salinity brines. Mechanisms of pressure/temperature gradients are extensively used. It is currently used for purifying returned waters from hydraulic fracking of unconventional oil wells. However, it could be customized for purifying other types of severely contaminated waters. A nano-porous graphene membrane technology was invented in the KFUPM and MIT laboratories. The method of producing the membranes and the material composition has the potential to significantly improve performance and decrease costs over state-of-the-art technology. The application of this technology includes water desalination, residential water filtration, bio-chemical filtration, fine chemicals processing, metal refining, industrial waste processing, ultrapure water, water recycling and agricultural wastewater treatment. A waste water treatment technology using polymer resin was invented jointly in the KFUPM and MIT laboratories. The compositions and methods of making polymer resin to treat waste water for removing toxic non-biodegradable metal ions such as lead and copper have been reported.

The Water Desalination and Reuse Center (WDRC) at KAUST conducts research on water desalination and water reuse focusing on membrane-based technology. The Center is exerting efforts in developing new membranes, such as Membrane Distillation (MD) and Forward Osmosis (FO). In 2012, KSU announced a chair in desalination research which was funded by the UN Education, Scientific and Cultural Organization (UNESCO) in order to: (i) examine the existing desalination technologies and patterns of national water consumption; (ii) propose potential uses of membrane-based desalination methods; and (iii) provide guidance on maintaining a sustainable desalination program.

Blue Carbon Initiatives

The PERSGA is the Regional Organization for the Conservation of the Environment of the Red Sea and Gulf of Aden. It is an intergovernmental body dedicated to the conservation of the coastal and marine environments in the Red Sea, Gulf of Aqaba, Gulf of Suez, Suez Canal and Gulf of Aden surrounding the Socotra Archipelago and nearby waters. The member states of PERSGA are Djibouti, Egypt, Jordan, the Kingdom of Saudi Arabia, Somalia, Sudan and Yemen. The PERSGA developed a number of protocols which include: (i) protocol concerning the conservation of biological diversity and the establishment of network of protected areas in the Red Sea and Gulf of Aden; and (ii) protocol concerning the protection of the marine environment from land-based activities in the Red Sea and Gulf of Aden.

In the coastal areas, carbon is stored as mangroves, seagrasses and organic soils of tidal wetlands which are known as “Blue Carbon”. A regional initiative in collaboration between the PERSGA and the UNEP is undertaken to: (i) formulate Blue Carbon policy; and (ii) build capacities for streamlining such policies in eight countries including Yemen, Abu Dhabi, Somalia, Sudan, Saudi Arabia, Jordan, Egypt and Djibouti. According to PERSGA (2010), Saudi Arabia has more than 100 mangrove stands in the Red Sea coast with an estimated area of 3,500 hectares. The stands are mainly concentrated in the coast of Jazan province and the Farasan islands.

The carbon stocks for coastal and marine ecosystems depend on the characteristics of vegetation and soil. Michaelowa and Nerger (2013) tentatively estimated the mangrove carbon stock of Saudi Arabia which is equivalent of approximately 6.2 million tons of CO_2.

Saudi Aramco has planned to develop a mangrove eco-park on the Gulf coast to protect an area of over 63 square kilometres. This park is expected to be completed within 2017. Approximately 150,000 mangrove seedlings will be planted in the park within the next two years (Saudi Aramco, 2014). Saudi Aramco has planted 400,000 mangrove seedlings along the Saudi coast since 2011. It is establishing a reef restoration program throughout the northwestern Arabian Gulf to submerge 728 modular artificial reef habitats that will act as nurseries for corals and associated marine life. In 2012, the company published the updated Marine Atlas of the Western Arabian Gulf. It documents the diverse marine and coastal environments of the Arabian Gulf and includes images and detailed information that showcase one of the region’s most diverse ecosystems (Saudi Aramco, 2012).

Climate Change and International Policy Responses

Efforts to Reduce the Impacts of Response Measures

The Parties to the UNFCCC have recognized the need for developed countries to reduce GHG emissions and take action to mitigate the adverse effects of climate change (UNFCCC, Article 3). They also have recognized that initiatives taken by the developed countries to mitigate climate change (known as response measures) could negatively impact developing economies and impede sustainable development efforts (UNFCCC, Article 4). The implementation of unilateral response measures taken by developed countries in many cases will hinder economic development in developing countries, specifically if the measures affect international trade. This issue is addressed in UNFCCC by declaring that "measures taken to combat climate change, including unilateral ones, should not constitute a means of arbitrary or unjustifiable discrimination or a disguised restriction on international trade" (UNFCCC, Article 3). The oil exporting non-Annex I nations are disproportionately affected by response measures due to their dependence on oil revenues. The impacts are attributable to negative shifts in trade and reduction in fossil fuel consumption.

The investigations of response measures by the developed countries to mitigate climate change are the cornerstone to develop the roadmap to reduce the impacts and to adapt to these impacts. The Kingdom is planning to conduct studies to investigate international policy responses to climate change, assess the multi-faceted social and economic impacts and develop the roadmap to enhance climate change resilience and reduce vulnerability (Saudi Arabia, 2015).

A study of McKay Consultants revealed that: (i) technology-related policies have the lowest impact; (ii) technology development based measures have the lowest impact on oil demand and thus provide the lower negative spillover effects on oil producing developing countries; (iii) technologies such as CCS provide solutions to address climate change and adverse effects of the policies and measures; and (iv) efficiency measures also provide good solutions with minimum impact. In the sixth CSLF Ministerial Meeting, carbon capture technologies and structured carbon management roadmaps are considered as solutions to reducing rising levels of GHG (CSLF, 2015). It was also advocated to adopt clean energy policies that support CCS along with other clean energy technologies.

The Kingdom has developed its carbon management research and technology development roadmap focusing on CCS which includes the five following elements.

(i) *Carbon Capture from Stationary Sources*

The program aims to develop and demonstrate improved cost-effective technologies for the separation and capture of carbon dioxide from stationary CO_2 sources. The research and technology development basis include: (i) characterizing national CO_2 emissions; (ii) CO_2 capture from combustion systems; and (iii) CO_2 capture from non-combustion systems.

(ii) *Carbon Capture from Mobile Sources*

This program aims to develop carbon management solutions supporting the continued use of petroleum liquid fuels in the transportation sector. The research and technology development basis include: (i) developing an on-board vehicle carbon capture system; and (ii) adapting stationary pre-combustion and post-combustion technologies to suit marine vessel and rail-train applications.

(iii) *Industrial Applications for Carbon and Carbon Dioxide*

This program aims to convert captured carbon dioxide and carbon generated during production of oil and gas and derived from petroleum fuel combustion to make valuable products. The research and technology development basis include: (i) production of various carbon containing materials from carbon or carbon dioxide; and (ii) enhanced oil recovery.

(iv) *Carbon Dioxide Geological Sequestration*

This program aims to develop technologies to help sequester CO_2 in saline aquifers safely and to monitor the movement of CO_2 underground and at surface. The research and technology development basis include: (i) assessment of sequestration potential in major candidate aquifers; (ii) investigation of mitigating problems in CO_2 storage; and (iii) identification and development of the monitoring and verification technologies.

(v) *Carbon Dioxide – Enhanced Oil Recovery (CO_2-EOR)*

This program aims to demonstrate at a pilot scale the technical and economic viability of CO_2-EOR by injecting CO_2 from in-Kingdom sources into a candidate oil reservoir. The research and technology development basis include: (i) CO_2 research and laboratory studies; (ii) reservoir simulation; and (iii) a Saudi Aramco CO_2-EOR pilot project.

3.4 Technology Transfer and Cooperation

The Kingdom has been following an increasing trend of engaging in international collaboration in scientific and technological development by direct cooperation between Saudi universities and research organizations and reputed foreign counterparts. The Ministry of Education has taken the initiative to establish centers of research excellence in Saudi universities in accordance with the principle of mutual competitiveness and with the requirement that these centers adhere to criteria and standards necessary to reach the intended goals. The Ministry has already established centers of research excellence in different areas including renewable energy, water distillation, climate change and nanotechnology. It also approved the establishment of a center of research excellence on natural disasters. In the Ninth Development Plan (2010-2014), the Kingdom reported a clear mandate for developing a globally competitive knowledge economy which involves establishing a world-class science and technology sector so that innovative activity would emerge as a driving engine of economic growth (Alshumaimri et al., 2010). Accordingly, the research entities of the Kingdom have been collaborating with the leading research institutions of many countries.

KACST is responsible for building the required infrastructure for supporting scientific research including the management of research grants, set-up of communication networks and science and technology databases and the execution of applied research (Korsheed and Al-Fawzan, 2014). KACST developed the *Comprehensive, Long-Term, National Science and Technology Policy* which was approved the Council of Ministers in 2002. This policy led to the National Science, Technology and Innovation Plan (NSTIP). It aims to establish programs for developing strategic technologies which are most important for the Kingdom. The Technology Development Center in KACST is responsible for contributing to technology localization and technological projects in the Kingdom.

The Center for Clean Water and Clean Energy was established as a partnership between the Massachusetts Institute of Technology (MIT) and KFUPM. The Center focuses on research in desalination, low carbon energy and the related areas of design and manufacturing. The fast track and dynamic R&D initiatives resulted in more than 20 intellectual properties and 3 technologies developed in water related developmental activities. The carrier gas extraction technology for purifying extremely contaminated waters is currently used for commercial production of water in two oil/gas fields in the US (KFUPM, 2016).

In 2015, KFUPM successfully transformed the results of basic scientific research into a technique used on an industrial scale for cracking and producing heavy oil (HS-FCC). This technology has been licensed in South Korea and based-on this technology, a large refinery of *S-Oil Korean Company* will be operated (KFUPM, 2015).

In order to address the limitations and constraints of the traditional technology transfer regime in facilitating knowledge spillovers and technology transfer, the Kingdom adopted a new approach following the goals mandated in the Eighth Development Plan. Accordingly, the Saudi Cabinet approved licenses for Dhahran Techno Valley (DTV) in KFUPM, Wadi Jeddah in KAU and Riyadh Techno Valley in KSU in 2010 (Alshumaimri et al., 2010).

The DTV science park at KFUPM encompasses R&D centers of national and multinational corporations committed to R&D and innovation and investing in applications that respond to local and global requirements driving the energy sector. The Riyadh Techno Valley aims to satisfy the demands of the knowledge-based industries and to commercialize its research findings (Gallarotti, 2013). The Wadi Jeddah Company was established focusing on knowledge-based investment. Its mission is “to establish and operate an economic model based on knowledge, research & development and profit” (Wadi Jeddah Company, 2016).

KSU established the Advanced Manufacturing Institute (AMI) in 2012 as an expansion of the Program of Manufacturing Technology Transfer. The mission of the institute is to advance the state-of-the-art in advanced manufacturing technologies through advanced research and development activities, national and international collaborations, specialized consultancy and training services, professional development of engineering students and active engagement with industry and community to deliver high quality solutions to design and manufacturing problems (KSU, 2015).

In 2015, the Ministry of Education awarded KFUPM an authorization to establish a Center of Research Excellence in Natural Disasters (CoREND) in order to meet the requirements of developing necessary capability and tools which identify and quantify natural hazards risks in the Kingdom of Saudi Arabia. It will set out to establish and operate a national center of excellence in natural disaster research to support interdisciplinary, collaborative research bridging science and technology that will drive research projects toward a better understanding and enhancement of the Kingdom’s capability to combat natural disasters. It will undertake and support highly innovative and goal-oriented research pertinent to identification, assessment, prediction, protection and management of dangers of the important natural disasters facing the Kingdom. The CoREND will aggressively pursue basic and applied research, specifically focusing on various issues related to the potential dangers of: (i) floods; (ii) landslides, land collapses and rock falls; (iii) desertification and sand dune movements; (iv) earthquakes and volcanic activities; and (v) radiological pollution, with a scale and focus leading to outstanding national, regional and international collaboration and recognition. The CoREND plans to actively collaborate with reputed international organizations including Commonwealth Scientific and Industrial Research Organization (CSIRO), Macquarie University, University of Melbourne, Tohoku University, State University of New York at Buffalo and Desert Research Institute for capacity development and technology transfer.

In order to implement the renewable energy roadmap in a sustainable manner, the Kingdom has been taking measures in different stages of the renewable energy supply chain. The

Kingdom already possesses two factories producing flat plate collectors which also reflect the progress towards the use of solar energy (Doukas et al., 2006). The First Energy Bank along with an American company named Vinmar International announced plans to build a polysilicon plant in Saudi Arabia in 2013 to meet the growing demand for solar energy. The production target is set at 7,500 tons per annum. The Khaled Juffali Company (KJC) and Soitec agreed to establish a joint venture to market and sell concentrated photovoltaic (CPV) systems. The IDEA Polysilicon Company is the first Middle East integrated Polysilicon and Solar Wafers Company in Yanbu Industrial City which will produce 10,000 tons per annum of High Purity polysilicon, ingots and wafers.

Although the Kingdom has been working in enhancing capacity building and technological strength, it requires close cooperation and support of the developed countries. This will aid capacity building and technology localization in order to enrich the Kingdom's resilience to climate change and thereby reduce vulnerabilities for adapting to the international climate change response measures.

3.4.1 International Treaty, Plan, Policy and Program Initiatives

The Kingdom of Saudi Arabia has been maintaining its sincere role in greenhouse gas emission mitigations through active engagement with relevant international treaties, plans, policies and programs. Major relevant international initiatives include:

- Saudi Arabia agreed to the United Nations Framework Convention on Climate Change on 28 December 1994.
- The Kingdom has signed Montreal Protocol for phasing-out Ozone Depleting Substances (ODS) and within the framework of a national strategy industrial facilities/plants are gradually stopping the use of certain ozone depleting chemicals.
- The World Bank selected King Abdulaziz University (KAU), as represented by its Center of Excellence for Climate Change Research (CECCR), to lead an Arab research team for a study on climate change in the Arab World. The CEECR was established in 2009. It is working on collecting and compiling relevant climate data for the Kingdom which can be used for policy development.
- The Kingdom of Saudi Arabia is a member of the Carbon Sequestration Leadership Forum (CSLF). This voluntary initiative focuses on the development of cost effective technologies for the separation and capture of CO_2 for its transport and safe storage (Liu et al., 2012). Its mission is to facilitate the development and deployment of such technologies via collaborative efforts that address key technical, economic and environmental obstacles. It also promotes awareness and champion legal, regulatory, financial and institutional environments encouraging to such technologies.
- Saudi Arabia, Norway, the Netherlands and the UK initiated the Four-Kingdom CCS initiative for potential collaboration on CCS in order to advance its development and deployment.
- Saudi Arabia is a member of the Regional Organization for the Protection of the Marine Environment (ROPME) which involves in the protection of the marine environment and the coastal area the Arabian Gulf including the regional conservation and management of mangroves and Blue Carbon.

- The Kingdom joined Global Methane Initiative (GMI) in January 2014 and will participate in the Oil & Gas Subcommittee, for knowledge sharing in methane capture and reuse in the areas of flare management and fugitive emissions control for oil and gas operations.
- The IUCN Regional Office for West Asia (ROWA) comprises 13 countries including Saudi Arabia. Its role is to coordinate activities within four major themes in the overall region including (i) water and climate change and (ii) marine and coastal zone management.
- The Kingdom is conducting the feasibility study for the Gulf Rail Project which starts from Kuwait via Dammam in the Kingdom of Saudi Arabia to the Kingdom of Bahrain through the proposed causeway to be built parallel to the King Fahd Causeway. The length of the track inside the Kingdom of Saudi Arabia under the project is approximately 663 km.
- The Ministry of Agriculture (MOA) currently MEWA developed the strategy entitled "Strategy for Sustainable Development of Agriculture in KSA up to 2030" includes the establishment of Extension Centers for Integrated Farms (ECIF). The extension centers emphasize on the application and development of good agricultural practices for the protection of consumers and the environment.
- The Gulf Cooperation Council (GCC) will establish a Center of Excellence in Renewable Energy Research in Saudi Arabia. The center is to be set up under auspices of UNESCO and the Islamic Educational, Scientific and Cultural Organization (ISESCO).
- The UNDP and the Government of Saudi Arabia launched in June 2010 a new urban planning project that will help guide the shape and pace of urbanization. It is set to change the Kingdom's development landscape over the next decade. Key outcomes of the project include updates to the NSS and establishment of a new nation-wide Urban Observatory Network to support monitoring and evaluation of local governance and urban development indicators.

3.5 Conclusion

The Kingdom adopted holistic approach by exerting its efforts in almost all the sectors which affect the environment, to ensure sustainable development for the present and future generations. One of the strategic principals for the Sixth Five-Year national development plan of the Kingdom provides environmental conservation, protection and enhancement as well as prevention of pollution. The national development plans have been emphasizing the increasing energy efficiency in industries along with strengthening the private sector and diversifying the economy. These kinds of strategic principals inspired many important agencies of the Kingdom concerned or related to environment to come forward and take sincere initiatives to reduce greenhouse gas emissions and to increase sinks to remove greenhouse gases.

The steps taken by the Kingdom to address Article 12.1(b) within the framework of this chapter include: (i) economic diversification initiatives with mitigation co-benefits; (ii) climate change adaptation initiatives with mitigation co-benefits; (iii) R&D activities on climate change; and (iv) efforts to reduce impacts of international climate change policy responses.

The government has been taking a number of plans, programs and policy measures for ensuring rational use of energy sources and consequently, established various relevant organizations. The Saudi Energy Efficiency Center (SEEC) was established for developing energy efficient technologies and energy conservation policies. It aims to develop appropriate criteria of using energy in all sectors as well as diffusing awareness in the fields of energy conservation, spreading the culture of energy rationalization and developing energy-efficiency databases. The Kingdom also established Public Transport Authority for regulating the public transport services within and between cities. The Saudi Arabian Standards Organization (SASO) has taken initiatives to reduce energy demand by promoting and encouraging the use of insulating materials in design and construction of new buildings. The SASO also approved the technical regulations of Saudi Standard for fuel economy of light vehicles.

The King Abdullah City for Atomic and Renewable Energy (KACARE) has been developing the National Energy Plan which aims to utilize a balanced mix of economically viable and technologically feasible atomic and renewable energy sources in a sustainable manner thus ensure longer-term availability of hydrocarbons for export and utilization in national industry.

The Kingdom has been investing resources to increase overall efficiency of power plants by adopting combined-cycle operation. As a result, the deployment of combined-cycle electricity generation units has been increasing steadily in the Kingdom. The investment for natural gas exploration and production and adopting measures to increase the share of natural gas in the national energy mix are also encouraged. As a result, the national natural gas consumption has been following an increasing trend.

The King Abdulaziz City for Science and Technology (KACST) developed the Energy Technology Program consisting of seven priority technical areas. The ongoing Research and Development (R&D) activities of the local universities and research organizations provided the initial justifications for the RES such as solar and wind energy conversion and hybrid systems. The local educational institutes are highly encouraged to take the responsibility of developing courses and programs exclusively for RES. The investment of the private sector in RES is paving the path of increased use of RES. The role of Saudi Aramco and SABIC in carbon capturing and management along with other efforts to reduce greenhouse gas emissions indicates the excellence in environment related research.

The Kingdom has been adopting advanced technologies to control flaring activities and reduce methane emissions. Saudi Aramco has been maintaining its pivotal role in controlling methane emissions from oil and gas operation facilities. A number of initiatives have also been taken to reduce greenhouse gas emissions in solid waste management which include methane gas collection and flaring system development and transforming waste materials to possible organic fuels.

The research entities of the Kingdom have been conducting a number of research projects focusing on membrane based technology for water desalination and water reuse. As a result, the research organizations in the Kingdom have already developed a number of pertinent technologies.

The Kingdom has realized the importance of blue carbon for adaptation with mitigation co-benefits and its importance for the storage of carbon in the coastal areas. In this regard, The Kingdom has been cooperating with international bodies in developing the protocol for the protection of the marine environment and formulating national blue carbon policy.

The Kingdom has been conducting a number of research programs for developing a knowledge-base for: (i) addressing multi-faceted effects of climate change; (ii) investigating the international policy responses to climate change; (iii) assessing the social and economic impacts; and (iv) developing the roadmap for enhancing climate change resilience and reduce vulnerability. In this regard, the Kingdom is expecting continuous support from the developed countries for capacity building and developing appropriate technologies.

The agreement of the Saudi Government to comply with many international environment conservation treaties shows its commitments to the regional and global environment. Moreover, the volunteering initiatives of non-profitable organizations have been increasing awareness about RES, RUE and other environmental efforts among the public. The Kingdom also submitted its initial Intended Nationally Determined Contribution (INDCs) to the UNFCCC secretariat in 2015.

The Kingdom's participatory and integrated efforts related to climate change mitigation and adaptation initiatives clearly demonstrate its sincere commitment for a sustainable development for the present and the future generations.

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SECTION – 4

Economic Diversification and Development and Transfer of Technology

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4.1 Economic Diversification

Diversifying the economic base of the Kingdom of Saudi Arabia has been a fundamental objective of the socio-economic development ever since the development planning process was initiated in 1970s. The focus of the successive development plans on diversifying the national economic base has been inspired to lower the dependency on oil sector in generating GDP and financing government investments. After decades of planning, the share of the non-oil sectors, to which the private sector contributes a large share, has grown about thirteen-fold in the real GDP at an average annual rate of 6 per cent, which endorses the success of the diversification policy in the Kingdom (MOEP, 2014).

Figure 4.1: Development of GDP by Oil and Non-Oil Sectors at 1999 Constant Price in The Kingdom of Saudi Arabia (MOEP, 2014)

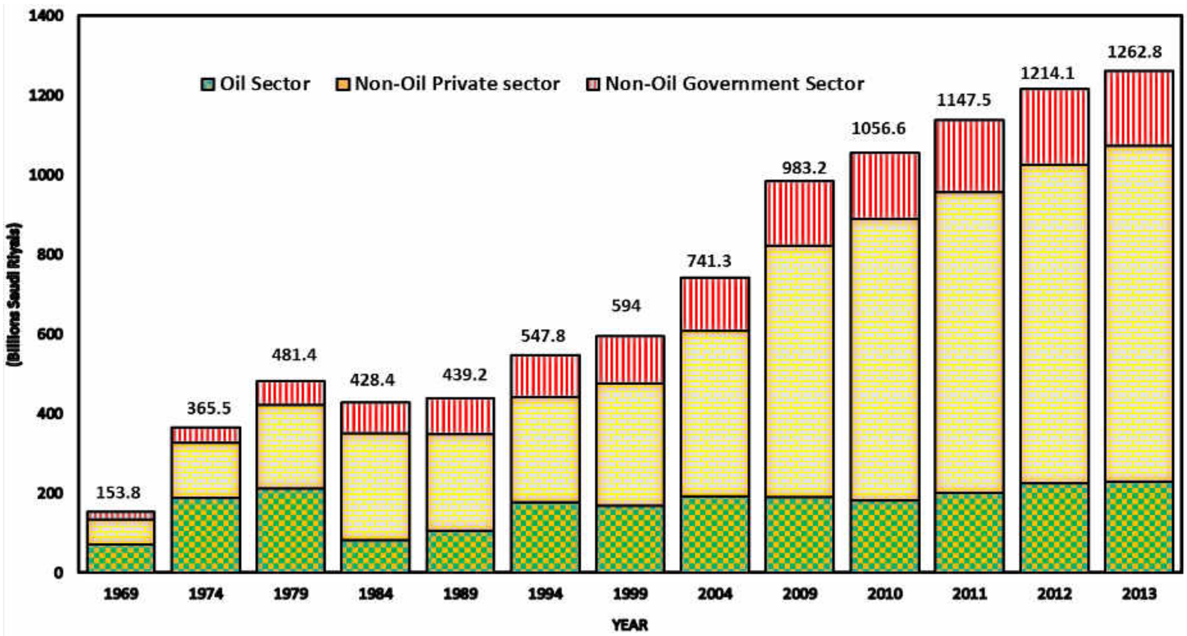


FIGURE 1. DEVELOMENT OF GDP BY OIL AND NON-OIL SECTORS AT 1999 CONSTANT PRICE IN THE KINGDOM OF SAUDI ARABIA

The 10th development plan of the Kingdom (2015-2019) constitutes the strategic national push towards diversifying the economic base from different dimensions, putting more focus on expanding production capacities of the industrial sector that mainly comply with the strategic areas highlighted by the National Industrial Strategy (NIS), promoting investment projects on diversifying energy sources, encouraging strategic partnerships at national and international levels to implement investment projects contributed to production base diversification of the national economy and considering comparative advantages in boosting spatial diversification of economic activities along with expansion in establishment of industrial zones and business and technology incubators to improve utilization of these advantages (MOEP, 2015), Table (4.1).

Table 4.1: Dimensions of the Economic Diversification in The Kingdom of Saudi Arabia

Dimension	Objectives
1. Vertical Diversification	• Raising utilization rates of mineral resources, diversifying pertinent activities and encouraging expansion in local production, processing and manufacturing of mining raw materials. • Developing production and service activities, which have strong linkages with oil and gas industries as well as upstream and downstream activities that depend on oil and gas.
2. Horizontal Diversification	• Expanding production capacities of the industrial sector, particularly in fields covered by the National Industrial Strategy. • Developing the services sector and increasing its contribution to GDP with due emphasis on financial, tourism, transport, engineering, communication and information technology (IT) services. • Diversifying economic activities in non-oil sectors with due emphasis on high- productivity and promising comparative advantage activities. • Investing in projects related with diversification of energy sources. • Developing non-oil exports and increasing their contribution to the total value of exports. • Encouraging local and foreign strategic partnerships to implement investment projects which contribute to diversification of the production base of the national economy. • Developing low-water-consuming agricultural products as well as fishing activities.
3. Spatial Diversification	• Making use of the comparative advantages of the provinces in boosting spatial diversification of economic activities along with expansion in establishment of industrial zones and business and technology incubators to improve utilization of these advantages.

Source: Ministry of Economy and Planning. The Objectives of the 10th Development Plan (2015-2019). The Kingdom of Saudi Arabia. 2015.

The Kingdom, also, puts more emphasis on raising the value added of natural resources in the national economy, diversifying their sources and ensuring their sustainability along with protecting the environment and conserving the wildlife. Developing the use of renewable energy sources for production of electricity, water desalination along with accelerating approval of necessary regulations and mechanisms, developing an integrated desalination industry which uses renewable energy sources and supporting it by advanced research centers (MOEP, 2015).

This chapter is an integral part of the Third National Communication (TNC) report of the Kingdom of Saudi Arabia. It tackles issues related to "Technology transfer and development, environmental and renewable energy technologies" in the Kingdom of Saudi Arabia.

Pursuant to the mandated terms of reference, this chapter is structured in three main sections, namely, technology transfer and development, renewable energy potential and energy efficiency application. The structure of this chapter considerate the strategic national push towards diversifying the economic base and the Intended Nationally Determined Contribution (INDC) of the Kingdom submitted to the UNFCCC.

4.2 Development and Transfer of Technology

Promoting the effective technology transfer and development has become a strategic option for developing countries to achieve their objectives to attain sustainable development in a climate-friendly manner. The Kingdom of Saudi Arabia has realized the significance of emphasizing the investment on technology transfer and high technology know-how through research, development and manufacturing processes to achieve its aspired socio-economic development objectives in a sustainable manner, particularly, the objective of diversifying the national economic base. The Economic Offset Program (EOP) with UK, USA and France was among the first initiatives launched in 1984 to promote investment on technology transfer and high technology know-how in the Kingdom and to benefit from technology transfer brought through private sector non-offset joint ventures. (Saudi Economic Offset program)

Technology assimilation has been considered as one of the means to expand the absorptive capacity of the national economy and to enhance its growth, stability and competitiveness through directing national and foreign investments towards high technology-content and high value-added sectors and encouraging creativity and innovation and accelerating implementation of the NIS (MOEP, 2015).

4.2.1 Policies

Policy instruments and technology solutions should be envisaged within the context of sustainable development to minimize or eliminate the risk of climate change to human life and property (Global Greenhouse Warming). A quit number of policies, initiatives and laws have been constituted and implemented in the Kingdom to promote the climate friendly technology transfer and development; to regulating ownership right to invest, to manage intellectual property, to set incentives and rights to the researchers in order to promote innovation and invention.

Pursuant to the mandated terms of reference of this chapter, the followings are the most pertinent policies, initiatives and laws in the Kingdom:

- The National Policy for Science and Technology (http://maarifah.kacst.edu.sa) was the first in its kind to trigger the initiative to diversify the national economic base by shifting the focus of the national economy from a natural resources-based economy to a knowledge-based economy, that builds, among others, on the transfer and development of environmentally sound technologies and on investing research in industry.

- Centers of Research Excellence Initiative is another arm of technology transfer and development in the Kingdom. Solar and Photovoltaic Engineering – King Abdullah University for Science and Technology (http://www.kaust.edu.sa/research-centers.html#rc7), Center of Research Excellence in Renewable Energy– King Fahd University of Petroleum and Minerals (http://ri.kfupm.edu.sa/core-re/), Sustainable Energy Technology Center – King Saud University (http://set.ksu.edu.sa/en) and others, are examples of centers of research excellence.
- The national technology incubator policy framework (https://www.badir.com.sa/), aiming to support technology entrepreneurs and innovators to increase national productivity to create high–value employment that would help establishing and developing high growth technology business ventures. The policy targets to implement 80 technology incubators in the Kingdom by 2025 in association with universities and the private sector (BADIR, 2015).
- The national trends to invest and to commercialize new technologies in strategic areas including renewable energy technologies. Saudi Technology Investment and Development Company 'TAQNIA' (http://www.taqnia.com), Riyadh Valley Company (http://rvc.com.sa), Dhahran Valley Company (http://dtvc.com.sa) are among the success stories in that field.
- The national intellectual property policy (http://maarifah.kacst.edu.sa) that determines the ownership rights of intellectual property resulting from research and development funded by the National Plan for Science, Technology and Innovation (Maarifah) and the responsibilities of parties involved. This policy, also establishes mechanisms for protection, investment, ownership of the intellectual property and incentives and rights to the researchers in order to promote innovation and invention in the Kingdom.
- The national system for protecting patents, layout designs, integrated circuits, plant varieties and industrial designs (http://www.kacst.edu.sa/ar/innovation/patents/DocLib/Law_arabic.pdf) that sets, along with the national intellectual property policy, the baseline for regulating ownership and management of intellectual property in the Kingdom.

4.2.2 Baseline Ecosystem

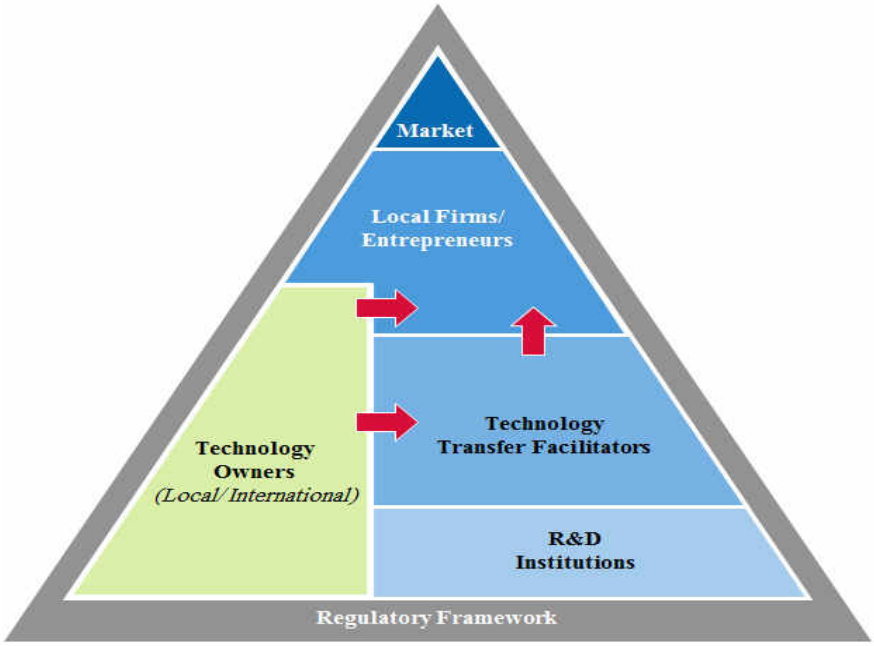
Analysis of the Technology Transfer and Development Ecosystem (TTDE) in the Kingdom revealed that foundation elements of TTDE are already in place, including, research and development institutions, technology transfer offices (TTO), commercialization institutions and intellectual property protection policies, etc. The analysis, also, revealed the great potential to enhance the TTDE elements in the Kingdom through (Booz and Co., 2014):

- Empowering existing entities to assume additional responsibilities in the technology transfer process.

- Defining regulatory guidelines and frameworks of technology ownership, required terms for drafting a technology transfer agreement, revenue sharing scheme, dispute resolution and applicable penalties and taxation reduction and financial support.

The potential baseline eco-system for the technology transfer and development in the Kingdom includes key stakeholders and their aspired roles and a regulatory framework that governs the technology transfer ecosystem through public policies and regulations and ensures proper technology transfer, (Figure 4.2).

Figure 4.2: Potential Baseline Eco-system for the Technology Transfer and Development in the Kingdom of Saudi Arabia (Booz and Co., 2014).



Enabler	Impact
Regulatory Framework	▪ Govern the technology transfer ecosystem through public policies and regulations ▪ Aim to ensure proper technology transfer
Technology Owners	▪ Own a technology in form of patented or non-patented innovation, intermediate good, machinery, etc. ▪ Negotiate technology transfer agreement with technology acquirer
R&D Institutions	▪ Conduct research and development across sectors to develop innovation, in the form of concepts, prototypes, processes, formulas, etc.
Technology Transfer Facilitators	▪ Support R&D institutions and technology owners in transferring technology to local firms and entrepreneurs ▪ Initiate marketing activities, support entrepreneurs/firms in technology transfer efforts
Local Firms/ Entrepreneurs	▪ Evaluate technology potential for commercialization ▪ Develop technology and disseminate product in the market
Market	▪ Constitute the technology demand market across all sectors ▪ Drive the need for innovation

➡ Technology Transfer

Challenges

The smooth operation of the TTDE in the Kingdom requires a proper identification of challenges and a well transformation of these challenges to opportunities.

The main challenges of the TTDE in the Kingdom could be clustered into two main groups, namely, natural uncontrolled and unregulated flow of inbound technology transfer and the limited successful flow of technology from research to commercialization, Table (4.2) (Booz and Co., 2014).

Table 4.2: Challenges to the Technology Transfer and Development Eco-system in the Kingdom of Saudi Arabia

Challenge	Description
1. Natural uncontrolled and unregulated flow of inbound technology transfer.	1.1. The lack of attractive incentives to local and international firms and entrepreneurs to partner and/ or to engage in the technology transfer development process in the Kingdom. 1.2. Insufficient regulations governing inbound horizontal technology transfer to the Kingdom and rights and obligations of all parties engaged in the technology transfer development process.
2. Limited successful flow of technology from R&D stage to commercialization stage.	2.1. The lack of a clear connection between R&D outputs and market requirements. 2.2. Non coordinated roles and responsibilities of the key players of the technology transfer ecosystem including R&D institutions and TTD facilitators, 2.3. Incomplete definition of revenue sharing mechanism between investors and the commercialization entities.

Sources: Booz and Co. Technology Transfer in KSA: Model and Regulatory Guidelines. 2014.

Technology Needs

The National Plan for Science, Technology and Innovation (Maarifah) (Maarifih, 2015), identified (11) core strategic technology areas that assess the national technology needs and the inspired scientific and technical advancement requirements in the Kingdom. The identified technology areas/ needs include water, oil and gas, petrochemicals, nanotechnology, biotechnology, information, electronics, communications and photonics, space and aeronautics, energy, environment, advance materials and mathematics and physics.

Maarifah developed 5-year strategic and implementation plans for each of these (11) core technology areas/ needs, considering the role of KACST, universities, government, industry and society (http://www.kacst.edu.sa), taking into consideration some qualifying criteria, such as:

- Need for self-dependence in technology/area.
- Ability to generate employment opportunities.
- Ease of transferring technology.
- Ability to generate investment opportunities.
- Potential for further development of technology.
- Potential to minimize governmental costs burden.
- Low technology adaptation and development cost.
- Potential environmental and health benefits.
- Availability of required infrastructure, including, national human resource qualifications.

Pursuant to the mandated terms of reference of this chapter, the indicative list of climate mitigation technology areas/ needs of the Kingdom including energy and environment technologies are presented in Tables (4.3-4.4). The energy technology area/ needs comprises seven tracks including renewable energy generation, conventional energy generation, electricity distribution and transmission, energy conservation and management, energy storage, fuel cell and hydrogen and combustion. Environment technology area/ needs comprises four tracks including waste, pollution, air quality and degradation of natural resources.

Table 4.3: The Strategic Energy Technology Areas/ Needs of the Kingdom of Saudi Arabia – 2008-2014

Technology Tracks	Technology Sub-Tracks
2. Renewable Energy Generation	2.1. Solar Energy (resource assessment, solar thermal, solar collectors, solar cooling, solar desalination, solar photovoltaic (PV) systems, PV cell fabrication, PV applications). 2.2. Wind Energy (resources assessment, grid-connected and stand-alone systems and wind energy applications).
3. Conventional Energy Generation	3.1. Steam and Gas Turbines (turbine efficiency and blades treatment). 3.2. Micro-Turbines. 3.3. Waste Heat Extraction Processes. 3.4. Multi-Generation. 3.5. Combined Cycle.
4. Electricity Distribution and Transmission	4.1. Electrical Transformers (auto/smart transformer, new construction material, sensors for measurement and protection). 4.2. Electrical Cables (new insulation material and design for high voltage).

Technology Tracks	Technology Sub-Tracks
	4.3. Electrical Networks (automation, smart network, development of software, hardware and sensors for communication in local and wide area network). 4.4. Electrical Circuit Breakers; CB (CB for high voltage and extra high voltage; EHV, advanced design and operating mechanism, protection, insulation material.
5. Energy Conservation and Management	5.1. Air conditioning and Refrigeration (heat pump, central AC, AC cycles, refrigerants, compressor, condenser, energy auditing, control, absorption chillers). 5.2. Lighting System (efficient lighting, ballast, auditing, compact fluorescent lamp, control). 5.3. Building Envelope (thermal insulation, window glazing and building shading, building energy management, building automation system). 5.4. Boiler / Furnace Efficiency. 5.5. Electric motors. 5.6. Heat Exchangers (compact heat exchangers).
6. Energy Storage	6.1. Super Capacitors. 6.2. High-Speed Flywheels. 6.3. Superconducting Magnets. 6.4. Advanced Batteries. 6.5. Thermal Energy Storage. 6.6. Pumped Storage.
7. Fuel Cell and Hydrogen	7.1. Hydrogen Production from Hydrocarbon Fuels. 7.2. Hydrogen Storage. 7.3. Proton Exchange Fuel Cell. 7.4. Solid Oxide Fuel Cell. 7.5. Direct Methanol Fuel Cell. 7.6. Stack Fabrication and Testing. 7.7. Fuel Cell Electrodes. 7.8. Fuel Cell Membrane. 7.9. Fuel Cell Catalyst.
8. Combustion	8.1. Automotive combustion. 8.2. Direct Injection.

Technology Tracks	Technology Sub-Tracks
	8.3. Auto-Ignition / Homogenous Charge Compression Ignition. 8.4. Industrial Combustion. 8.5. Efficiency Enhancement. 8.6. Emission Reduction. 8.7. Combustion Modeling. 8.8. Laser Application. 8.9. Fuel Technologies.

Source: King Abdulaziz City for Science and Technology. "Strategic Priorities for Energy Technology Program". The National Plan for Science Technology and Innovation (Maarifah). Kingdom of Saudi Arabia.

Table 4.4: The Strategic Environmental Technology Areas/ Needs of the Kingdom of Saudi Arabia – (2008-2014)

Technology Tracks	Technology Sub-tracks
1. **Waste**	1.1. Municipal waste water. 1.2. Municipal solid waste. 1.3. Industrial waste water. 1.4. Hazardous medical waste. 1.5. Hazardous waste. 1.6. Industrial solid waste. 1.7. Agricultural waste.
2. **Pollution**	2.1. Food contamination. 2.2. Oil Pollution. 2.3. Radioactive contamination. 2.4. Thermal pollution. 2.5. Noise Pollution
3. **Air Quality**	3.1. Ambient air quality. 3.2. Greenhouse gases.
4. **Degradation of Natural Resources**	4.1. Desertification. 4.2. Degradation of coastal areas. 4.3. Biodiversity.

Source: King Abdulaziz City for Science and Technology. "Strategic Priorities for Energy Technology Program". The National Plan for Science Technology and Innovation (Maarifah). Kingdom of Saudi Arabia.

Key Success Indicators

Building research and development infrastructure is a key component of the advancement of TTDE's value chain in the Kingdom, which strategically aspire to develop and localize technologies and know-how, to produce and commercialize highly efficient and cost effective technologies in areas that the Kingdom has competitive advantages and/or has a potential impact to diversify the national economy, to provide promising investment opportunities to the private sector and to build competent human resources pertinent to science and technology sector.

The followings are some selected achievements of the R&D initiations in the Kingdom, shedding more lights on climate mitigation technologies.

- Promoting scientific research and development: More than 2,000 research and development projects have been awarded under the National Plan for Science, Technology and Innovation (Maarifah) with more than 3.4 Billion Saudi Riyals (SR) throughout 2008-2015. Research and development projects in the environment technologies, energy technologies and oil and gas technologies received about 8.6 per cent, 7.3 per cent and 1.9 per cent of the total funded projects, respectively. More than 20,000 scientific personnel participated in the awarded research and development projects (researchers, consultants, students, technicians, scientific staff), out of which, 27 per cent are grade students (Maarifih, 2015).
- Supporting technology entrepreneurs and innovators to establish and develop high growth technology business ventures. BADIR Program for Technology Incubators (BADIR) works with the national universities and research centers to support the conversion of applied-research and innovative product development into successful business opportunities. Currently, BADIR establishes about (84) startups with a market value of about 185 Million Saudi Riyals, clients' revenue of about 7.8 Million Saudi Riyals and successfully created more than 3,000 jobs. The Kingdom targets to implement 80 technology incubators by 2025 in association with universities and the private sector. (BADIR, 2015)
- Increasing industrial cooperation and patent commercialization activity of the Saudi academic institutions and national and international commercial organizations to which produced patents have been co-assigned, showing the level of commercial IP transaction, licensing, security interests or the transfer of intellectual property rights. The Saudi academic institutions - industrial collaboration profile has expanded considerably in 2012, particularly with other academic institutions such as the Universities of California, Jordan, Illinois, Texas A&M and others. Other potential industrial collaborations however, include: Hitachi, 3M and Illinois Tool Works. Among the most fruitful area of co-assignment appears in petrochemical sector between KFUPM and Saudi companies such as SABIC, Saudi Aramco as well as Nippon Oil from Japan and Exxon Mobil of the USA (Thomson Reuters, 2014).
- Identifying a positive trend within the Kingdom, with increases in publication volume reaching about 16,200 in year 2014 (Country Ranking, 2015) and improvements in publication quality. The impact of published papers, measured by the Average Citation Impact, has also markedly increased. At the country level, the Kingdom confirms its lead in terms of volume of annual scientific output. The growth rate in publication output for

the Kingdom remains higher than other GCC countries. Since 2012, the Kingdom's publication outputs surpasses any other output in the region including Egypt (Country Ranking, 2015). While scientific output grows, it is noticeable to see that the Kingdom's influence also improves as the normalized citation rate increases (0.94) and is now very close to the World average (1.0) which is a significant accomplishment over a very short period of time (Thomson Reuters, 2014).

Commercialization and Entrepreneurship

The Kingdom has directed itself toward knowledge based economy in alignment with the objective 3.5 in the 10th national development plan "utilizing the results of scientific research" and "the transformation of knowledge into wealth"(MOEP, 2015). However, there is a gap between the outcomes of R&D (e.g., innovations, patents, industrial solutions) and the implementation of the GHG mitigation projects. This gap could be filled by technology commercialization and entrepreneurship activities from labs, research centers and universities to the industries.

In terms of investing in R&D, the investment risk is extremely high in transforming new ideas (e.g., inventions) to commercialization products to reduce GHG emissions. These were in line with the objective 3.9 "encouraging the universities and companies to invest in research, development and innovation fields "and the objective of 4.9 "directing national and foreign investments towards high technology content and high value added sectors".

National Industrial Strategy (NIS)

In line with the objective 4.10 of the 10th National Development Plan, an effort was made to bridge the gap between the implementation entities (e.g., industries) and the R&D centers through launching the National Industrial Strategy (NIS) to vision the future of the Kingdom industry in 2020 (MOCI, 2007). The vision of NIS was based on knowledge based industry as indicated in the vision "A globally competitive industry based on innovation".

Enhancing the technology content in Saudi industry from 30 per cent in 2007 to 60 percent in 2020 was set as a future national target and as an indicator to the achievement of the goal by the end of 2020. However, to achieve these ambitious targets, many programs are set such as building technology clusters and complexes which is in alignment with axis 2 of the NIS and in line with the objective 22.7 of the 10th National Development Plan "establishing creativity and innovation clusters in the various regions of the Kingdom through strengthening the relations between the private sector, universities and research centers". Other programs were included in the 4th axis as listed below (MOCI, 2007):

- Industrial innovation coordination program.
- Industrial research developing and commercialization program.
- Industrial innovation fund program.
- Industrial technology centers program.

Investment in Research

Three technology-based companies were launched [mainly through public fund] in 2010-2011 in order to invest in the outcomes of R&D and scaling up the developed and invented technologies: TAQNIA (2011), Riyadh Techno Valley Co. (2010) and Dhahran Techno Valley Co (2010). Furthermore, BADIR program for technology incubators has established about (84) startups with a market value of about 185 Million Saudi Riyals, clients' revenue of about 7.8 Million Saudi Riyals and successfully created more than 3,000 jobs (BADIR, 2015).

TAQNIA chose energy industry sector as one of the highest opportunities along with water technology and advanced materials. TAQNIA used four parameters to assess each industry sector in order to find the best industry opportunities: strategy relevance, economic attractiveness, risk profiles and competitive dynamics. Going through this assessment processes, six startup companies were established including TAQNIA Energy (2014) and Advanced Water Technology Co (2012). TAQNIA Energy is working on the transfer of solar power and waste to energy This is still in the early stage of implementation (TAQNIA, 2015).

Riyadh Techno Valley (RTV) Co. was established under the umbrella of King Saud University in 2010 on an area of 1.7 km^2. RTV chose to work in three industry sectors; among which, renewable energy and sustainable resources. RTV has been successful to initiate six startup companies (RVCo., 2016).

Dhahran Techno Valley (DTV) Co. was established under the umbrella of King Fahad University of Petroleum and Minerals (KFUPM) in 2010 on an area of 1 km^2 in Dhahran city. Six fields of industry sectors were chosen by DTV to startup companies, among which, renewable energy, energy storage and efficiency and carbon management (DTVCo., 2016).

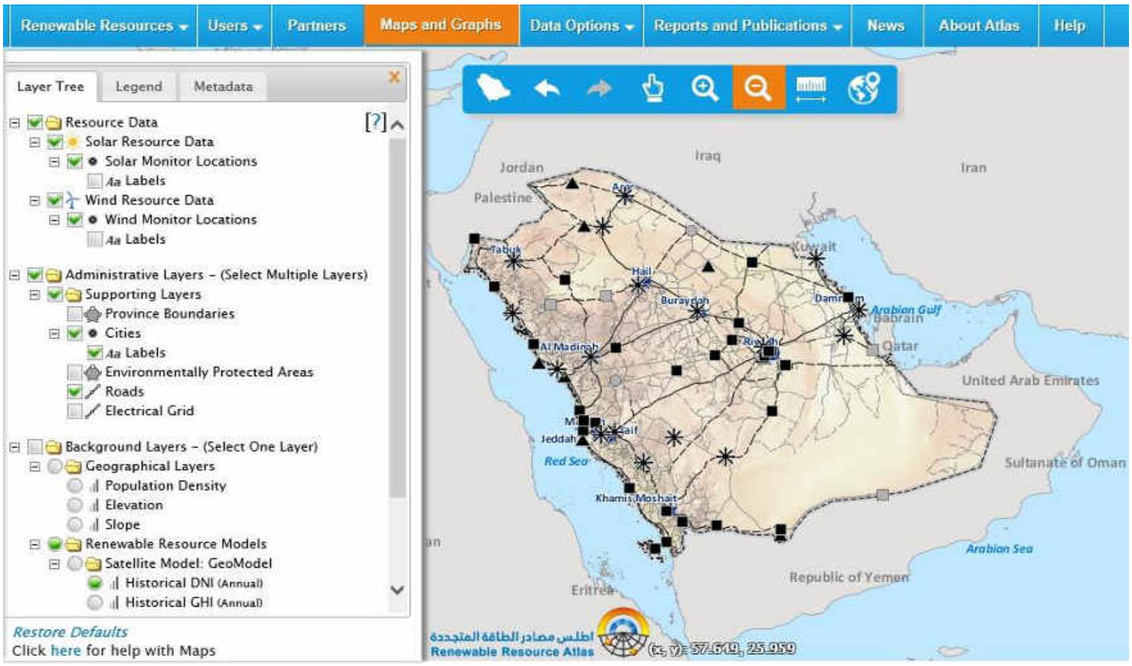
Research and Development Outputs

In the 2nd Saudi National Communication, 2011, (SNC, 2011) the Kingdom was still in the R&D stages in most of the environmental technologies that are related to climate change. However, in this report, the early outcomes of R&D are obvious and are embodied in pilot and large scale high technology projects to reduce and avoid GHG emissions using renewable energy technologies, Carbon Capture and Storage (CCS) technologies and adapting advanced public transportation systems.

(i) Renewable Energy Technologies

1. The Renewable Resource Atlas https://rratlas.kacare.gov.sa/rrmmpublicportal/ has been introduced as a foundational program to support the endeavor to achieve the desired sustainable energy mix in the Kingdom. The Atlas provides newly collected and historical solar and wind resource monitoring data and satellite-based modeled data, for use by developers, researchers, government institutions and policy-makers. Beneficiaries are able to get reports of the solar monitoring network as well as individual stations (http://www.kacare.gov.sa). This Atlas is a continuation of a national endeavor to assess the potential of the renewable energy resources applications and utilization in the Kingdom in the 90s (http://www.kacst.edu.sa).

Figure 4.3: The Renewable Resource Atlas



https://rratlas.kacare.gov.sa/rrmmpublicportal/

The Atlas

Click on the map (or the maps and Graph menu item) to launch the Atlas and begin exploring solar resource data.

Requst a log-in to view modeled monthly and annual average data, see finer scale data, or access graphing and downloading functions. Daily or hourly data is also available for purchase through the data download.

You can also contact K.A.CARE to learn about tailord consulting services offered.

- Pilot production of high-purity poly-silicon templates (REC, http://www.kacst.edu.sa)
- Developing and manufacturing efficient solar cells from silicon, gallium arsenic material. (REC, http://www.kacst.edu.sa)
- Production and installation of high concentrated and efficient solar energy system. (REC, http://www.kacst.edu.sa)

- Developing a commercialized solar panel coated glasses that prevent adhesion of dust on glass roofs. (REC, http://www.kacst.edu.sa)
- Investigation on the potential to develop dry sodium batteries used as an electrical energy storage that suite the Kingdom environment (REC, http://www.kacst.edu.sa).
- Developing a thermal energy storage system using chromite sands heat exchanger to generate electricity (REC, http://www.kacst.edu.sa).
- Designing an integrated wind energy system to feed a remote farming area with electric power at a competitive price of about 9.6 US cents per kilowatt hour (SETC, http://set.ksu.edu.sa/en).
- Designing and manufacturing smart materials incorporated into buildings to reduce waste in energy by enhancing performance and identifying glitches in the solar cell systems energy efficiency (SETC, http://set.ksu.edu.sa/en).
- Developing an electrical interconnection smart system to manage and to monitor network performance, thus, to close the gap resulting from the increase in electricity demand at peak times (SETC, http://set.ksu.edu.sa/en).
- Designing and developing a bio-diesel production pilot plant to generate about 400 watts of electrical power for small applications such as restaurant and food plants (SETC, http://set.ksu.edu.sa/en).
- Developing cost effective and high efficient catalysts materials used to stimulate production of hydrogen in cars fuel cells (SETC, http://set.ksu.edu.sa/en).

(ii) Environmental Technologies

The national demand for the registration of emission reduction projects and get approved by Designated National Authority (DNA) to gain certified emission reduction (CER) units can be used as a national performance indicator for the implementation of mitigation technologies that are aimed to reduce or avoid future GHG emissions.

According to Saudi DNA (DNA, 2015), by the end of 2015, the annual certified emission reduction units are 533,225 as presented in Table 4.5 which distributed into five projects with different types of mitigation activities. Most of these reductions occurred in landfill gas capture projects that represent 89 per cent of the total reductions, followed by improving energy efficiency systems.

Around forty seven mitigation projects were submitted for registration at the Saudi DNA and most of them were in improving energy efficiency systems (60 %) and enhancing oil recovery (19 %).

These GHG mitigation projects that are registered or submitted for registrations, highlight the advancement of R&D in this field of study to reach the stage of pilot or full scale implementations that enable the Kingdom to solve the GHG problem.

Table 4.5: Registered Emission Reduction Projects and Certified Emission Reductions (CERs) Units (Updated in 2016 by Saudi DNA) (DNA, 2015)

No.	Registered Emission Reduction Projects	CERs Units Annually
1	Madinah Landfill Gas Capture Project	139,108
2	Jeddah Old Landfill (JOLF) and Jeddah New Landfill (JNLF) Gas Recovery Bundled Project	335,425
3	Solar Power Project at North Park Building	10,346
4	Installation of a Tri-generation System Supplying Energy to a Commercial Building	6,515
5	Efficiency Improvement by Boiler Rehabilitation in Fossil Fuel-Fired (Natural Gas) Steam Boiler System	41,831
	Total	**533,225**

Carbon Capture and Storage Implementation Projects

Recently, Saudi large companies (like Aramco, SABIC and SEC) and governmental institutions have been active in carbon capture and storage (CCS) techniques, which are in alignment with section II/part 3 of the Saudi INDC regarding mitigation. These CCS activities can be divided into five categories as discussed below. Selected efforts will be highlighted under each category.

Blue Carbon Sequestration Technologies

Mangroves

Part of the national adaptation efforts and in line with section III/part 1.2 of INDC, The Kingdom has been implementing coastal management strategies that are designed to reduce coastal erosion and increase the sinks of blue carbon. The Kingdom has realized the benefits and the role that the plant can play to capture carbons in its biomass. Mangroves trees, which represent 0.4 per cent of the total area of forests in the world, capture approximately 18 million tons of carbon dioxide annually around the globe (Patil et.al., 2012). Selected species of Mangrove trees (Avicenna Marina), which is one of the heist ability trees in capturing carbon, was chosen to be planted along the shores of the Arabian Gulf starting in the early of the 1990s (Saudi Aramco EED, 1994), followed by a project of planting 60,000 mangrove trees/seeds yearly. An ambitious plan was set to plant 1.2 million mangrove plant along the shores of the Kingdom by the end of 2020 (Oil & Gas News, 2016). To highlight some of the efforts have been made towards achieving that plan, a forest of approximately 200,000 mangrove trees was established in Abu Ali Island. Also, in 2013, Tarout Bay was planted with 10,000 mangrove trees (Tarout Mangroves, 2015).

Algae

As part of the efforts of the Kingdom in the implementation of the blue carbon sequestration techniques, a pilot project was conducted in Muzahimiyah Research Station (west of Riyadh region) to limit GHG emissions by producing protein rich edible algae. These algae can be fed on CO_2 to produce proteins to feed livestock or used as biofuels. Algae can capture 58 to 90 tons of CO_2 per hectare per year, which is 2 to 3 times higher than that of forests (Al Hafedh, 2015).

Enhanced Oil Recovery (EOR)

The Kingdom launched another project using CCS techniques at the end of 2015 to capture CO_2 from power plants and inject it into oil reservoirs to enhance oil recovery in Uthmaniyah field. The annual capacity of the project is about 800,000 tons of CO_2 making it the largest project of its kind in the Middle East (Saudi Aramco, 2015, MIT, 2016).

CO_2 Utilization & Recycling

In 2015, the Kingdom launched the world's largest project to utilize and recycle CO_2 that are produced from glycol ethylene plants in Jubail (a petrochemical industry area) with a capacity of capturing 500,000 tones yearly of CO_2 to produce urea (used as an input in fertilizing industry) and methanol (used as an input in petrochemical industry) (O'Hanlon, 2016, Tahir Ikram, 2016). Another project to utilize CO_2 is planned to purify CO_2 to a food grading level that can be used as an input in food industry (e.g., beverage industry) (Tahir Ikram, 2016).

Mobile Capture of CO_2

A prototype of a vehicle was developed to capture and storage 10 per cent of CO_2 that are produced from the exhausting gas emissions of the vehicle. The stored CO_2 can be disposed during refueling time at designed spaces for that. This prototype vehicle needs to be improved to a higher carbon capture capacity before scaling up to a commercial level (Al-Meshari et.al., 2016).

Methane Recovery Projects

Landfills are the largest source of methane gas in the Kingdom representing about 73 per cent of the total amount of methane, followed by livestock farms (24 per cent) (Al Abdulkader et. al., 2015). Therefore, as indicated in CDM activities (Section 3.3), most of the granted certified emission reduction units come from landfill gas recovery. Madinah landfill gas recovery project and Jeddah Old & New Landfill Gas Recovery project yield 139,108 and 335,425 Certified Emission Reduction (CER) units annually, respectively.

Public Transportation

- ***Current Energy Consumption and GHG Emissions***

Public transportation is an important CO_2, emitting sector, annually the Kingdom imports about 760,000 vehicles which highlights the large accumulated fleet of vehicles in the Kingdom. International Energy Agency (IEA) indicated that 25 per cent of the global CO_2 emissions comes from transportations and the number of vehicles would be doubled in 2050 in case of no global reduction action. These statistics urged decision makers to take appropriate measures and actions to reduce CO_2 emissions, as indicated in the objectives 21.12 and 21.14 of the 10th National Development Plan, by developing efficient public transport systems (intra-city and inter-city public transportation systems). These measures and actions are in line with section 6 subsection 3c of INDC regarding means of implementations through using transportation technologies that reducing transportation related emissions (REF, 2015).

- ***Riyadh Public Transportation Project***

The new Riyadh public transportation project emerged since 2014 which consists of two subprojects: Riyadh bus project and Riyadh metro project. Riyadh bus project contains 24 lines, 1,200 km of networks and 6,700 stops & stations. While Riyadh metro project contains 6 lines, 176 km of network and 85 stations. This project is expected to be completed in 2018-2019

- ***Other Saudi Major City Public Transportation Planed Projects (Inter-city Systems)***

Important initiatives have been undertaken in the Kingdom regarding public transportation systems after launching the National Transport Strategy in 2011 and the establishment of Public Transport Authority in 2012. Beside Riyadh Public Transportation project, four other public transport projects are planned in Saudi large cities with high population densities namely Makkah, Jeddah, Madinah and Dammam. The construction phase of these projects are yet to commence and their status of implementation will be reported in subsequent national communications.

- ***Intra-city Public Transportation Systems***

A strategic plan was developed in 2010 entitled "Saudi Railway Master Plan" to adopt technologically advanced transport systems between the major and industrial cities in the Kingdom, which is in alignment with the national transportation strategy. This strategic plan is consisted of three levels distributed into 30 years (from 2010 to 2040).

The 1st level of the strategic plan is consisted of five projects which are summarized in the following table. Indeed, these future railway projects will limit a large amount of GHG emissions by reducing the number of vehicles travelling in the highways between cities and would also reduce the trucks that are traveled daily to transport goods commercially.

Table 4.6: Summary of 1st level of the Saudi Railway Master Plan in the Kingdom of Saudi Arabia.

	Name of the project	Details of the plan
1	Haramain High Speed Rail Project	In line with the objective 21.13 of the 10th national development plan, a railway project is under construction to link the holy cities of Makkah and Madinah through Jeddah with 450 km electric rail line and 360 km/h speed.
2	North-South Line Project	North-South railway project is going to link the northern region with the capital city and the industrial area of the eastern regions with approximately 2,400 km line and 200 km/h speed.
3	Land Bridge Project	It is planned to connect: i) The capital city of Riyadh to the Red Sea (to Jeddah city) and ii) Dammam to Jubail industrial area. This project is going to connect the Arabian Gulf Sea with the Red Sea.
4	The Double Line Upgrade of the Existing Dammam-Riyadh Railway	It is an upgrade to the old railway between the capital city of Riyadh and the Arabian Gulf Sea.
5	GCC Railway Network	This project is a fruit of collaboration between the GCC countries and it would approximately cover a line of 650 km in the Saudi territories.

4.3 Renewable Energy in The Kingdom of Saudi Arabia

The Kingdom of Saudi Arabia has passed through a quantum economic growth during the last decades which has been attendant with an increased population growth rate equivalent to about 2.55 per cent in 2014 (CDSI, 2015) and ever-increasing internal demand for the primary energy resources.

Subsequently, rigorous measures have been taken to curb the escalating internal demand for the primary energy resources and its consequences, particularly in the largest demanding sectors for the primary energy in the Kingdom of Saudi Arabia such as electricity, transportation, water and the industrial sectors (REF, 2015). Taken measures, include, developing and deploying renewable energy sources, constituting energy efficiency system (Alyousef et. al., 2010) and lowering subsidies on energy products, electricity and water services (MOF, 2016).

Developing and deploying renewable energy have been considered among the most sustainable and reliable sources of energy in the Kingdom to meet the increased internal demand for the primary energy, thus minimize the opportunity cost of lost export revenues.

The Kingdom is among the first nations in the world that initiated unique programs on solar energy applications and utilizations, including, the SOLERAS (KSA-US Cooperation program in Solar Energy), a Saudi Arabia-USA joint program on solar energy applications, initiated in 1977 and HYSOLAR (KSA-German Cooperation program in Solar Energy), a Saudi Arabia-German joint program on solar hydrogen production and utilization, initiated 1986.

Renewable energy sources have tremendous advantages, including the potential to provide energy services in a sustainable manner, particularly in mitigating climate change, availability of a wide range of renewable energy technologies that can meet the full need from energy services with little or zero-CO_2 emissions depending on the level of technical maturity and commercial scale of renewable energy technologies, an equitable and sustainable economic development, secure energy supply, energy access and environmental and health benefits (Moomaw et.al., 2011).

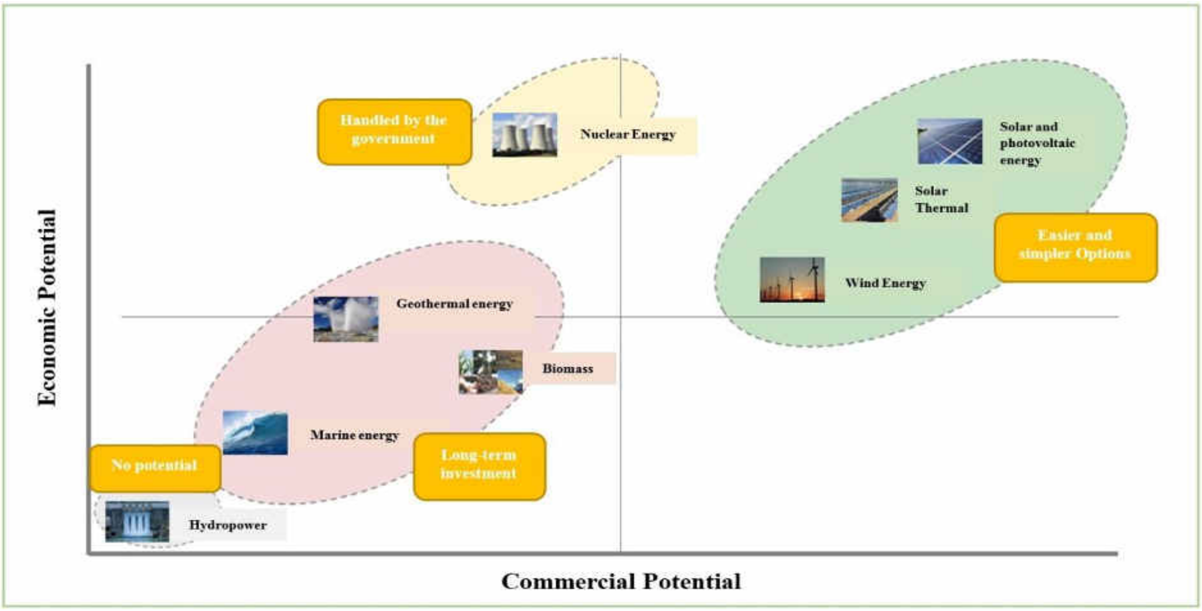
The ambitious future energy mix is strategically important to the Kingdom to attain long-term prosperity, energy security and leading position in the global energy market. Yet, it success requires drafting a new national long term strategic energy plan that considers the following steps (www.kacare.gov.sa):

- Monitoring the supply of and the demand for renewable energy compared to fossil fuel energy.
- Deploying renewable energy technologies based on a pilot based approach to minimize the technical uncertainty.
- Promoting the large scale deployment of RE technologies that require available capacity building.
- Ensure the effective involvement of stakeholders at all planning stages (water desalination, electricity power generation, energy suppliers, legislative entities and major customers etc.).
- Evaluating all available energy supply options, including, the conventional resources, renewable and alternative resources and future technologies.

Potential Sources of Renewable Energy Technologies

Building on some commercial and economical potentials of renewable energy technologies, solar photovoltaic energy, concentrated solar energy and wind energy are envisaged the most potential renewable energy sources in the Kingdom compared to the other technologies (Figure 4.4) (REF, 2015).

Figure 4.4: Potential Sources of Renewable Energy Technologies (REF, 2015)



Private Sector

Private sector plays a critical role in the achievement of the sustainable economic and social development objectives. Conducive environment, integrated economic frameworks and clear implementation plan are imperative to ensure an efficient and sustainable involvement of the private sector in the national development plan. The participation of private sector in developing a reliable renewable energy sources in the Kingdom could be promoted through implementing some multi-level economic frameworks that could be selected on a basis of technologies, applications and goals of development process, (Table 4.7). The effects of the economic frameworks including revenue assurance, cost reduction, reduce impediments to entry (REF, 2015).

Table 4.7: Economic Frameworks for the Renewable Energy Sector in the Kingdom of Saudi Arabia

Renewable Energy Technology	Applications	Criteria
1. Solar Photovoltaic Energy **2. Concentrated Solar Energy** **3. Wind Energy**	1. Large and small scale applications 2. Out grid applications 3. Limited generation application 4. RE based-water desalination application 5. Cooling application 6. Residential buildings roofs application.	1. Ease implementation 2. Private sector involvement 3. Compatibility with the national orientations. 4. Cost effectiveness.

Source: Riyadh Economic Forum, 2015. "Economics of Renewable and Alternative Energy in the Kingdom of Saudi Arabia: Challenges and Future Prospects"

Institutional Arrangements

The Kingdom has taken specific measures to ensure the reliable and efficient implementation and deployment of renewable energy sources among the energy mix and strengthen the energy efficiency system, including, establishing the required institutional arrangements, as follows:

- Establishing King Abdullah City for Atomic and Renewable Energy (www.kacare.gov.sa) as a driving force for making renewable energy an integral part of a national sustainable and reliable energy mix, creating and leveraging the competitive advantages of relevant technologies for the social and economic development of the Kingdom of Saudi Arabia. K.A.CARE has been mandated to support and foster scientific research and development activities, localize technology, coordinate the activities of the scientific research institutions and centers in the Kingdom in its fields of specialization, organize local conferences and participate in international conferences, determine priorities and national policies in the field of atomic and renewable energy in order to build a scientific technical base in the field of generating power and producing desalinated water and in the medical, industrial, agricultural and mining fields (www.kacare.gov.sa).
- Building a reliable research and development infrastructure in the field of renewable technologies through the establishment of world class research institutions and centers national network that carry out research, development and innovation activities, including the Renewable Energy Program - King Abdulaziz City for Science and Technology (http://www.kacst.edu.sa), Solar and Photovoltaic Engineering – King Abdullah University for Science and Technology (http://www.kaust.edu.sa/research-centers.html#rc7), Center of Research Excellence in Renewable Energy– King Fahd University of Petroleum and Minerals (http://ri.kfupm.edu.sa/core-re/), Sustainable Energy Technology Center – King Saud University (http://set.ksu.edu.sa/en) and others,
- Developing BADIR program for technology incubators (https://www.badir.com.sa/) to increase national productivity, to create high–value employment, to support technology entrepreneurs and innovators that would help establishing and developing high growth technology business ventures.
- Investing and commercializing new technologies in strategic areas including renewable energy technologies. TAQNIA ENERGY - Saudi Technology Investment and Development Company 'TAQNIA' (http://www.taqnia.com), Riyadh Valley Company – KSA (www.rvc.org.sa), Dhahran Valley Company (http://ttie.kfupm.edu.sa/site/) are among the success stories in that field.
- Rationalizing and enhancing energy consumption efficiency. Currently, the Saudi Energy Efficiency Center (http://www.seec.gov.sa/) is establishing initiatives for the most important three sectors, which its consumption represents more than 90 per cent of the total national energy consumption, namely, construction, land transportation and Industry sectors.

Applications

A number of applications of renewable energy sources in the Kingdom are available, mainly, that of solar energy applications in petrochemical industry, water sector and power generation sector.

(i) Petrochemical Applications

- Developing and commercializing a prismatic structure of the thermoplastic panels used to collect solar energy. The solar energy collectors are now produced locally in the Kingdom through SABIC and used for commercialization purposes (Booz & Co., 2014).

(ii) Water Applications

- Launching the national initiative to desalinate water using solar energy, targeting the application of the best technologic solutions with the minimum cost. The first phase of desalinated water production has already started with the objective to build a plant for desalinating water with a production capacity of 30,000 cubic meter/Day to meet the demand of Al Khajfi city (Booz & Co., 2014).
- Designing and implementing a solar energy project to provide a (30 kW) water pumping capacity at Hail city (REC, http://www.kacst.edu.sa).
- Designing and implementing a desalination solar-powered plant with a current capacity of about 60 thousand cubic meters per day and 38 MW electric power (REC, http://www.kacst.edu.sa).

(iii) Power Generation Applications

- Design and implement solar energy projects to feeding Riyadh city network with (15 kW) (REC,http://www.kacst.edu.sa).
- Implementation of a (50 MW) solar plant at Aflaj city (REC,http://www.kacst.edu.sa).
- Designing an integrated wind energy system to feed a remote farming area with electric power at a competitive price of about 9.6 US cents per kilowatt hour (SETC, http://set.ksu.edu.sa/en).
- Constructing a solar power plant with a capacity of 500 kWp over an area of 7700 m^2 in Farasan Island, south of the Kingdom, as a stand-alone system intended to feed the Island. This plan has been in operation since 2011(Almasoud & Gandayh, 2015).
- Building the world's largest solar parking project in Dhahran that has a 10MW carport system with a capacity to cover 200,000 m^2 (Almasoud & Gandayh, 2015).
- The installation and operation of 2 MW PV cells solar power plant consisting of 9300 modules of 215 Wp (the peak power rating of a solar panel) over 11,600 m^2. The plant is intended to produce 3300 MWh of clean energy annually (Almasoud & Gandayh, 2015).

Industry

The Kingdom has successfully initiated a promising energy industrial infrastructure. TAQNIA ENERGY, TAQNIA SOLAR, PV panel production line and the solar panel rust-resistant installation system production line are among the key pillars of the energy industry in the Kingdom. Among the top achievements of TAQNIA ENERGY is a 50 MW PV Layla Project. The 50 MW solar facility will become the first solar Independent Power Producer (IPP) agreement in the Kingdom.

Building on the quantum R&D achievements, the Kingdom has initiated promising solar technology production lines at the Solar Village, the biggest project of its type in 1980 that include producing and manufacturing cost effective and competitive mono and multi-crystallized silicon cells using the cutting-edge technologies with production line capacity of 100 MW annually (KACST Solar Energy program, (http://www.kacst.edu.sa). The current annual production capacity of the PV panel production line is about (14 MW) and a potential annual production capacity of 100 MW is target by year 2016 (KACST Solar Energy program, (http://www.kacst.edu.sa).

Initiatives and Policies

The 10th development plan of the Kingdom (2015-2019) has targeted the development and implementation of the renewable sector thru investing in projects related to diversification of energy sources, developing the use of renewable energy sources for production of electricity and water desalination and accelerating the approval of necessary regulations and mechanisms (MOEP,2015).

Some recent in-depth analysis have successfully introduced a variety of initiatives and policy options that are related to introducing renewable energy along with minimizing energy consumption on the supply and the demand sides in the Kingdom. These initiatives and policy options, motivated by a variety of factors, would have driven escalated growth in the development of renewable energy technologies in the near future.

(i) Initiatives for reducing energy consumption on the demand side (Alyousef, et. Al., 2010)

- Introduction and implementation of a new energy conservation law.
- Introduction and implementation of building regulations.

(ii) Initiatives for reducing energy consumption on the supply side (Alyousef, et. Al., 2010)

- Modernization of existing power generation plants.
- Minimum efficiency standard for new power generation plants.
- Minimum overall efficiency standard for co-generation desalination plants.
- Developing and deploying renewable energy sources to displace non-renewable energy sources.

Building on the available best practices worldwide, among other criteria, thirteen initiatives have been identified to develop a sustainable renewable energy sector in the Kingdom. These initiatives have been classified in to three themes as follows: (REF, 2015):

(i) Initiate implementation plan to deploy alternative and renewable energy, including seven initiatives:

- ➢ Identify the role of stakeholders.
- ➢ Identify the objectives of renewable energy.
- ➢ Implement the renewable energy economic framework.

- Set policies and model to deploy alternative energy.
- Implement the alternative energy economic framework
- Secure financial fund.
- Establish universal service centers for alternative and renewable energy.

(ii) Build atomic and renewable energy value chain, including three initiatives:

- Develop a supply chain.
- Develop a human capital.
- Develop a technology capital.

(iii) Build a sustainable energy ecosystem, including three initiatives:

- Energy support management.
- Integrated resources planning.
- Integration of renewable energy and energy efficiency.

Barriers

Developing and deploying sustainable and efficient renewable energy sector in the Kingdom faces a number of barriers that should be dealt with appropriately to trust the success of renewable energy sector in the Kingdom. The abundance of fossil fuel at a competitive price along with the low participation of the private sector in the development of renewable energy sources, financial risks and lack of public and institutional awareness about the potential economic and environment benefits of the renewable energy are among the exiting barriers and issues to the implementation of renewable energy in the Kingdom, (Table 4.8).

Table 4.8: Barriers to the Implementation of Renewable Energy in The Kingdom of Saudi Arabia (Alyousef, et. Al., 2010)

Barriers	Description
Policies	1. Abundance of oil created a no-urgency need to develop renewable energy policies. 2. Lack of incentives for renewable energy technologies in comparison to fossil fuel-based electricity generation and so electricity from oil-fired power generation is very cheap.
Economic	1. More cost-effective sources of energy are available. 2. Low financial incentives for renewable technologies. Thus, RE is more expensive than fossil-fuel generation technologies. 3. Lack of private investment involvement. 4. High capital costs and long payback period.
Awareness	1. Limited public knowledge about some renewable energy technologies. 2. Lack of public knowledge about the environmental benefits of renewable technologies. 3. Resistance to change. 4. Low public acceptance of new energy options. 5. Absence in the curricula of schools of renewable technologies 6. Lack of professional training.

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SECTION – 5

Analysis of Socioeconomic Impacts of Response Measures and Policies

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5.1 Objective:

This chapter discusses the implications of climate change response measures and policies for the Kingdom of Saudi Arabia and frames the climate change issue within the broader sustainable development context. It provides a background and an update on the issue and the related provisions. The chapter also illustrates the Saudi Arabian economy's potential vulnerability as a result of the implementation of Annex I response measures and policies aimed at mitigating greenhouse gas emissions. This vulnerability arises due to the fact that Saudi Arabia's remains highly dependent on hydrocarbon exports while significant demographic pressures continue to tax the government's ability to provide for the needs of its population.

Consistent with the Kingdom's aspiration for sustainable development a remedy to this potential concern would be for Saudi Arabia to diversify its economy sufficiently to reduce its dependency on hydrocarbon to adapt to the implementation of these Annex I climate change response measures. The chapter further provides detailed discussion of the Kingdom efforts on economic diversification as well as an account of the challenges and needs to make the effort a success. Consistent with the relevant provisions of the UNFCCC and the Kyoto Protocol, it needs not be emphasized that developed countries are obliged to fulfill the needs of vulnerable developing countries like Saudi Arabia in order to meet the former countries' commitments under these climate change agreements and beyond.

5.2 Background

In the 1980s, concerns emerged about potential links between human-induced greenhouse gas emissions with the risk of global climate change. As a result, certain governments voiced their concerns about this potential problem. This ultimately led to the creation of the United Nations Framework Convention on Climate Change (UNFCCC), which entered into force in 1994. The objective of this convention is the stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. This objective must also be accomplished in a way to provide sufficient time for natural systems to adapt without undermining sustainable development.

Developing countries have raised concerns about the potential impacts of climate change related policies undertaken by developed countries to mitigate greenhouse gas emissions. As a result, Articles 4.8 and 4.10 of the UNFCCC as well as Articles 2.3 and 3.14 of the Kyoto Protocol as outlined below stipulate that Annex I parties agree to meet specific needs of developing countries arising from the impact of the implementation of response measures and policies.

5.2.1 UNFCCC Article 4.8:

In the implementation of the commitments in this Article, the Parties shall give full consideration to what actions are necessary under the Convention, including actions related to funding, insurance and the transfer of technology, ***to meet the specific needs and concerns***

***of developing country Parties arising from the adverse effects of climate change and/or the impact of the implementation of response measures**, especially on:*

- *a) Small island countries;*
- *b) Countries with low-lying coastal areas;*
- *c) Countries with arid and semi-arid areas, forested areas and areas liable to forest decay;*
- *d) Countries with areas prone to natural disasters;*
- *e) Countries with areas liable to drought and desertification;*
- *f) Countries with areas of high urban atmospheric pollution;*
- *g) Countries with areas with fragile ecosystems, including mountainous ecosystems;*
- ***h) Countries whose economies are highly dependent on income generated from the production, processing and export and/or on consumption of fossil fuels and associated energy-intensive products; and***
- *i) Land-locked and transit countries.*

5.2.2 UNFCCC Article 4.10:

*The Parties shall, in accordance with Article 10, take into consideration in the implementation of the commitments of the Convention the situation of Parties, particularly developing country Parties, with economies that are vulnerable to the adverse effects of the implementation of measures to respond to climate change. **This applies notably to Parties with economies that are highly dependent on income generated from the production, processing and export and/or consumption of fossil fuels and associated energy-intensive products and/or the use of fossil fuels for which such Parties have serious difficulties in switching to alternatives.***

5.2.3 Kyoto Protocol Article 2.3:

*The Parties included in Annex I shall strive to implement policies and measures under this Article in such a way as **to minimize adverse effects, including the adverse effects of climate change, effects on international trade and social, environmental and economic impacts on other Parties, especially developing country Parties and in particular those identified in Article 4, paragraphs 8 and 9, of the Convention**, taking into account Article 3 of the Convention. The Conference of the Parties serving as the meeting of the Parties to this Protocol may take further action, as appropriate, to promote the implementation of the provisions of this paragraph.*

5.2.4 Kyoto Protocol Article 3.14:

*Each Party included in Annex I shall strive to implement the commitments mentioned in paragraph 1 above in such a way as **to minimize adverse social, environmental and economic impacts on developing country Parties, particularly those identified in Article 4, paragraphs 8 and 9, of the Convention.** In line with relevant decisions of the Conference of the Parties on the implementation of those paragraphs, the Conference of the Parties serving as the meeting of the Parties to this Protocol shall, at its first session, **consider what actions are necessary to minimize the adverse effects of climate change and/or the impacts of response measures on***

Parties referred to in those paragraphs. Among the issues to be considered shall be the establishment of funding, insurance and transfer of technology.

These provisions on impacts of response measures are also relevant for the current Post-Kyoto negotiations and should guide mitigation policies and measures under any climate change deal including the one reached in Paris 2015 and beyond.

5.2.5 Later Developments Related to the Issue of Response Measures Include:

COP 13: In December 2007, COP 13 and CMP 3 in Bali, Indonesia, resulted in agreement on the Bali Roadmap on long-term issues. Parties adopted the Bali Action Plan (BAP) 1/CP.13 and established the *Ad Hoc* Working Group on Long-term Cooperative Action under the Convention. Under the BAP, Parties agreed on enhanced national and international action on mitigation, including consideration of economic and social consequences of response measures.

COP 16*:* In December 2010 in Cancún, Mexico, Parties agreed to convene a ***forum on the impact of the implementation of response measures*** in June and December 2011 during SB 34 and 35. The objective of the forum was to develop a work program under the subsidiary bodies (SBs) to address impacts, with a view to adopting at COP17 modalities for operationalizing a work program and a possible forum on response measures.

COP 17: In December 2011, in Durban, South Africa, the COP decided to establish the *response measures forum* and mandated it to meet twice a year under a joint agenda item of the SBs. Parties adopted a work program on response measures aimed at improving understanding of the impact of response measures in eight distinct areas.

Parties have not been able to make much progress on response measures since Durban. It becomes increasingly obvious that there is the need for a mechanism under the COP to advance the issue of the impacts of response measures. Towards that objective and during the closing COP and CMP plenaries of COP 20 in Lima, 2014, Parties adopted a decision to forward a draft decision on the forum, contained in the annex for consideration by SB 42 in June 2015.

5.2.6 The Paris Agreement:

In December 2015 at **COP 21** in Paris, 195 countries adopted an international climate agreement labeled "**The Paris Agreement**". Paris Agreement is a hybrid approach to climate policy that includes: bottom-up elements in the form of "Intended Nationally Determined Contributions" (INDCs), which are national targets and actions that arise from national policies; and proposed top-down elements for transparency, oversight, guidance and coordination. The agreement and the INDCs apply to all countries based on their national circumstances and respective capabilities, hence dropping the "Annex I non-Annex I" common but differentiated responsibilities (CBDR) differentiation clause of the UNFCCC and Kyoto Protocol. The relevant decision of the agreement calls on parties to submit their intended nationally determined contributions (INDCs), aiming at achieving the objective of Article 2 of the agreement. Many countries, including KSA, submitted their INDCs before COP 21. The submitted Kingdom's INDCs outlined a set of bottom up actions based on adaptation with co-benefits that may lead to annual avoidance of GHG emissions of up 130 million tons of CO_2-equivalent.

The Paris Agreement includes two innovative features to ratchet NDCs to meet Article 2 objective overtime: “Stocktaking” which refers to a global assessment of adequacy of INDCs to meet the temperature goal and “Progression” which refers to improving countries submitted NDCs over time.

Article 4.15 on Response Measures and relevant decisions under the Paris Agreement
Article 4.15 is a continuation of addressing the issue of the impacts of Response Measures (RM) on developing countries with economies that are most affected by these measures under the new agreement. The greatest significance is the obligatory language to consider RM issues under the new agreement, yet it is unclear how the dilution between Annex I (AI) and Non Annex I (NAI) is going to affect the work on RM. The immediate task, however, is to operationalize this article in a manner that will allow Parties to continue examining RM issues beyond 2020. Furthermore, the current decision language ensures that RM will be dealt in institutional continuity under a permanent forum.

5.3 Socioeconomic Trends and Key Vulnerabilities

The Saudi Arabian economy is vulnerable to both the climate change impacts, being characterized by a harsh environment and the impacts of climate change response measures, being dependable on a single commodity (hydrocarbons). The implementation of greenhouse gas (GHG) emissions mitigation policies by Annex I countries will undoubtedly impact the economies of oil-exporting nations. The extent of impacts will depend on the degree of vulnerability of the given oil economy to negative oil demand and excessive price volatilities. The Saudi economy is particularly vulnerable to such volatilities because of high dependence on hydrocarbons, strong demographic pressures and limited scope for diversification outside the hydrocarbons sector:

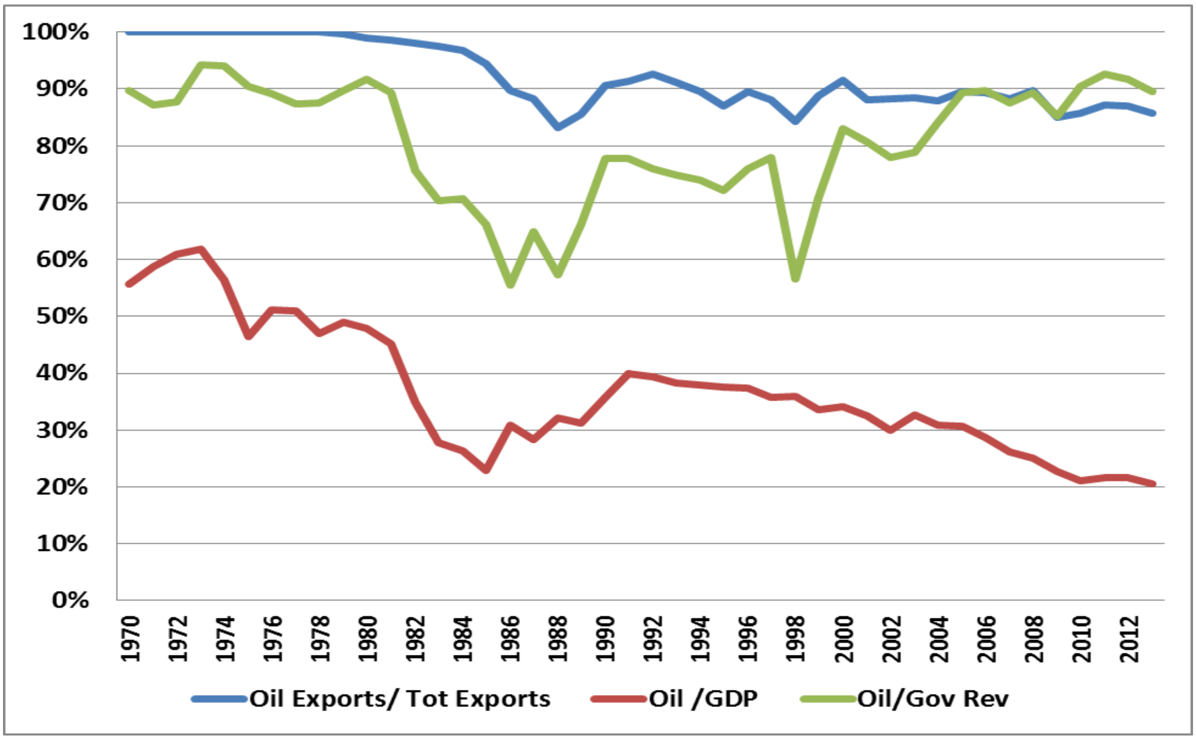
5.3.1 High Dependency on Hydrocarbons

The high dependency of the Kingdom’s economy on hydrocarbons is reflected by the contributions of the oil sector to GDP, exports and to government budget. These contributions are graphically shown in Figure 5.1 below for the period 1970-2013. The essential features summarized by the graph include:

- The dominance of the oil sector with average contributions of more than 30% to GDP, more than 70% to budget revenues and more than 90% to export proceeds.
- Sharp fluctuations implying lack of consistent trends towards diversification, or diversification efforts being interrupted by oil market conditions.
- Clear trend of transformation towards non- hydrocarbons economy with contribution of oil to GDP falling from above 60% in the 70s to around 20% in 2010s. In contrast, there is very limited or no diversification taking place with respect to budget revenues and exports, particularly after the mid 80s. This is an indication that diversification in GDP took place in sectors that have very little contribution to exports and budget revenues. These are mostly in the service sector and non-tradable or non-competitive manufacturing products.

Hence, despite apparent diversification in GDP composition, Saudi economy remains heavily dependent on the hydrocarbons sector for both budget revenues and export proceeds.

Figure 5.1: The Contributions of Oil to GDP, Exports and Government Revenues (1970-2013)

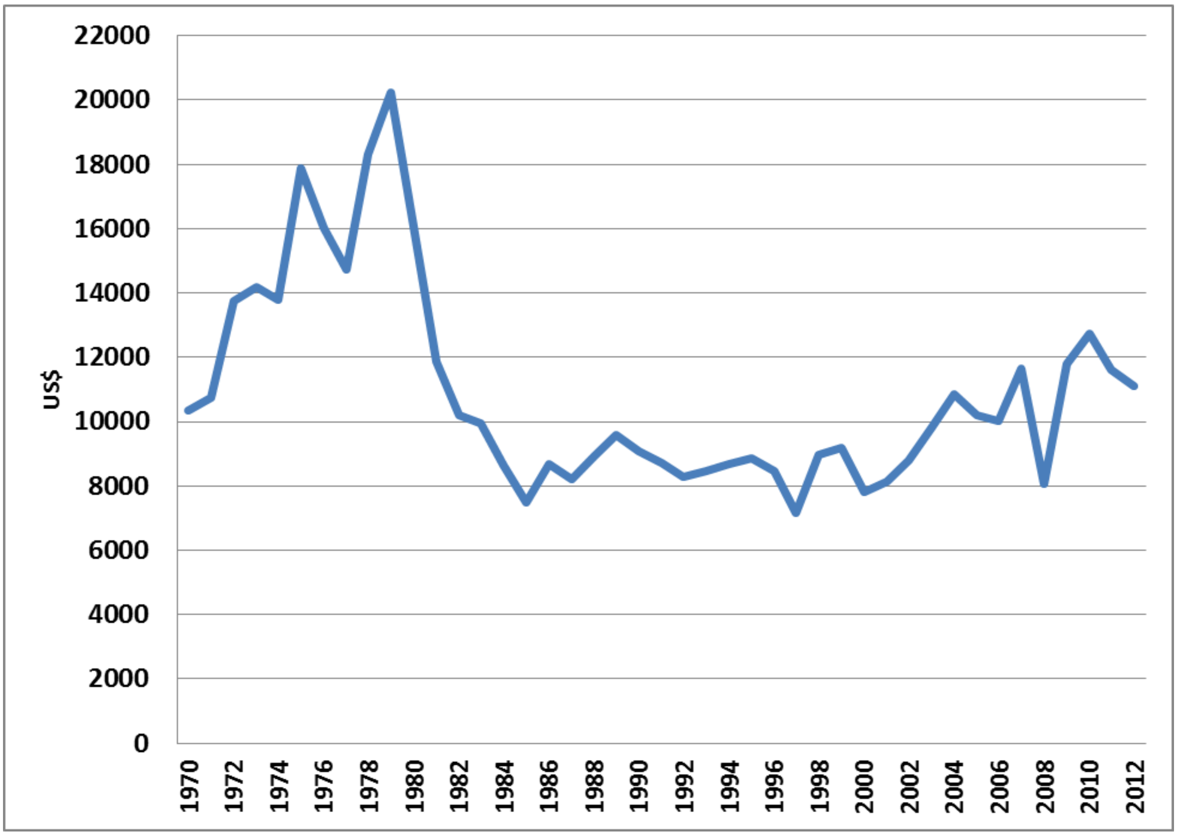


Source: Central Department of Statistics and Information (CDSI) & Saudi Arabia Monetary Authority (SAMA), various issues

5.3.2 Strong Demographic Pressures

Saudi Arabia has one of the highest rates of growth in population in the world. During the last four decades, the average annual population growth rate was 3.8%. Such population pressure has led to deterioration in real per capita incomes and living standards, even despite the recent upward trend in oil prices (see Figure 5.2). In addition, the figure also reflects the sharp fluctuations in GDP per-capita caused by the oil market ups and downs. In turn, this further amplifies Saudi Arabia vulnerability to oil demand and excessive price volatilities and hence to the implementation of climate change response measures and policies.

Figure 5.2: Per-Capita Real GDP (1970-2012)



Source: Central Department of Statistics and Information (CDSI) & Saudi Arabia Monetary Authority (SAMA), various issues

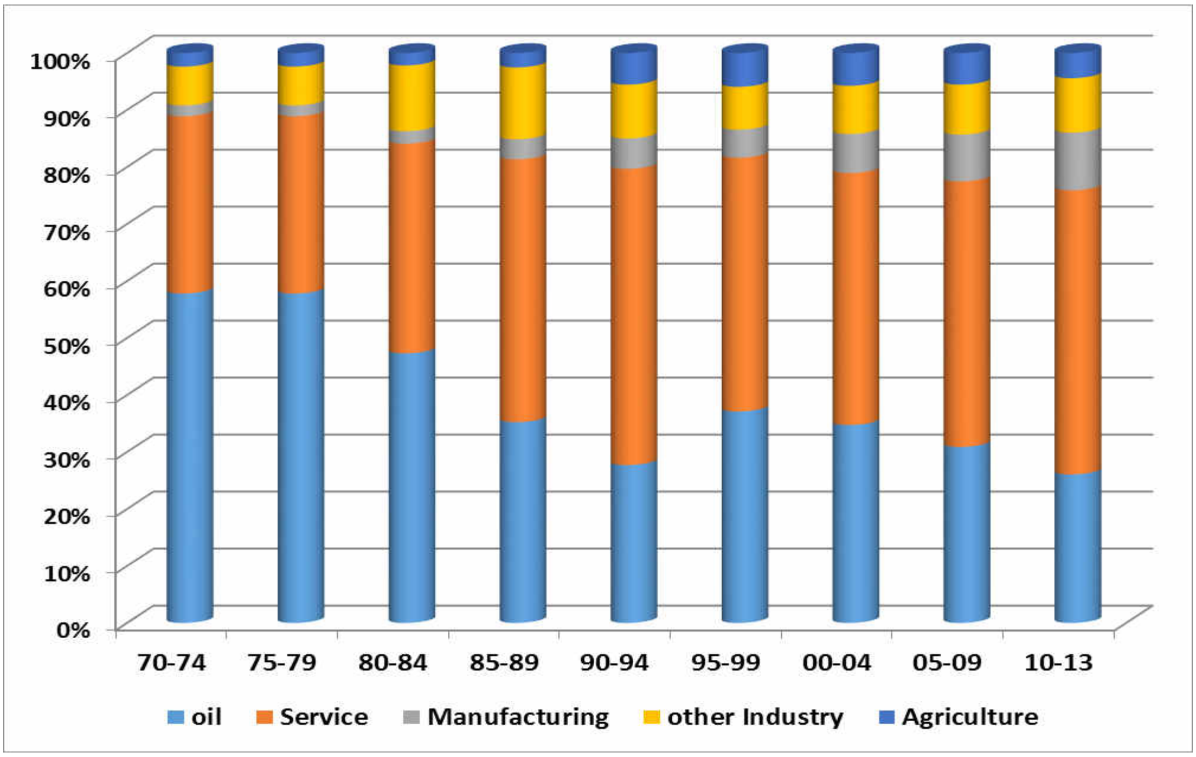
5.3.3 Limited Diversification Potentials

Efforts to diversify the Saudi economy away from oil have started very early and have resulted in a remarkable structural shift towards the services sector. Yet the potentials for structural transformation of the Saudi economy seemed to have been exhausted by mid 90s, after which the structure of the economy has remained stagnant except for a noticeable trend towards manufacturing (mostly petrochemicals). These trends and structural shifts are graphically depicted in Figure 5.3 for the period 1970-2013. Two observations need to be noted that:

- The potentials for further diversification of the Saudi economy are limited. In particular the easy options in the low value added services and manufacturing activities and those based on comparative advantages are mostly exploited.
- Despite the remarkable shift away from hydrocarbons, the Saudi economy remains heavily reliant on oil for export proceeds and budgetary revenues.

These two observations reveal the challenges facing diversification in the Saudi economy and further underscore its vulnerability. A successful and effective diversification has to generate substitutes for both government revenues and export proceeds. Such diversification must be towards dynamic, high-value added and competitive products and services, which would require enhanced knowhow and technology transfer and dissemination, in addition to market access. Some efforts and initiatives are currently underway including the establishment of economic cities and industrial zones, yet the challenges remain significant.

Figure 5.3: Structural Change and GDP composition (1970-2013)



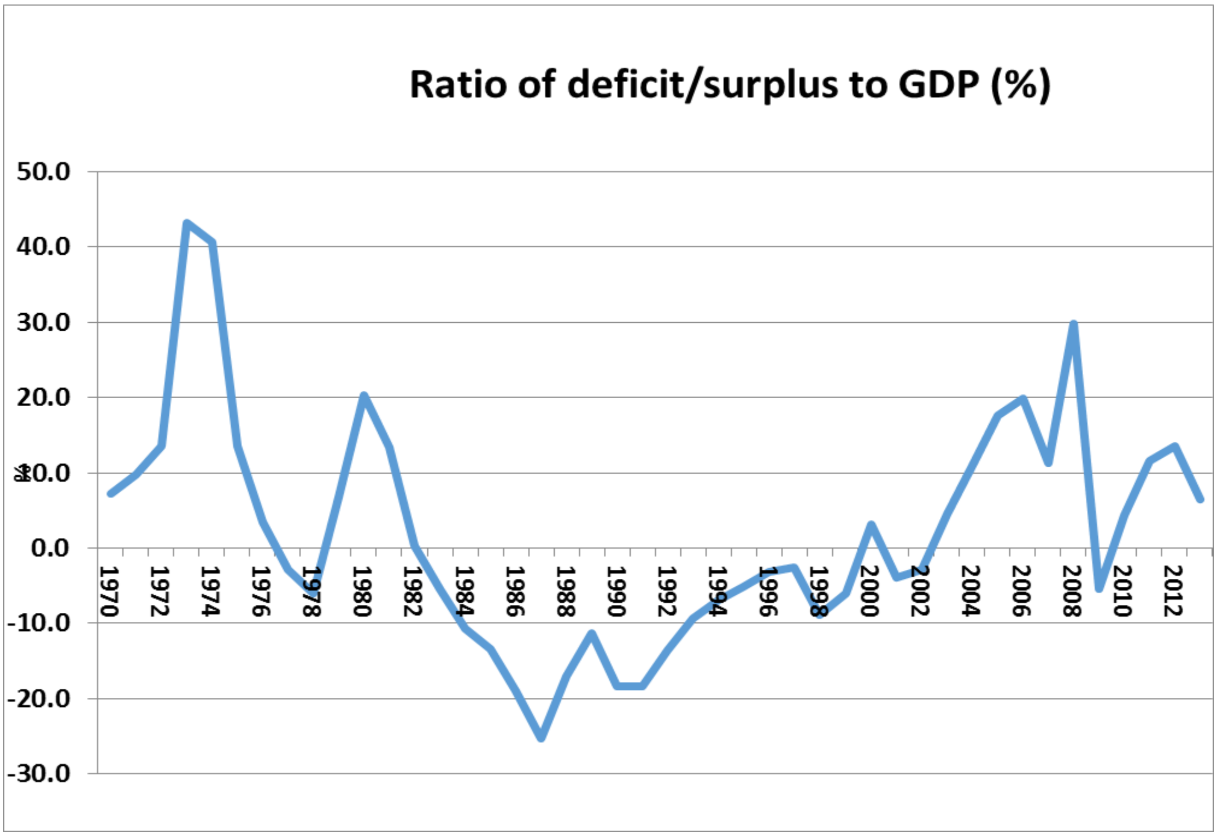
Source: Central Department of Statistics and Information (CDSI) & Saudi Arabia Monetary Authority (SAMA), various issues

5.4 The Budgetary Implications for Hydrocarbons based Economy

Oil revenues have historically had a direct impact on Saudi government spending and fiscal policy. The volatility of the world oil markets contributed to the continued unpredictability of the oil revenues and consequently the fiscal budget. While 1970's and early 1980's were the years of considerable budget surpluses from oil revenues, the national budget had been running in deficit for two consecutive decades (1983-2003) and only after the 2000s rally in oil prices does it show a surplus (Figure 5.4). The two decades, during which government expenditures have predominately outstripped government receipts, have resulted in the accumulation of a high domestic debt reaching as much as 100% of GDP in the late 1990s. It is then clear, in the absence of alternative fiscal means or non- hydrocarbons revenues, that such pattern of annual budgetary deficits will be unavoidable would the hydrocarbons sector be exposed to a significant downside risks such as the implementation of climate change mitigation policies.

The loss of oil revenues, due to climate change policies, will be much more difficult to replace for particular oil exporters like Saudi Arabia. This is due to the fact that the Kingdom's domestic industrial base for the production and export of non- hydrocarbons based goods and services is very limited. Without expanding and diversifying the domestic industrial base, the economy will continue to be vulnerable to exogenous world oil demand and excessive price volatilities such as those expected from the implementation of climate change response measures and policies.

Figure 5.4: Trend of Saudi Government Budgetary Balances (1971-2013)



Source: Central Department of Statistics and Information (CDSI) & Saudi Arabia Monetary Authority (SAMA), various issues.

Even though Saudi Arabia has established robust downstream hydrocarbons and petrochemical industries, the contribution of these industries to economic diversification remains far below the level needed to support the economy withstand shocks to the crude sector. This lack of economic cushion certainly places the Kingdom's economic development at risk, especially if industrialized countries are to implement policies that have negative impacts on the international demand for oil.

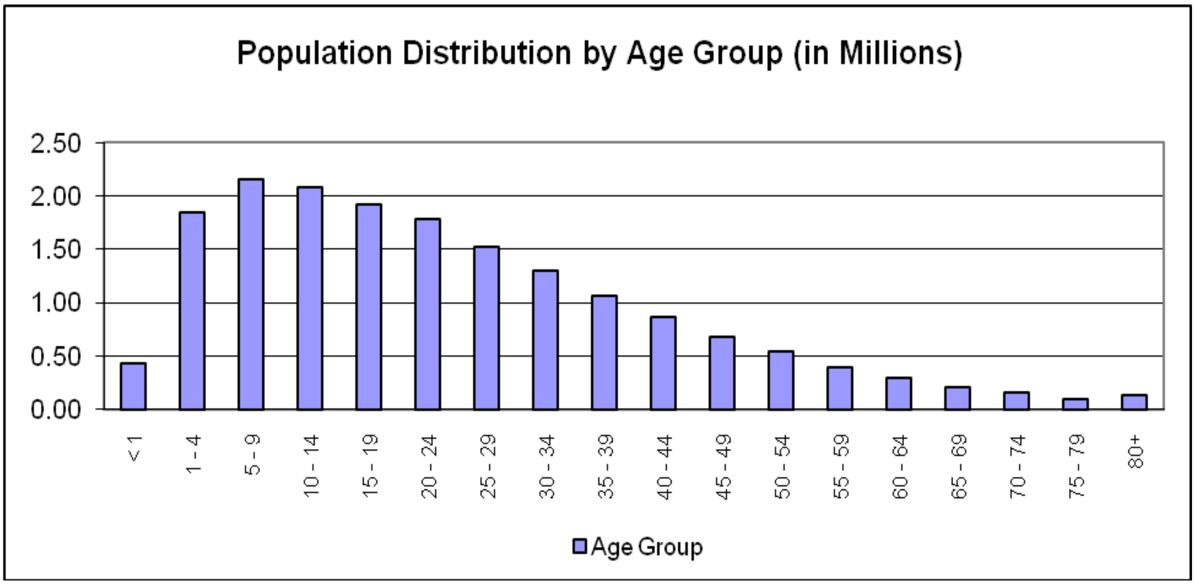
5.5 Population Dynamics

Past and current patterns of population growth put in front of Saudi planners significant future challenges and opportunities with respect to living standards and sustainable development. According to the 1992 census, the total population of Saudi Arabia was approximately 17 million. In 2007, Saudi Arabia's population exceeds 24 million of which Saudis make up 73% of the total. This was due to a major influx of expatriate workers and the high natural growth of the indigenous population. However, the projected population of Saudi Arabia by 2020 is estimated to reach 32 million, given an annual average growth rate estimate of 1.8%. Despite the expected declining trend in Saudi Arabia's population growth, it is still amongst the highest in the world even when compared to growth rates of 1.7% and 0.7%, respectively for developing and industrial country populations, during the 1990s.

High Saudi population growth rates can challenge the future economic development of Saudi Arabia and may have adverse implications on the government's ability to spend on physical and social infrastructure. Following the oil shocks of the 1970s, Saudi Arabia's economy expanded due to windfalls profits from surging oil prices resulting in the implementation of major domestic infrastructure projects. However, this situation continued to be vulnerable to changing conditions of the oil market. In addition, demographic pressures had become a major issue in the 1990s when population growth rates began to outstrip economic growth.

Concerns over the booming population and high Saudi unemployment in the 1990s have coincided with the slowdown of economic growth. This had become a serious concern for the government; namely, increasing financial burdens due to a growing population in the face of declining oil revenues. Employment of Saudi youth is currently a big challenge and the problem will further worsen if current collapse of oil prices continues and even worse if mitigation response measures were to be added. A major current concern is that 60% of the growing Saudi population is below the age of 25 (Figure 5.5), implying significant challenges ahead in terms of education and employment. Hence from an economic policy perspective, the challenge that the Saudi government currently is facing is whether the Saudi economy can generate sufficient employment opportunities within the next 10 years for this burgeoning labour force.

Figure 5.5: Saudi Demographic Youth Bulge



Source: Central Department of Statistics and Information (CDSI), Population Census 2007.

There is a need for enhancing the quality of this potential labour force through better training and through reforming the education system. Economic diversification will require accelerated capacity building in cognitive skills and computer literacy for the Saudi workforce. The quality of education at all levels must be enhanced so that the Saudis can meet the demands of the 21st century. Major efforts on streamlining the education system and the labour market are already under way. However, the successful implementation of a major realignment of the education system will require scientific laboratories and educational know-how, which means that additional resources need to be channeled to scientific institutions to accommodate the growing Saudi youth population.

5.6 Economic Impacts of Climate Change Response Measures and Policies

5.6.1 Transmission Mechanisms:

There are two channels through which climate change actions by Annex I countries adversely affect the economies of non-Annex I countries. These channels are demand for hydrocarbon (Direct) and terms of trade (Indirect). Mitigation of greenhouse emissions reduces demand for hydrocarbon and depresses their international prices, causing direct revenue losses for hydrocarbon exporters. Implementation of response measures and policies can also induce spillover effects through the international trade channel. Restrictions on the use of hydrocarbon energy in Annex I countries, whether through prices and taxes or through direct control, increase production costs and hence prices of exportable goods and services. Provided that the majority of developing countries imports are from Annex I markets, the mitigation action of Annex I will effectively translate into an adverse movement in terms of trade for developing countries. Being a major oil exporter and a highly open economy, Saudi Arabia will be significantly impacted through both channels.

More recently the understanding of the socioeconomic impacts of response measures has been further enhanced by viewing response measures within the sustainable development lenses. In spite of the fact that the current literature does not assess the impacts of response measures on sustainable development in a fully integrated fashion but rather in an end-of-the-pipe treatment fashion, several implications of response measures on developing countries ability to achieve sustainable development are identified including the negative impacts on agriculture exports, food security, tourism, energy access, employment and migration.

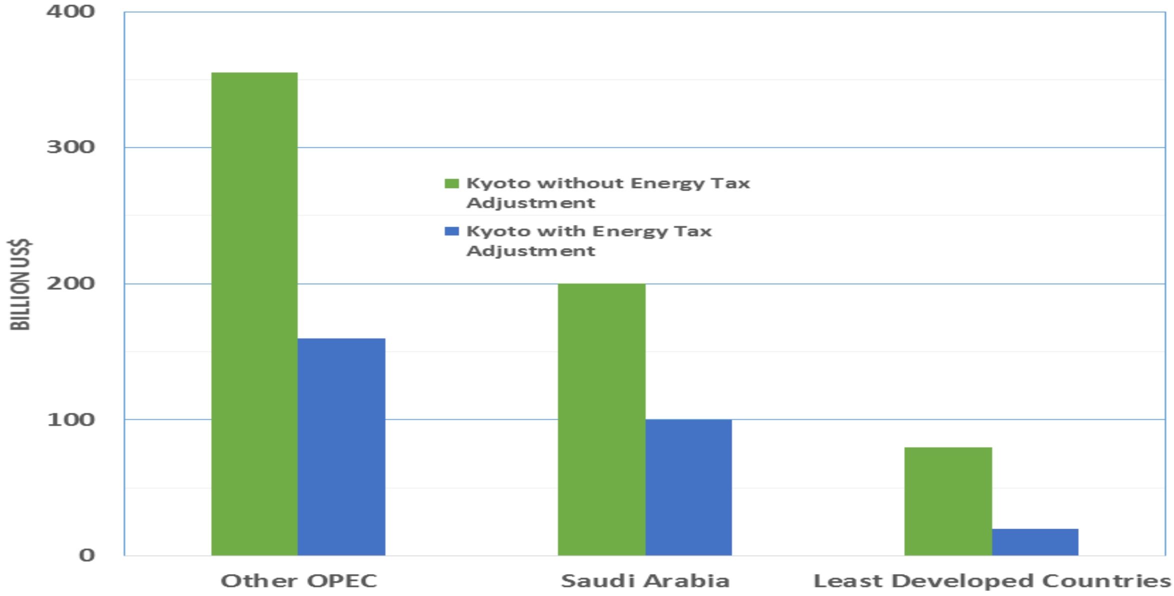
5.6.2 IPCC TAR & Earlier Assessments of Kyoto Impacts:

The IPCC Third Assessment Report (TAR) provided a detailed evaluation of the impacts of climate change response measures and policies on non-Annex I countries for the original version of Kyoto (including the US). The studies and model comparisons cited in the report, e.g. Weyant et. al. (1999), have indicated that oil exporting countries will be negatively impacted by Annex I mitigation action and that the extent of the impacts on these countries would be greater than those to be experienced by Annex I countries themselves.

Climate change response measures and policies will impact world oil demand by making hydrocarbon energy more expensive in Annex I countries, thus leading to a reduction in oil imports and a downward pressure on the international oil price. This will have negative economic impacts as well as adverse effects on Saudi Arabian welfare since lower incomes can lead to deteriorating socio-economic standards.

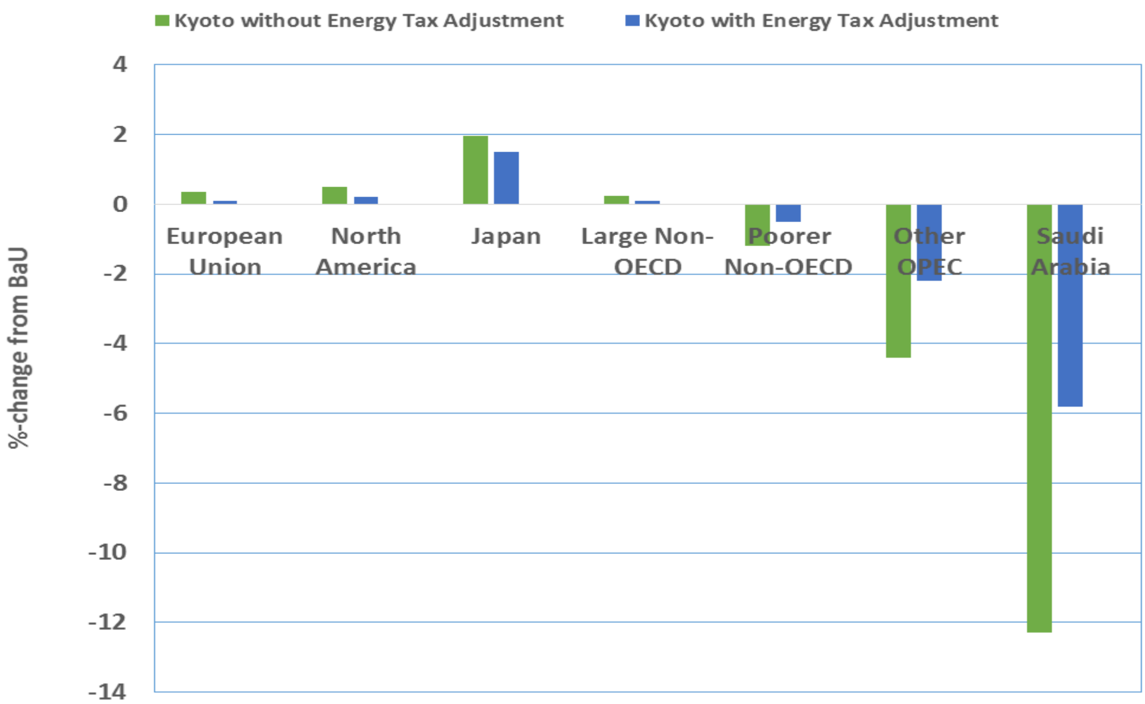
The Multi-Sector/Multi-Regional Trade (MS-MRT) model results indicate that it would require a present value lump-sum payment between $100-200 billion to offset the economic damage to Saudi Arabia during the period between 2000 and 2030 due to Annex I climate change response measures and policies (Figure 5.6). The Intergovernmental Panel on Climate Change (IPCC) has also projected declines in oil demand and revenues for developing countries that are highly dependent on the export of hydrocarbon such as Saudi Arabia. These economic losses will vary; however, Saudi Arabia, being the largest oil-exporting economy, will experience disproportionate losses to its economic welfare compared to other developing countries. In addition, Saudi Arabia will also face disproportionate losses compared to those Annex I countries who are obligated by the UNFCCC and the Kyoto Protocol to take the lead in reducing their greenhouse gas emissions. The high welfare losses for Saudi Arabia and other oil exporting countries are not only because of revenue losses but also due to spillover effects caused by the adverse movement in their terms of trade (Figure 5.7), particularly given their dependence on the import of consumer and capital goods from Annex I markets.

Figure 5.6: Net Present Value of Cash Compensation



Source: Charles River Associates (2000)

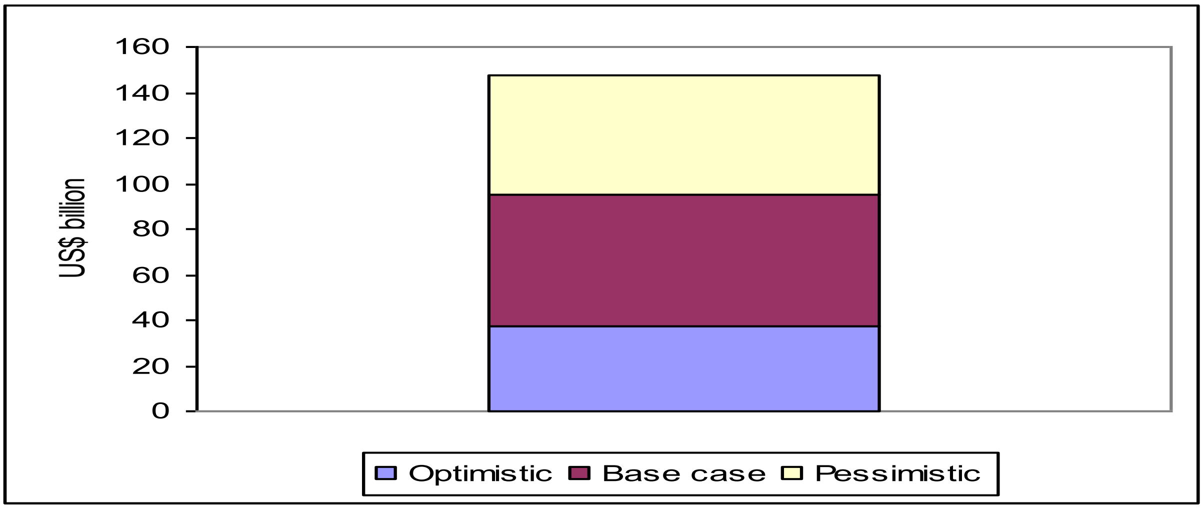
Figure 5.7: Percentage Changes in Terms of Trade



Source: Charles River Associates, 2000

The Mackay Study (2006) assesses the impacts of Kyoto type policies on petroleum consumption and incomes of the National Oil Companies (NOC) along three scenarios: a base case, a pessimistic scenario and an optimistic scenario. The results on lost oil consumption caused by Annex I climate change response measures and policies under these scenarios based on 60 US$ per barrel are shown in Figure 5.8.

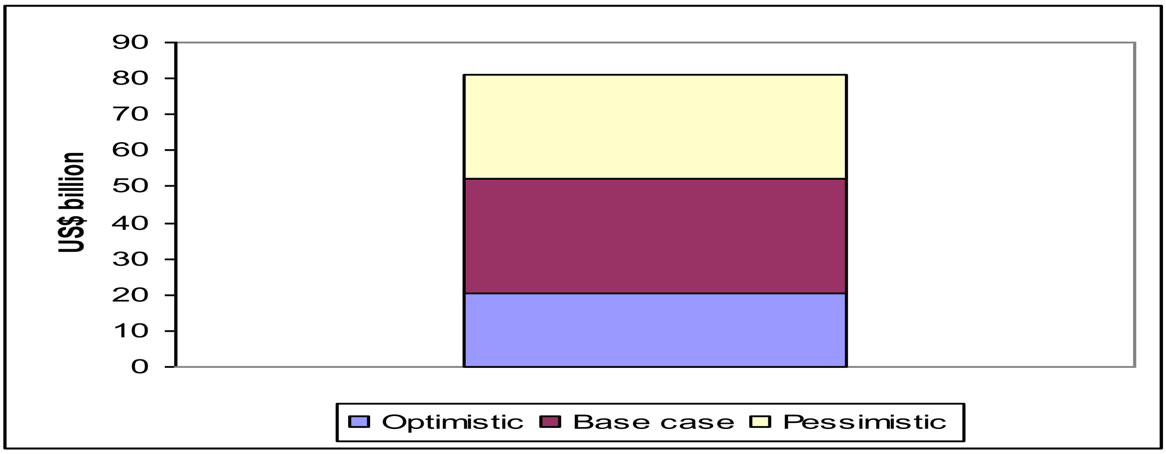
Figure 5.8: Value of "Lost" Petroleum Consumption in 2015



Source: Mackay NOC Study (2006)

These oil demand losses are expected to translate into significant revenue losses for the National Oil Companies and consequently Government revenues, estimates of which are shown in Figure 5.9 under the three scenarios.

Figure 5.9: Value of "Lost" NOC's Revenues in 2015



Source: Mackay NOC Study (2006)

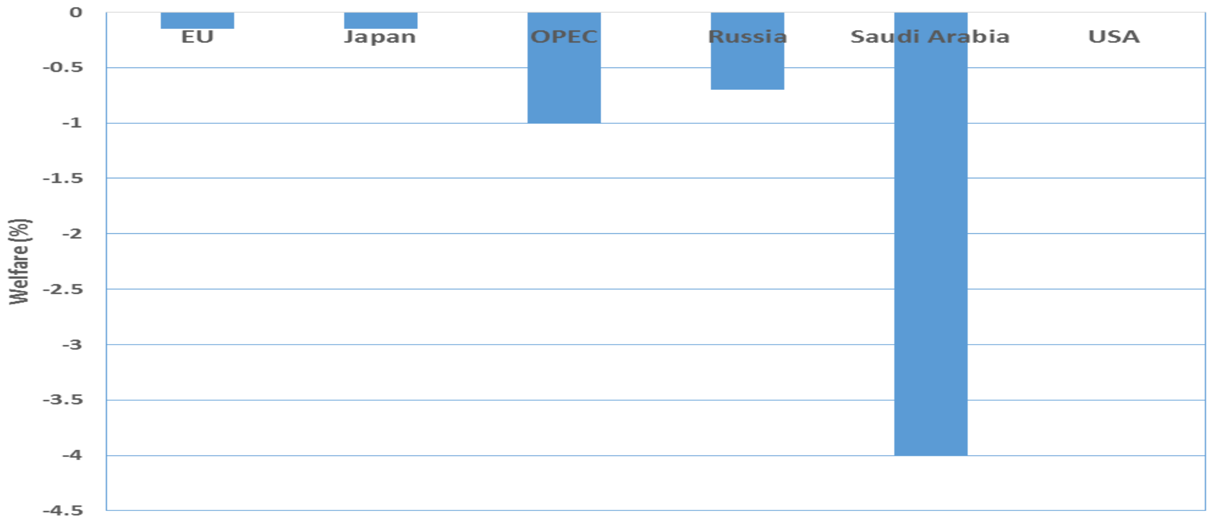
5.6.3 AR4 & Later Assessments of Kyoto Impacts:

In its Fourth Assessment Report (AR4), the IPCC concluded that the literature since the publication of its Third Assessment Report confirms the earlier findings with respect to the impacts of Annex I response measures and policies on non-Annex I. In particular, the report confirmed that hydrocarbon exporters would expect lower demand and prices and lower GDP growth due to Annex I mitigation policies.

It is understandable that, Entering force without the US, the Kyoto Protocol will yield both lower costs and lower climatic impacts than the original Kyoto setup. Nonetheless, the scope of spillover effects, the distributional impacts and the direction of the adverse effects of Annex I mitigation actions on developing countries and oil exporters would be the same.

The Multi-Sector/Multi-Regional Trade (MS-MRT) model was again used to assess the impacts within the new Kyoto setting (i.e. without US). The model was updated to the most recent available data and used to simulate a policy scenario in which US implements a regulatory regime following the Bingaman Bill and the rest of Annex I countries follow Kyoto. The welfare impacts of the policy package are shown graphically in Figure 5.10. These results support the AR4 conclusions and the earlier TAR results that the Annex I mitigation action will have negative impacts on hydrocarbon exporters, particularly on Saudi Arabia and as well confirm the finding in the literature that oil exporters would shoulder greater burden than Annex I countries themselves. Given its heavy dependence on oil, Saudi Arabia is seen to face even higher economic and welfare costs than the other oil exporters.

Figure 5.10: Welfare Costs of Kyoto (with Bingaman Bill for US)



Source: Charles River Associates (2006).

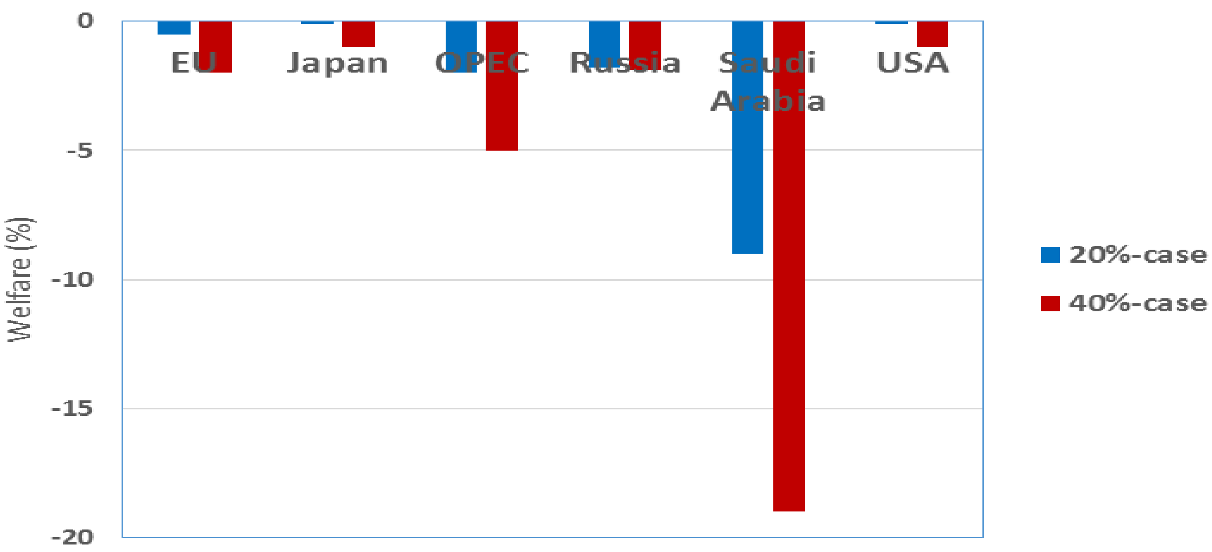
In 2007, the Bali Action Plan set forth the negotiation stage for a post-Kyoto regime by laying out the essential concerns and aspects regarding mitigation, adaptation, technology transfer and financing and by calling for a shared global vision. Following Bali, COP15 (Copenhagen, 2009) and COP16 (Cancun, 2010) were attempts to articulate Bali vision leading to Durban Enhanced Action Platform agreed to by COP17 (Durban, 2011). The Durban Enhanced Action Platform has provided the initial building blocks for the negotiations started in COPs 18 (Doha, 2012), 19 (Poznan, 2013) and that are expected to lead to a climate deal in COP 21 in Paris to be held in December 2015.

Different initiatives and proposals for post-Kyoto were put on the table in 2008-2010. The G8 countries had declared a goal of a 50% reduction in global emissions by 2050. The EU had a target of 20% reduction below 1990 by 2020 if no global agreement and 30% if there is a global agreement and a global target of 50% below 1990 by 2050. Australia had declared a target of 5% below 1990 by 2020 if no global agreement and up to 15% if there is a global agreement. The US had a target of reducing emissions to their 1990 level by 2020 and by 80% by 2050. Given the stringency of such global mitigation targets, their implications for the impacts of response measures and policies on developing countries in general and oil exporters in particular would be critical.

Based on the G8 reduction goal, an MIT study (Jacoby et. al., 2008) simulates a scenario in which global greenhouse gas emissions are reduced gradually by 10% in 2015 to 50% in 2050 from their 2000 levels. The study has considered various allocation and burden sharing schemes, including the participation of developing countries and the impacts of response measures and policies. The study concluded that the 50% global target is unachievable without the participation of developing countries and that, unless appropriately compensated, the bulk of the mitigation costs will fall on developing countries if they participate in the mitigation regime. Among developing counties, the oil exporters will be the most burdened with welfare costs for the Middle East ranging between 18% in 2020 and 51% in 2050 for the case of no compensations and between 5% in 2020 and 9% in 2050 when compensated for mitigation costs only (i.e., no compensation for the impacts of response measures and policies). In contrast, the welfare cost in the latter case for US ranges between 1% and 7%, for Japan between 0.6% and 4% and for EU between 2% in 2020 and 8.5% in 2050, confirming the higher burden on oil exporters and the legitimacy of the call for consideration of the impacts of response measures and policies.

To inform on cost implications of more stringent post-Kyoto mitigation regimes, the Multi-Sector/Multi-Regional Trade (MS-MRT) model was used to simulate cases with 20% and 40% reduction in Annex I emissions from their 1990 levels starting 2015. Consistent with the above results, the model reported life time welfare losses for Saudi Arabia of 9% and 19% for the 20% and 40% cases, respectively (Figure 5.11). Further, the results also confirm the difference in order of magnitudes of the impacts on oil exporters compared to those on Annex I and therefore the more urgent the need to take measures to minimize the impacts of Annex I response measures and policies.

Figure 5.11: Welfare Costs of Post-Kyoto Regime



Source: Charles River Associates (2006).

A further dimension of impacts on oil producers not reflected in the cost of policy uncertainty on future investment decisions with respect to new developments and capacity expansions, which will negatively impact supply-demand balance and energy security.

5.6.4 The AR5 Assessment and the Implications on Sustainable Development

The literature on the implication of mitigation measures since AR4 confirms the pre-AR4 findings of negative impacts on energy exporting countries through energy demand and terms of trade channels. Recent studies exemplifying this literature are Leimbach et al. (2009) using REMIND-R model, Jacoby et al. (2010) using EPPA model and Massetti and Tavoni (2011) using the WITCH model. Though these studies were conducted independently to simulate the G8 target of reducing global GHG emissions by 50% from their 2005 level by 2050, they have arrived at very similar results regarding the impacts of such mitigation measure on energy exporting countries. Leimbach et al study showed that oil price falls by 70% by 2100 from BAU and that region Middle East and North Africa (MEA) bears the highest costs regardless of the design of policy regime, with average loss of 10% in present value consumption from BAU compared to a world average cost of 1.5% loss. Jacoby et al study showed an undiscounted welfare loss of 50% in 2050 compared to BAU for region MEA and estimated the need for total transfers of about 3 trillion US$ in 2050 out of which 750 billion US$ to MEA to completely compensate for the needed mitigation and its negative impacts in developing countries. Massetti and Tavoni study showed the impacts of the proposed mitigation effort to include a carbon price rising to $750 in 2050, a fall in oil demand by about 80% in 2050 from BAU and a fall in oil price by 70% from BAU by 2050. In addition the study confirms significant negative impacts for energy exporting countries particularly MEA and former soviet region, with discounted costs as percentage of discounted GDP during 2005-2050 reaching 11% for MEA compared to a world average of 1.5%.

On the broad sustainable development implications of response measures for developing countries, the literature on the trade and socioeconomic related spillover impacts of climate change mitigation has grown considerably over the last decade. The main negative impacts highlighted in the recent literature include competitiveness and industry relocation effects (Aldy and Pizer, 2009 and 2011), adverse terms of trade and exchange rate movements (Luken et al., 2011), trade protectionism and burden shifting (Bohringer et al., 2012), induced factor mobility and unemployment and induced international transport related impacts on energy intensive, food and tourism sectors, particularly for developing countries (Nurse 2009; ICTSD, 2010; Pentelow and Scott 2011).

The range and strength of these adverse effects and risks depend on the type of policy intervention and the stringency of the mitigation effort. Aldy and Pizer (2011) reports for the US that a $15 per ton CO_2 price will cause competitiveness effects on the order of 1.0 to 1.3 percent reductions in production among the most energy-intensive manufacturing industries. Bohringer et al. (2012) indicates that the main effect of border carbon adjustment to correct for such competitive effects is to shift the economic burden of emissions mitigation to the non-abating countries through international prices and in turn leads to a rise in protectionism and retaliatory trade measures. Luken et al. (2011) shows through decomposition that more than 20% of GDP losses for the fossil energy exporters under the various mitigation scenarios is due to the trade channel.

Similar impacts were also reported for developing countries tourism and international transport industry. Pentelow and Scott study showed a reduction of tourist arrivals in the Caribbean countries by 24% in 2020 for a scenario characterized by a $200 per ton levy on international aviation. The International Centre for Trade and Sustainable Development (ICTSD) 2010 study on the trade implications of regulating emissions from international transport reports that a levy of US$ 15-30 per ton of CO_2 on international maritime causes GDP losses in the range 0.08-0.15 percent for developing countries compared to 0.02-0.04 percent for developed countries. These impacts are particularly pronounced in the case of Least Developed Countries (LDC) and Small Islands Developing states (SIDs), for which the ICTSD study reports for the various mitigation scenarios estimates of GDP losses in the range 0.2-1.8 percent due to reduction of maritime trade between these countries and EU.

Other sustainable development implications of mitigation measures that the recent literature reported include good security and rural-urban migration. The food-mitigation tradeoffs literature (e.g., Reilly et al., 2012) tends to suggest negative impacts for poor developing countries because of the high share of their incomes spent on food. The literature on societal risks along transformation pathways (e.g., Liang and Wei, 2012) showed mitigation might increase rural-urban gap and deteriorate the living standards of large sections of the population in developing countries exacerbating over time.

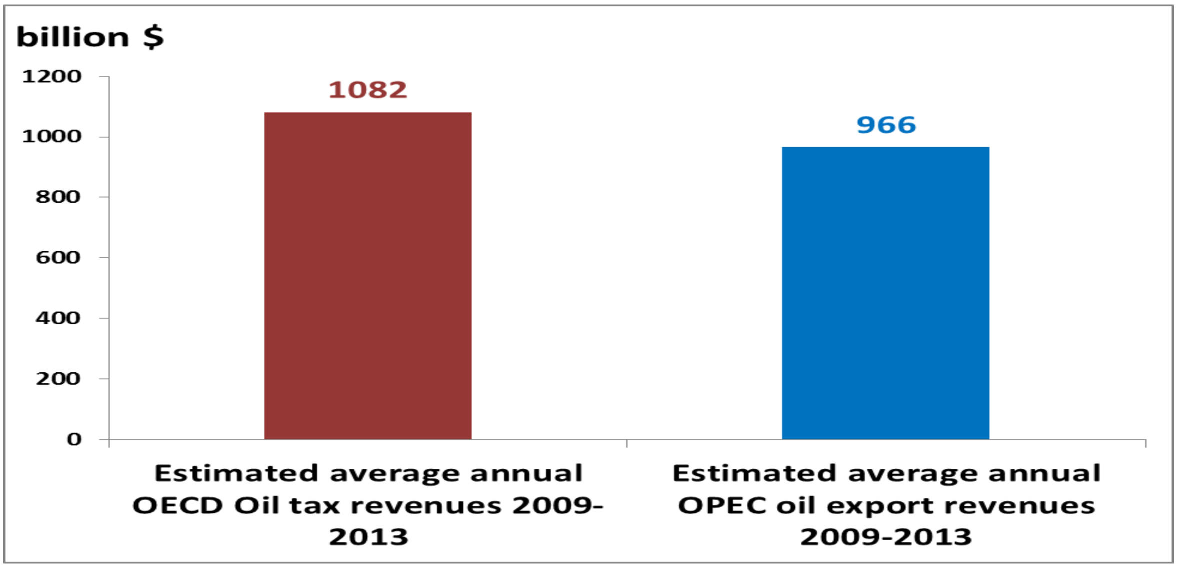
5.7 Implications of the Choice of Response Measures and Policies

5.7.1 General Perspective

Under the UNFCCC as well as Kyoto, Annex I countries have an obligation to minimize the impacts of their response measures and policies on developing countries. The first step towards meeting that obligation would be to select policy measures with that objective in mind. In contrast to this, there is a profound concern among oil exporting countries that Annex I countries may strategically use their climate change policies to target the hydrocarbons sector. Historically, developed countries have shown a trend of formulating policies and regulations that tend to target oil unfairly for environmental and energy security considerations. For example, the subsidization of coal and nuclear energy production as well as the relatively high and discriminate taxation on petroleum products (see Figure 5.12) are both environmentally unfriendly and have adverse impacts on economic growth of oil exporting countries like Saudi Arabia. The continuation of such policies certainly contradicts the aim of assisting economic development and world sustainable growth and contravenes the requirements of Articles 4.8 and 4.10 of the Convention.

Reforming the existing fuel taxation system in OECD to be more geared towards curbing greenhouse emissions will be a necessary step. The use of carbon taxation based on carbon content as well as the removal of environmentally unfriendly production subsidies (predominantly for coal and nuclear power) in developed countries will result in reduced economic burden on all countries, in particular oil exporting countries like Saudi Arabia. This can also yield global economic and environmental benefits.

Figure 5.12: Oil Taxation in OECD - Who gets what from a liter of oil in OECD



Source OPEC Website (http://www.opec.org/opec_web/en/data_graphs/)

5.7.2 Climate Change Policy Architecture

A good architecture should adequately accommodate the distribution, efficiency and technology aspects of the policy design. On distribution and equity, mitigation policy and measures should aim at balancing costs vs. benefits, burden across sectors and regions, treatment of all emission sources and the treatment of the impacts on developing countries. On the efficiency front, policies and measures should employ instruments and implementation mechanisms that encourage emissions reduction from the least cost sources. On the technology front, good climate policy architecture should aim at availing a level-playing field for all types of innovation and should encourage the development of technologies with large abatement potentials, such as Carbon Capture and Utilization and Storage (CCUS) technologies.

Provided these characteristics, climate change policies and measures that would likely have the least costs on oil-exporting developing countries, such as Saudi Arabia, would be:

- Broad and comprehensive rather than sector-specific measures and policies.
- Use carbon-based rather than fuel-based policy instruments.
- Based on climate change concerns rather than inspired by energy security or energy independence objectives.
- Encourage maximum flexibilities across time, sources and location, including utilization of potentials from land use change, sinks and non-CO_2 greenhouse gases such as Methane and the broad use of Kyoto-type flexibility mechanisms (Trading, JI and CDM) and new mechanisms and or initiatives.
- Take into account the full environmental impacts of the response measures and policies, including their impacts on sustainable development.

- Facilitate trade of technology components (goods and service) and disseminate technology use without resorting to measures of protectionism that will result in disguised trade measures.

5.7.3 Policy Choice Makes a Difference

Sector-specific policies in general and those targeting the oil or transport sectors in particular are damaging to oil-exporting countries and world economy. Taxonomy of some of the most damaging response measures and policies for the oil exporting countries are:

- Fiscal policies involving direct or indirect taxes on petroleum and/or petroleum products. These measures are directly affecting the oil consumption and consequently global demand for oil, leading to lower export quantities from Saudi Arabia combined with lower prices. A simulation-run of MS-MRT with a border adjustment tax on carbon content of imports in the EU of US$ 25.00 per ton of carbon produced an 8% fall in the oil price and 15% loss of export revenues for Saudi Arabia.
- Fiscal policies involving subsidies to alternative fuels. Increasing subsidies by developed countries on low-carbon energy sources such as nuclear and hydro will negatively impact oil demand and oil exports.
- Mandatory fuel switching or fuel mixing in the transport sector has major effect on the economics of the transport sector that is reflected in less oil based fuel being consumed in this sector. Though such policies may have little impacts in the short run, their impacts on the environment and the world food supplies in the long run will be devastating.
- Unilateral measures applied by certain countries and/or groups of countries, such as policies initiated by the European Union or some of its members, specifically targeting petroleum imports has a low effect on emission reduction but has a very high effect on the incomes of the countries exporting the particular petroleum products.

5.8 Saudi Arabia's Adaptation Efforts and Requirements to Cope with Climate Change Response Measures and Policies

Climate change mitigation actions will have adverse effects on Saudi government revenues and thus impede the government's ability to provide for the needs of its citizens. Therefore, minimizing the impact of climate change policies on developing countries that are heavily reliant on oil exports was recognized from the inception (1992) of the Climate Change Convention. Since these response measures and policies will impact these economies, it is imperative that developed countries meet their obligations of providing assistance to these countries to help them adapt to the negative impacts of these measures and policies. These requirements are stipulated in decision 5 CP.7 entitled "Implementation of Article 4, paragraph 8 and 9 of the convention" which specifically addressed the needs of developing countries to adapt to climate change as a result of the implementation of response measures and policies from Annex I countries.

5.8.1 Integrating Response to Climate Change Within Sustainable Development

Addressing climate response measures requires the establishment of a new paradigm to enhance the understanding of the impacts of these measures and to ensure the proper treatment of their implications such that the development of some countries does not undermine the development of others. Many observers agree that sustainable development with its overarching principles provides the right framework and paradigm for the study of climate change and its response policies. The contemporary literature discussed in the previous sections reveals that climate mitigation response measures have complex implications when seen through the sustainable development lenses including negative impacts on agriculture, food security, international transport, tourism, energy intensive products, living standards, migration, societal wellbeing and poverty. There are important synergies and trade-offs between mitigation response measures and sustainable development that need to be considered. Developing countries may have good understanding of the role of mitigation in climate change; however, they may not have the same level of understanding of the diverse economic, social and cultural impacts of mitigation response measures. The understanding of these later impacts can be seen as an integral part of any successful mitigation policy package to deal with climate change that has developing countries on board.

On the international front, many developing countries have particular vulnerabilities that make them susceptible to negative impacts of response measures such as reliance on a single sector or a single commodity; mitigation policies and measures need to be mindful of these vulnerabilities.

On the national front, national circumstances, national resources, strengthening resilience and adaptation to mitigation response measures are necessarily the guiding principles for the domestic climate change actions and contributions by developing countries. Measures to strengthen resilience and adaptation such as safety nets, building of institutions, poverty eradication and energy access should assume priority. It is paramount that developing countries contributions (INDCs) under the currently negotiated climate treaty should be viewed within this context.

5.8.2 Economic Diversification

Perspectives:

During the Doha COP (COP 18, 2012), the GCC states pledged the pursue of economic diversification as the framework for their national contributions to address the global climate change. Economic diversification is seen as the right vehicle to achieve sustainable development and enhance economic resilience to adapt to the negative impacts of response measures through reducing the reliance on production and export of crude oil. Contribution to GHG mitigation along the economic diversification path compared to BAU will be coming from energy efficiency, the use of improved technology and the efficient exploitation of national resources among other paths.

Saudi Arabia believes in economic diversification as the ultimate solution to sustainable development and the mitigation of the negative impacts of response measures; and as a member of the GCC is committed to the GCC economic diversification initiative. Historically, Saudi Arabia has made good efforts towards diversifying its economy as reflected in the noticeable structural shift in the GDP composition in Figure 5.3 away from oil and towards service and manufacturing sectors. Currently, Saudi Arabia is embarking on enormous efforts and large investments to foster economic diversification, including the establishment of economic cities, the investment in infrastructure, the development and use of gas and the modernization of the power sector.

Benefits to the global economy:

The diversification of the Saudi economy is not only in the best interest of Saudi Arabia, but may also be in the best interests of the global economy. If the Saudi economy continues to be dependent heavily on oil revenues and the concomitant increase in fiscal commitments due to its current population boom, then the only method the Kingdom has in its disposal to meet its domestic financial commitments is to increase its oil revenue through oil supply management. This will lead to higher global oil prices and may potentially have adverse effects on the global economy. In addition, lower national income per capita and an increase in the unemployment of a youthful Saudi population will reduce social standards which may increase the risk of future unpredictability. Thus, these conditions will not be desirable for the global economy since Saudi Arabia is considered the world's "central bank of oil". Therefore, there are potential risks that may be faced by all countries in the absence of future economic diversification of Saudi Arabia.

Why is a well-diversified Saudi economy in the best interest of Annex I countries? Saudi Arabian economic diversification may be in the best interests of all parties for the following security, economic and environmental considerations:

- A diversified economy tends to generate a healthy social society. Since 25% of the global oil reserves are in Saudi Arabia, stability in the region will have a global benefit it will help ensure global energy security.
- Diversification would help Saudi Arabia develop towards a post oil age over the next several decades and thus may lead to the reduction of greenhouse gas intensive nature of its economy.
- The marginal cost of greenhouse gas emissions abatement in Saudi Arabia is considerably low. Therefore, investment in modernization (creating a more energy efficient economy) will reduce overall environmental degradation.
- A diversified economy will lend itself to more global trade and thus a benefit to the global economy. Saudi Arabia exports oil while it imports manufactured goods, services and high tech equipment from certain Annex I countries. Since the hydrocarbons based economy may not be sustainable in the long-term due to climate change policies, this will reduce Saudi Arabia's ability to purchase goods and services from developed countries.

Setting the Domestic Stage for Economic Diversification:

An important criterion for a nation to undergo economic diversification is to undertake steps in liberalizing its economy. Saudi Arabia has taken these liberalization steps in the past several years in order to diversify its economy: These steps can be summarized as:

- Allowing for the first time foreign investors to participate in exploration and production of natural gas. This "gas initiative" has resulted in the restructuring of certain investment laws in the Kingdom.
- Privatization of certain industries, e.g. telecommunication.
- Accession to the World Trade Organization (2005).
- The signing of a number of bilateral Free Trade and Investment Promotion and avoidance of double taxation agreements (about 20 bilateral investment agreements).

- The recent opening the capital market (stock market) to foreign investors (June 2015).

The Foreign Investment Law provides investment incentives including:

- 100% ownership of companies and lands by foreign investors.
- No restrictions on capital transfer abroad.
- Foreign investors are no longer required to take local partners in many sectors.
- Taxes on companies at 20% of profits, separate rates apply to investments in hydrocarbons.
- Losses can be carried forward for an indefinite period.
- The right to benefit from local and foreign financing institutions.

The Economic Cities:

The Kingdom of Saudi Arabia has announced the launch of six economic cities. The objective of the economic cities is to grow the national economy and raise the standard of living for Saudis through:

- Enhancing the competitiveness of the Saudi economy
- Creating new jobs
- Improving Saudis' skill levels
- Developing the regions
- Diversifying the Economy

To ensure success, the economic cities will be developed according to six key design principles:

1. Each city will be developed around at least one globally competitive cluster or industry, which will serve as an anchor and a growth engine for the city, around which other business will locate.
2. The cities will utilize their greenfield opportunity to adopt state-of-the-art technology solutions to make them truly competitive.
3. Each city will be developed by the private sector and will therefore generate major private investment opportunities in infrastructure, real estate and industry.
4. By Identifying and attracting core investors, core jobs will be created which will then spur other supporting services jobs.
5. To achieve our high aspirations in terms of job creation and investment volume, the cities need to offer an attractive lifestyle to grow beyond a mere industrial free zone.
6. The cities will enjoy a business friendly regulatory environment which is competitive to other free zones globally.

King Abdullah Economic City in Rabigh

Location	: Built at a pristine location off the Red Sea north of Jeddah
Focus	: Port and logistics, light industry and services
Size	: 168 million square meters
Investment size	: US$27billion
Employment	: 1 million jobs

Prince Abdulaziz bin Musaid Economic City in Hail

Location	: on the cross roads of trade and transportation routes for the Middle East
Focus	: Logistics, agribusiness, minerals and construction material
Size	: 156 million square meters
Investment size	: US$8billion
Employment	: 55,000 new jobs

The Knowledge Economic City in Madinah

Location	: Near the Holy Mosque of the Prophet in Madinah
Focus	: Knowledge based industries with an Islamic focus and services including Biotechnology
Size	: 4.8 million square meters
Investment Size	: US$7billion
Employment	: 20,000 new jobs

Jazan Economic City

Location	: On the Red Sea in the South Western region of the Kingdom
Focus	: Energy and labour intensive industries
Size	: 100 million square meters
Investment Size	: US$27billion
Employment	: 500,000 new jobs

The other two remaining cities are the economic city of Tabuk in the north and the industrial developments in the eastern province including the Dammam and Dhahran techno parks and the energy intensive industry complex of Ras AlKhair.

As far partnerships with and technical assistance from developed countries in relation to climate change and response measures are concerned the main areas in which Saudi Arabia would require technology transfer and dissemination as well as more investments from the Annex I parties in order to advance its diversification efforts are the following: power generation, water resources, non energy use of hydrocarbon, research and development particularly of Carbon Capture Utilization and storage (CCUS) and most importantly education.

Power Generation

As the population of Saudi Arabia continues to grow, so does the demand for electricity. Annex I investments in this area would be of essence to provide power generation requirements through providing the best and more efficient ways to use Saudi Arabia's low cost energy resources for the purpose of producing electricity. Some of the areas that can be addressed are:

- Possessing one of the largest reserves of natural gas, tapping into this resource has the potential of producing less-greenhouse intensive power generation for Saudi citizens.
- Due to Saudi Arabia's low cost energy, technology transfer and dissemination into residual gasification through CDM projects can produce environmental friendly power.
- Technology transfer of renewable and nuclear energy production for power generation would reduce dependence on oil, particularly, Solar and Wind technologies and applications.
- Large scale application of solar generation for water desalination
- Co-generation technologies

Water Resources

Water is the most precious resource in the world. Due to its enormous population growth, Saudi Arabia's ground water supplies will not be enough to meet this growing demand. Therefore, Saudi Arabia has resorted to highly expensive desalinization technology to provide this critical resource. Annex I parties can assist Saudi Arabia through transferring technology and dissemination and allowing this capital intensive process to be more economical. For example, nano-fibers can be used to make this process considerably less expensive.

Desalinization of seawater is not the only means of securing future water resources for Saudi Arabia. Capacity building through integrated water management would be another method for meeting the growing needs of Saudi Arabia in this area. This can be accomplished mainly through water conservation and the reuse of wastewater streams.

A third area for technical assistance is development of salinity-tolerant crops and agriculture.

Non-Energy Use

Saudi Arabia is currently attempting to diversify its economy through the expansion of its domestic petrochemical industry. Saudi Arabia can offer Annex I countries economical feedstock to produce petrochemicals. However, Saudi Arabia will need assistance including the following areas:

- ***Finance***: The production of petrochemicals is a capital intensive industry; therefore, Saudi Arabia will require a considerable amount of foreign direct investment to expand this industry domestically.
- ***Technology Transfer and Dissemination***: Consumer markets are quite demanding when it comes to the performance of certain plastic products; therefore, Saudi Arabia will need the

latest in technological development in this field to produce modern products that are demanded by end users.

- ***Market Access***: Saudi Arabia needs support from Annex I countries to remove certain trade tariff and non-tariff barriers in order for its end products to reach the desired markets. This is very critical because diversifying the economy without diversifying exports will not reduce the country dependence on oil for budget revenues and foreign currency.

Research & Development and Technology

- *CCUS Technologies:*
  - Research, development, deployment, dissemination and scale up of technologies that can achieve significant reduction in CO_2 capture costs.
  - Gaining a better understanding of the science behind CO_2-EOR for future use in Saudi Arabia.
  - Develop appropriate actions for carbon storage in subsurface reservoirs, both aquifers and hydrocarbon traps.
  - Develop use of CO_2 as business opportunities.
  - Work towards proving the technology and its qualification as a CDM activity**.**
- *Green Oil technologies:*
  - Develop technological solutions that reduce CO_2 emissions from mobile sources.
  - Identify and develop industrial applications for emitted CO_2.
  - Strengthen efficiency in upstream and downstream activities.
  - Technological development of non-energy uses of hydrocarbon.

Education

Saudi Arabia has a very large youth population. This can be seen as a potential burden if the economy is not able to create sufficient employment opportunities. However, a large young population can have considerable long-term benefits if this workforce has the sufficient skills required by the labour market. The suitable education for this young population is the key factor in building the future wealth of this nation; namely, through skilled labour and a competitive work force. This is the most important future challenge that Saudi Arabia must face; namely, building the proper skills of its workforce in order to effectively diversify its economy. Annex I countries can assist Saudi Arabia through a transfer and dissemination of technical know-how. This would be beneficial to educate the young population in order for this nation to generate a more competitive workforce. This will allow the Kingdom to build a wealth of knowledge in the long term.

5.9 Improvement of Governance for Response Measures

Articles 4.8 and 4.9 of the UNFCCC and articles 2.3 and 3.14 of the Kyoto Protocol have provided the foundation for the basic obligations and commitments of developed countries in relation to the impacts of their climate change response measures and policies. A number of decisions followed to provide guidelines with respect to actions, implementation and reporting related to these commitments, e.g. paragraphs 3 and 8 of decision 9/CP.7, decision 5/CP.7, decision 1/CP.10 (The Buenos Aires Program of Work on Adaptation and Response Measures), decision 15/CMP.1 and paragraph 8 of decision 31/CMP.1. Unfortunately progress regarding compliance with these provisions and obligations remain to date unsatisfactory.

The following are some recommendations for improving compliance and for addressing the unfinished business with respect to the adverse impacts of response measures and policies:

- Undertake a comprehensive review of current actions, as a platform for the process of implementation referred to in paragraph 1 of decision 9/CP.7.
- Develop methodologies and specify criteria/indicators to evaluate and account for adequacy of compliance. The specific criteria/ indicators are needed to measure the impacts of the implemented/proposed response measures and policies, the impacts of the alternative measures and policies that might be implemented and to assess the adequacy and effectiveness of funding, insurance and technology transfer and dissemination arrangements to minimize these impacts.
- Standardize reporting requirements for Annex I on the impacts of policies and measures, creating a common template to be used as supplementary information submitted with national inventory reporting.
- Standardize reporting on support-type programs to reduce the impacts of response measures and policies, based on the six actions spelled out in paragraph 8 of decision 9/CP.7. This also should feature as part of national inventory reporting.
- Require that the GEF report annually to the COP on programs undertaken that comply with the commitments spelled out in paragraphs 22-29 of decision 5/CP.7.
- Create guidance for the facilitative branch as to the nature, timing and substance of its responsibility to assess compliance with the basic obligations on response measures and policies. This should be an annual assessment and should be based on the reporting described above, as well as on a special technical report by either the IPCC or an expert modeling group of various policies and measures and their relative impacts.
- Commit to a future review of actions to decide what further actions might be needed. This would be based on *inter alia*, a best effort to model the impacts of past response measures and policies.
- Create a special fund to support technology transfer, dissemination and economic diversification as methods for addressing the impacts of response measures.
- Create a mechanism under the COP to deal with the impacts of response measures and the outcomes from the forum on response measures.

5.10 The Kingdom’s INDCs

The Kingdom of Saudi Arabia submitted its Intended Nationally Determined Contributions (INDCs) to the United Nations Framework Convention on Climate Change (UNFCCC) Secretariat according to the decisions agreed to in COP19 and COP20. The KSA INDC is based on the operationalization of decision (24/CP.18) approved in Doha. The submitted Kingdom’s INDCs consists of projects and programs that are action-based rather than a result-based ones with expected emissions avoidance outcome of up to 130 MT of CO_2 eq. annually by 2030.

All submitted INDCs are based on bottom up approach that is nationally driven with no pressure from UN or any other party to the convention, hence the name intended nationally determined contribution. As a result, INDCs diver in methodologies, focus, coverage, format, etc. and references to UNFCCC articles that are of interest to a country. For KSA, the following provide key important elements:

1. The INDC of the Kingdom of Saudi Arabia is action based and designed so as to ensure full utilization of indigenous resources, namely oil, gas, minerals, sands and sun, as well as others such as tourism and services.
2. The actions and plans outlined in the submission seek to achieve mitigation co-benefits ambitions of up to 130 million tons of CO_2eq avoided by 2030 annually through contributions to economic diversification and adaptation. These ambitions are contingent on the Kingdom's economy continuing to grow with an increasingly diversified economy and on availability and accessibility of needed technologies. It is also premised on the fact that the economic and social consequences of international climate change policies and measures do not pose disproportionate or abnormal burden on the Kingdom's economy.
3. The Kingdom INDCs are viewed as ambitious compared to other developing countries. There is clarity in actions, have a clear follow up mechanism at the national level and included a quantitative Avoidance ambition.

5.11 Conclusion

The Saudi Arabian economy will undoubtedly be impacted by climate change response-measures and policies since these actions will be implemented as policy measures to reduce primarily CO_2 emissions. This will reduce oil demand and affect negatively global oil prices. The implication of this for Saudi Arabia would be a reduction in crude oil exports and a decline in its oil export revenues which comprise a large portion of its GDP. However, Saudi Arabia will be working hard to adapt these response measures and policies by diversifying its economy sufficiently away from crude oil exports.

Under the new structure of the global climate regime articulated in the Paris Agreement, the Kingdom will make sincere effort to meet it's submitted INDCs while pursuing economic diversification within the context of sustainable development and the exploitation of its indigenous resources.

Saudi Arabia will require technical cooperation and support from developed countries to diversify its economy in order to adapt to the impacts of potential climate change related policies. However, this will require a joint effort between developed countries and Saudi Arabia in order to implement solutions for Saudi economic diversification. This can be achieved by leveraging the Kingdom's potential assets (abundant and economic energy resources as well as a large youth population) and providing investments as well as implementing technological know-how of developed countries. Therefore, developed countries can realize benefits when supporting the Kingdom in diversifying its economy. Not only will the best interests of the Kingdom be served, but also the interest of the world reflected in energy reliability, viability, affordability, the global economy and the environment.

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SECTION – 6

Climate Change Scenarios

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6.1 Introduction:

The process of assessing the vulnerability of certain sectors to climate change requires the construction of projected visions of what the future climate would be. These visions, the future climate change scenarios, are to be compared then with a picture representing the present climate, the baseline climate scenario. The results of such comparison can be used as indicators for the future impacts that might be experienced by the considered sector and put the appropriate adaptation strategy of these impacts.

The effects of climate change in Saudi Arabia were studied using PRECIS, which adds high-resolution information to large-scale projections of a global climate model and generates more accurate climate scenarios for Saudi Arabia. In the Second National Communication Report (SNC), a PRECIS model was used to describe past (1960–1990) and future (2070–2100) climate scenarios on a global scale, including changes in wind speed, temperature, relative humidity and precipitation. In this report, a PRECIS model has also been used to project the same parameters, in addition to the mean sea level pressure from 2030 to 2080 in a regional scale setting.

The future climate change scenarios when compared with a picture representing the present climate (the baseline climate scenario) the results could be used as indicators for the future impacts that might be experienced by the considered sector and put the appropriate adaptation strategy for these impacts. This report covers two main aspects (**i**) Baseline climate change scenarios and (**ii**) Future climate change scenarios.

6.2 Baseline (Historical) Climate Change Scenarios:

Climatic parameters such as wind, temperature and precipitation over nine stations representing the various climatic regions of the Kingdom of Saudi Arabia namely Tabuk, Arar (Northern region), Riyadh, Qassim, (Central region), Dhahran, Qaisumah (Eastern region), Jeddah (Western region), Khamis Mushayt (mountainous region) and Sharourah (Southern region) as shown in Figure 6.1 were assessed for a period of 35 years starting from 1978 – 2013.

6.2.1 Recurrences and Trends of Extreme Events in the Baseline Scenarios

In order to explore the recurrences and trends of extreme events in the Kingdom of Saudi Arabia, data of extreme wind, temperature and precipitation was collected for the baseline period from 1978 – 2013 from the above mentioned stations

Figure 6.1: Location of the Selected Nine Meteorological Stations

These extreme events are discussed in details below.

Heat wave:

Heat wave is an extended period of hot weather, which may be accompanied by high humidity, relative to the expected conditions of the area at that time of the year. The World Meteorological Organization (WMO) defines Heat Wave as: "when the daily maximum temperature of more than five consecutive days exceeds the average maximum temperature by 5°C".

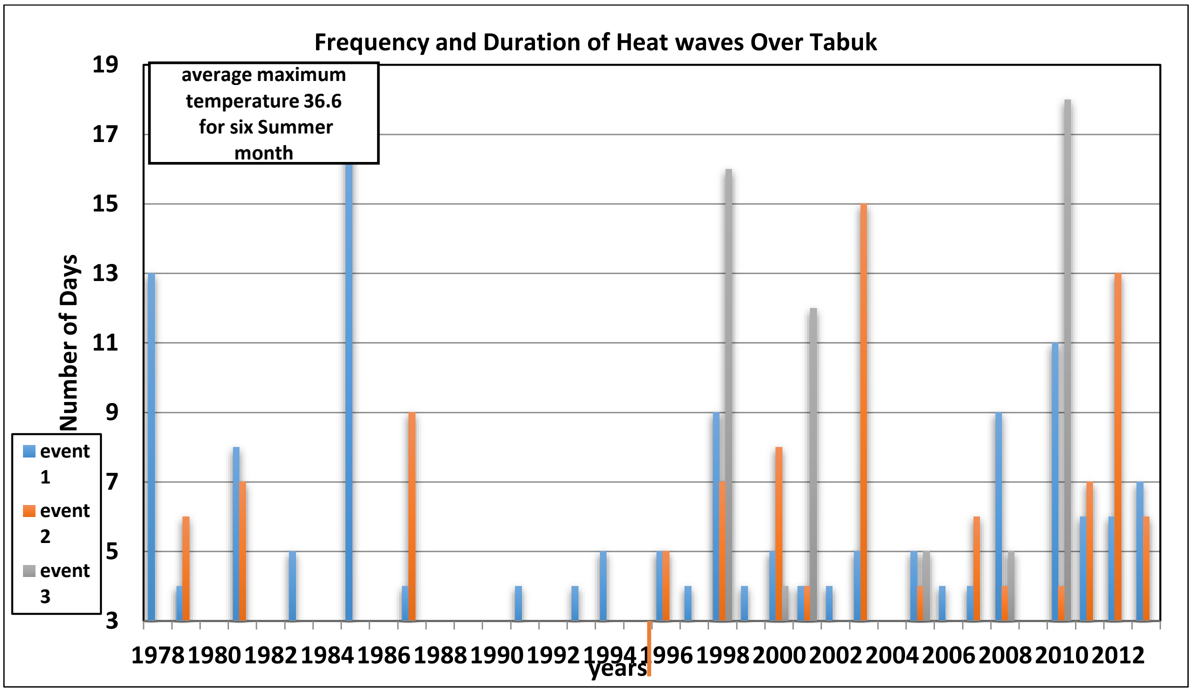
These events are common in the Middle East region during summer when a warm upper air ridge supports the low level extension of the south western Indian monsoon low pressure dominating this region as the air subsides adiabatically from these ridges. Upper air ridge systems are slow moving and can persist over an area for a prolonged period of time such as days or weeks.

Heat wave is considered here as an event when "T => 4°C above the six summer months average maximum temperature (over 1978-2013 period) lasting for at least 4 days". The six summer month reflect the domination period of the southwestern Indian monsoon over the Kingdom of Saudi Arabia region.

Heat waves recurrences and trends have been obtained for the above mentioned nine stations by considering the number of days with temperature higher than certain threshold value. Figure

6.2 show the frequency and duration of heat wave events over the baseline period 1978-2013 for Tabuk.

Figure 6.2: Example of Heat Wave Frequency and Duration in Tabuk



The trends of heat wave occurrence for the considered stations has been extracted by splitting the base line period into two equal sub-periods, 1978-1995 & 1996-2013 and compared the counted events in each. Table 6.1 shows the results with tremendous increase (positive trend) in events occurrence in the second sub-period in all stations.

Table 6.1: Summary of Heat Wave Recurrences and Trends

Station Name	6 Summer Months Mean Tmax	1978-1995	1996-2013
Riyadh	40.9	11	35
Jeddah	37.8	2	10
Dhahran	40.9	13	57
Qassim	40.5	2	62
Qaisumah	41.5	26	56
Tabuk	36.6	11	33
Arar	38.1	24	70
Khamis Mushayt	30.4	0	2
Sharourah	40.8	0[1]	13[2]

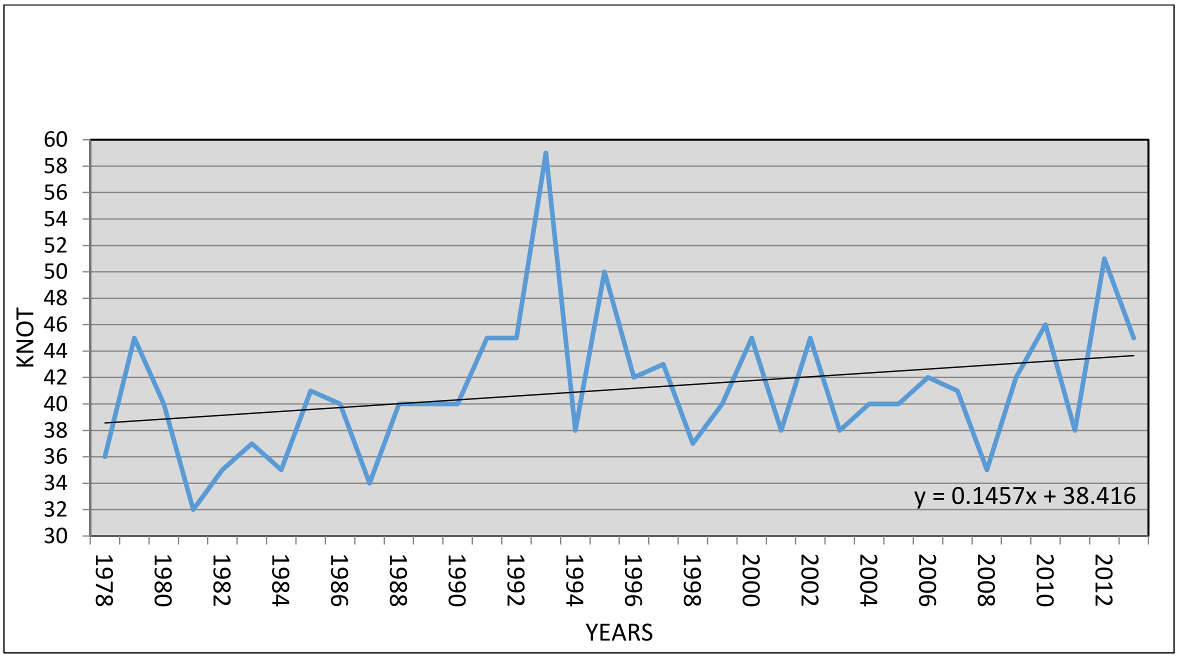
[1] Period 1985-1999 [2] Period 2000-2013

Extreme wind:

Extreme winds at the surface blow due to strong horizontal pressure gradient or due to strong downdraft from thunderstorm clouds. Extreme wind from thunderstorms is much more common than those related to pressure gradient in Saudi Arabia. Wind speeds can reach as high as 100 km/h with a damage path extending for tens of kilometers.

Trend of extreme wind at the selected nine stations have been extracted from plots of time series extending from 1978 to 2013. Figure 6.3 shows the extreme wind trend for Qassim.

Figure 6.3: Extreme Wind Trends for Qassim



Results for the selected nine stations are tabulated in Table 6.2.

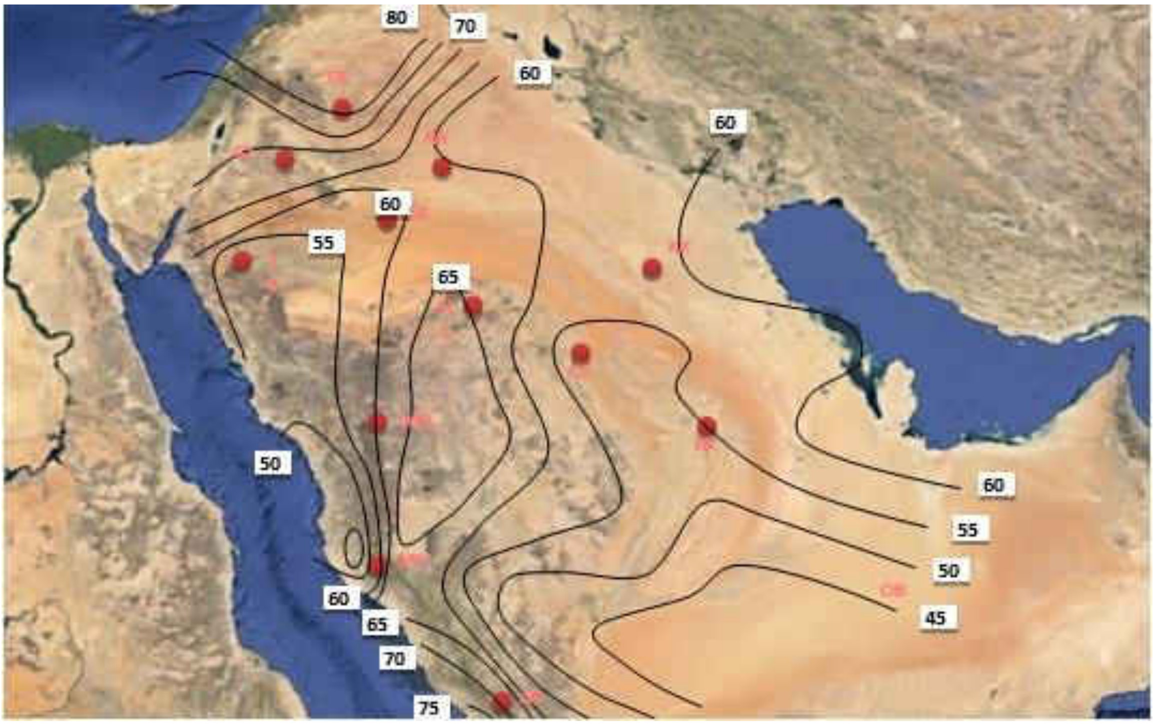
Table 6.2: Trends of Extreme Wind in the Selected Nine Stations

Station Name	Slope of Trend Line
Riyadh	0.03
Jeddah	-0.21
Dhahran	0.15
Qassim	-0.29
Qaisumah	-0.26
Tabuk	-0.24
Arar	-0.18
Kahmis Mushayt	0.21
Sharourah	-0.25

As can be seen from this table, except for the mountainous site of Khamis Mushayt and Dhahran of the Eastern province, all other stations are showing negative trends i.e. have experienced reduction in the strength of extreme wind during 1978-2013 period. No significant change was observed in Riyadh.

The spatial distribution of the extreme winds is shown in Figure 6.4 where isotachs of the extreme wind are drawn. It is clear from this chart that the lowest extreme wind values (less than 55 knots) are found mainly over the Empty Quarter and along the middle part of the Red sea shores (e.g. Jeddah). The highest values (more than 70 knots) were confined to the northern region and to the southern part of the Red sea shores (e.g. Jazan).

Figure 6.4: Isotachs of Extreme Winds Recorded in Saudi Arabia over Periods up to 2013

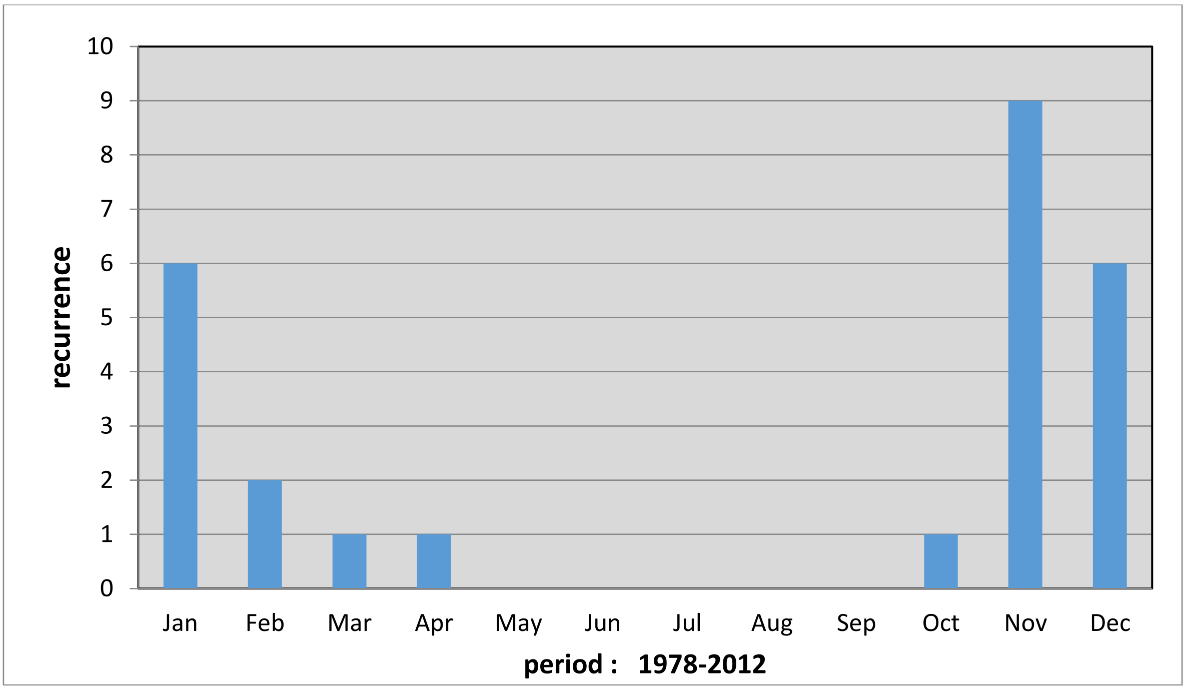


Flash Floods:

Flash floods can occur in many locations in the Kingdom after heavy rains. All "wadis (valleys)" are considered floodplains and are vulnerable to flooding after severe rainstorm.

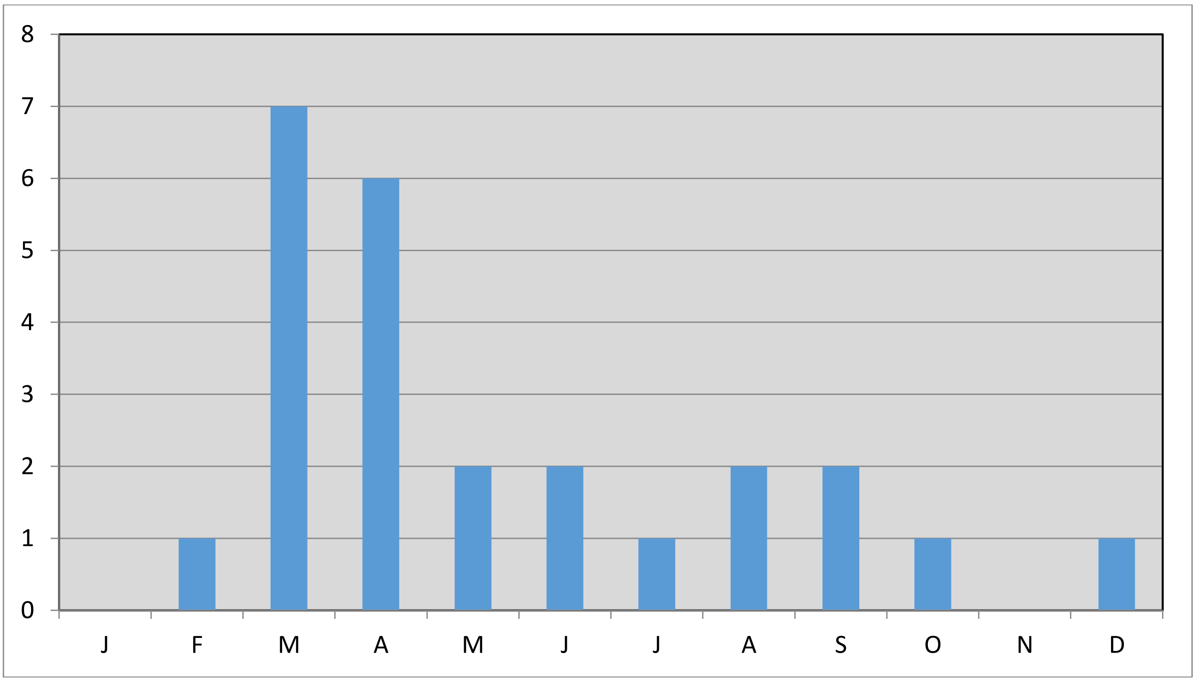
Monthly frequencies of torrential rain events that may cause flooding for the selected nine stations and their general trend have been analyzed. Torrential rainfall is defined here as precipitation in excess of 20 mm per day. As an example, the monthly recurrences of torrential rain in Jeddah (Figure 6.5) over the 1978-2012 period (total 26 events) reveals that torrential rains recurrence is the highest in November (9 events) followed by December (6 events) and January (6 events). No torrential rain events were detected in the summer months (May, June, July, August and September).

Figure 6.5: Recurrence of Torrential Rain in Jeddah



Another example, which show totally different regime of torrential rain recurrence was that of Sharourah in the South (Figure 6.6).

Figure 6.6: Recurrence of Torrential Rains in Sharourah



The highest recurrence was reported in spring (06 and 07 events in the months of March and April respectively) out of twenty five (25) events over 1985-2013 period, while winter months (October, November, December, January and February) showed the least recurrence.

Results for the selected nine stations are tabulated in Table 6.3.

Table 6.3: General Trend of Torrential Rain Events 1978-2013

Station Name	Trend	1978-1995	1996-2013
Riyadh	+	9	12
Jeddah	+	11	15
Dhahran	-	16	11
Qassim	-	21	18
Qaisumah	-	19	11
Tabuk	-	5	3
Arar	-	5	3
Khamis Mushayt	-	32	26
Sharourah	+	10[1]	16[2]

[1] Period 1985-1999 [2] Period 2000-2013

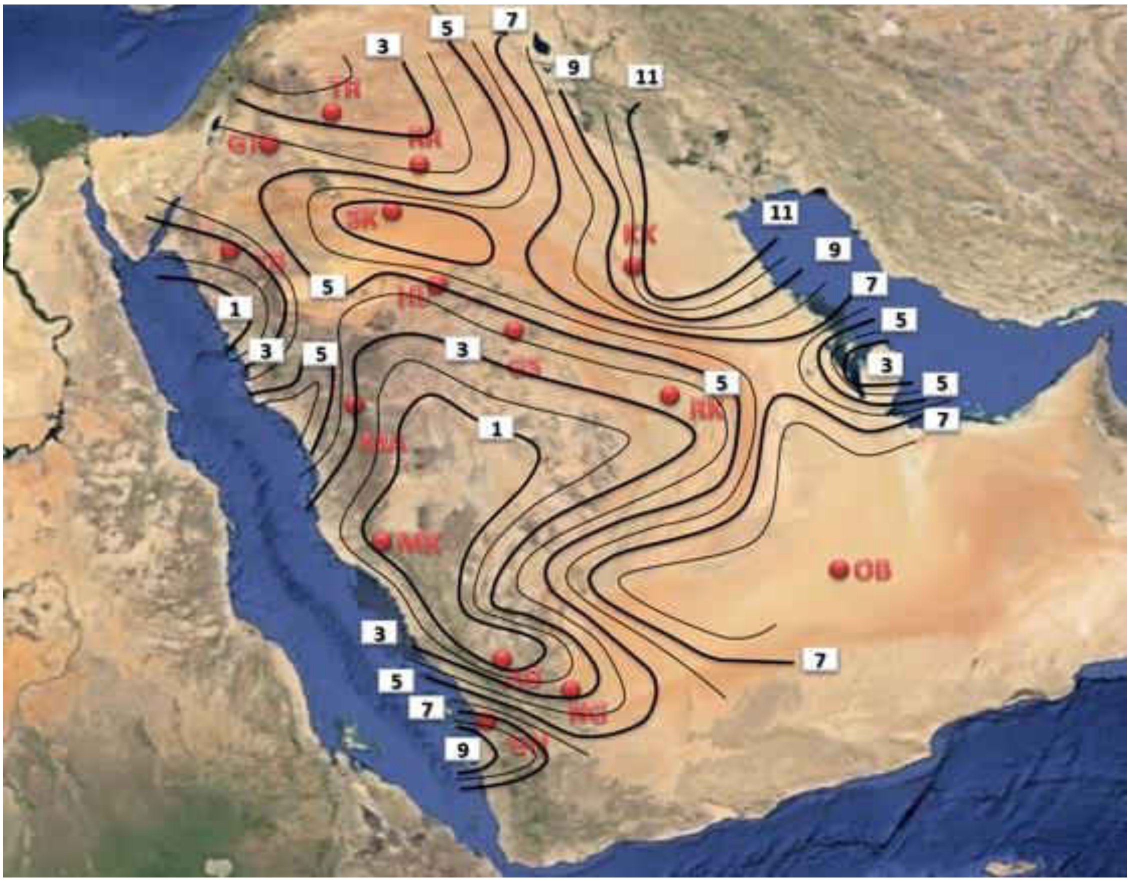
As can be seen from the table above, most of the regions have experienced reduction in the occurrence of torrential rain events. Appreciable increases (33%, 36% and 60%) were observed in Riyadh, Jeddah and Sharourah respectively.

Sand/Dust Storms

Dust and sandstorms are ensembles of particles of dust or sand lifted up to higher levels by strong and turbulent wind. A dust storm usually arises suddenly in the form of an advancing dust wall that may be many kilometers long and a kilometer or so deep.

Dust storms were observed to occur almost all over Saudi Arabia. Chart for the spatial distribution of the number of days with dust/sand storm occurrence per year is shown in Figure 6.7.

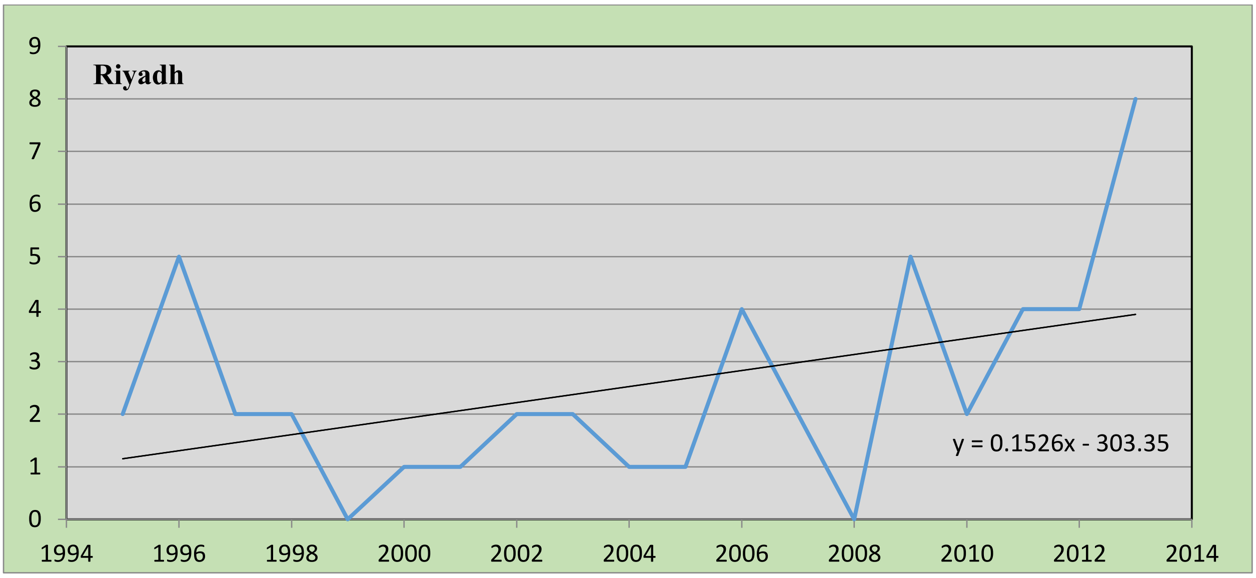
Figure 6.7: Spatial Distribution of Number of Days with Annual Dust/Sand Storm Occurrences



It shows that the Northeastern parts, the Empty Quarter and the far southwest coastal regions (e.g. Jazan) have the highest recurrence of dust/sand storm (more than five days per year).

The trends of "Dust Storm" for the nine stations were observed. Figure 6.8 shows the outcomes (in terms of number of days with the event) for Riyadh and Jeddah as examples. Table 6.4 shows the trends of dust/sand storms in the selected nine stations (over the last 20 years)

Figure 6.8: Trend and Number of Days with Dust/Sand Storms for Riyadh and Jeddah



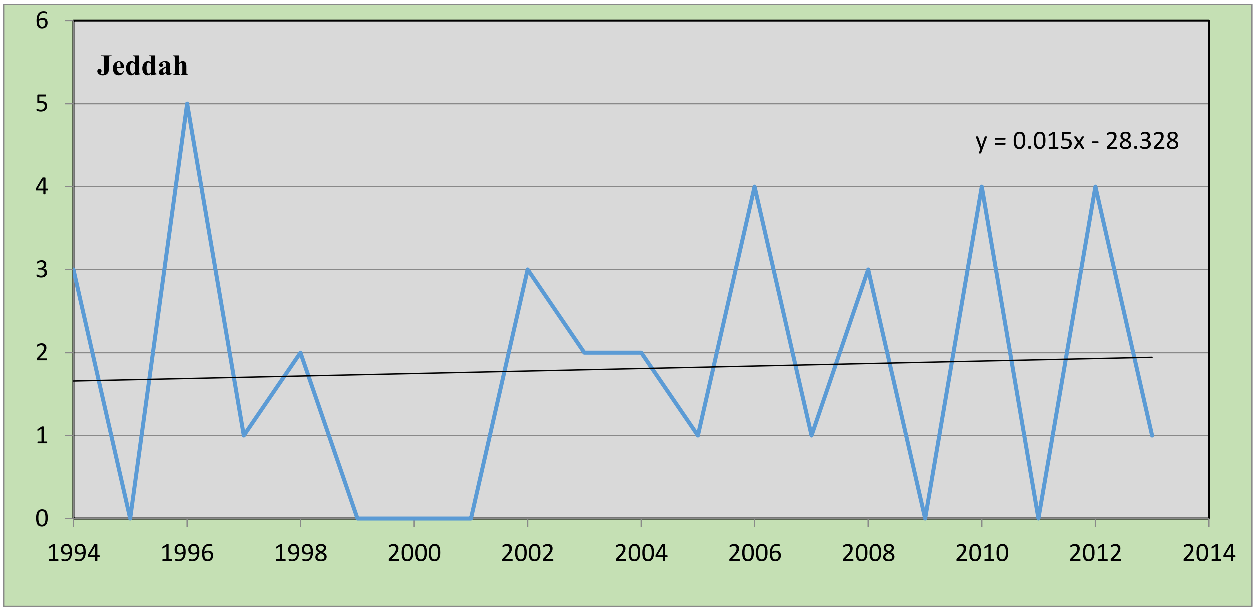


Table 6.4: Summary of Trends of Dust/Sand Storms in the Selected Nine Stations over the last 20 years

Station Name	No. of Events 1995-2004	No. of Events 2004-2013	Rate of Change
Riyadh	18	31	72%
Jeddah	15	20	33%
Dhahran	16	30	88%
Qassim	42	29	-31%
Qaisumah	106	76	-28%
Tabuk	20	21	0.05%
Arar	17	34	100%
Khamis Mushayt	7	7	00%
Sharourah	26	8	-69%

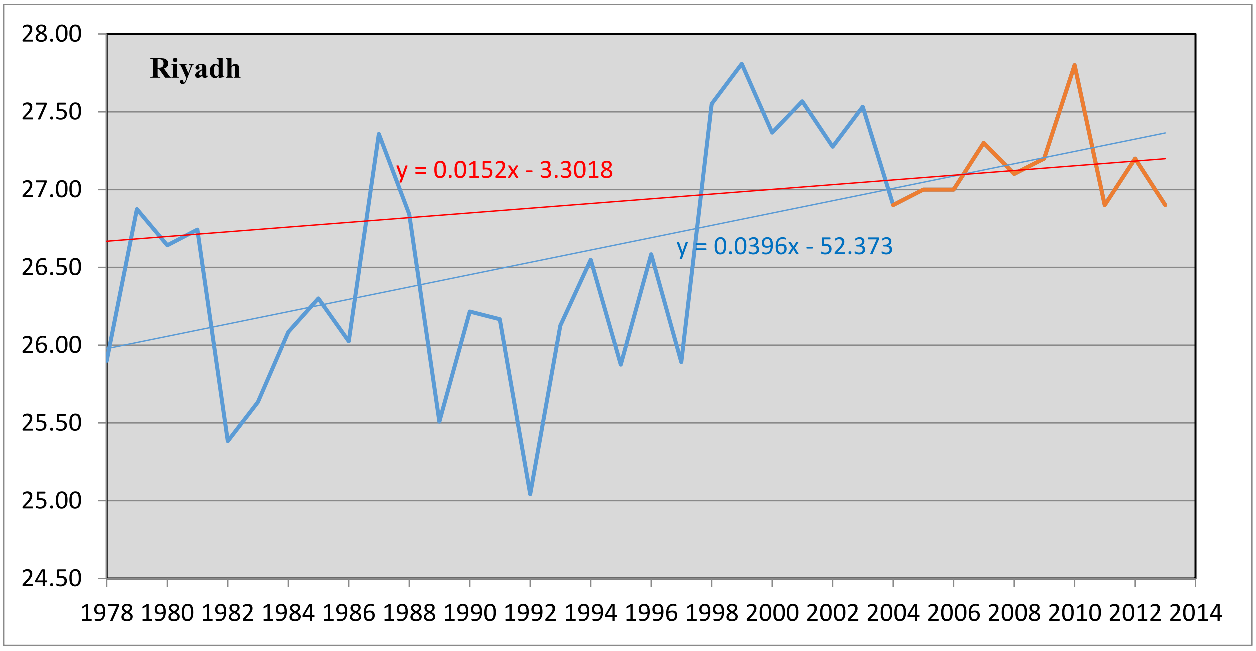
Maximum increase in dust/sand storm events occurred in Arar (100%) and a maximum decrease was recorded in Sharourah (-69%).

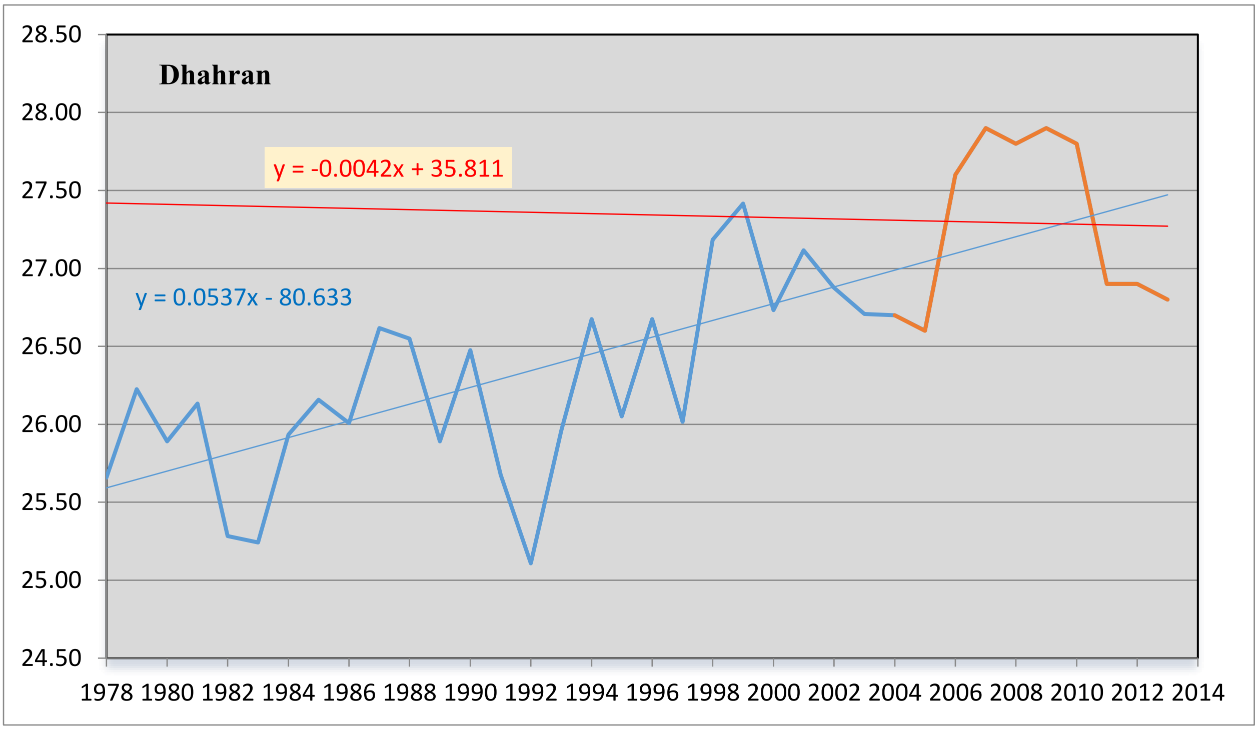
6.2.2 Detection of Changes in Climate in the Last Ten Years

Assessment of changes in temperature and rainfall trends for the period 2004-2013 has been undertaken for the selected nine stations mentioned above. The comparison utilizes the slope of the trend lines of the last ten years period (as compared with that of 1978-2003) as an indicator for the change of trend. This is explained in the following examples.

Figure 6.9 shows a sample of changing trends in Dhahran and Riyadh annual mean temperatures. The slopes are both positive but with stronger value for 2004 -2013 period i.e. there is a continuation of warming but with higher rate during the period 2004 – 2013. On the other hand, Dhahran showed a decrease in temperature in this period.

Figure 6.9: Changing Trends in Riyadh and Dhahran Annual Mean Temperature over 2004-2013





Analyses results of the nine stations are shown in Table 6.5 for temperature.

Table 6.5: Change of Annual Mean Temperature Patterns for the Period 2004-2013 and 1978-2003 in Terms of Slope

Station Name	Change in Temperature Trend	Periods	
		1978-2003	2004-2013
Riyadh	Weak W	0.048	0.015
Jeddah	Strong W	0.015	0.069
Dhahran	Very Weak C	0.05	-0.004
Qassim	Strong W	0.052	0.12
Qaisumah	Strong W	0.043	0.059
Tabuk	Strong W	0.024	0.072
Arar	Strong W	0.044	0.099
Khamis	Weak W	0.086	0.005
Sharourah	Strong W	0.023[1]	0.055

W: Warming C: Cooling [1]Period: 1985-2003

It shows that, except for Dhahran where very weak cooling has been recorded; there was continuous warming in all stations, but with weaker rate in Riyadh and Khamis Mushayt.

For rainfall, results of analyses of the nine stations are shown in Table 6.6.

Table 6.6: Change in Annual Total Rainfall Patterns for the Periods 2004-2013 and 1978-2003 in Terms of Slope

Station Name	Change of Trend RF	Period	
		1978-2003	2004-2013
Riyadh	Drastic decrease	2.15	-1.24
Jeddah	Less increase	2.33	1.66
Dhahran	Increase	1.41	2.85
Qassim	Drastic decrease	-0.41	-11.34
Qaisumah	Decrease	-2.25	-4.31
Tabuk	Strong increase	-1.03	5.85
Arar	Decrease	-1.34	-1.4
Khamis Mushayt	Drastic decrease	-0.42	-10.18
Sharourah	Drastic decrease	7.12[1]	-1.55

Shades of Green: Increase Shades of Brown: Decrease [1] Period 1985-2003

There has been a continuous increase in Dhahran, an increase followed by decrease in Tabuk, but with decrease in all other stations with changing trend from increase to decrease in Riyadh and Sharourah.

6.3 Elaboration on Future Climate Change Scenarios:

In the Second National Communication (SNC) report of the Kingdom of Saudi Arabia, high resolution information of climate fields that provided more detailed regional and local climate change, Regional Climate Model (RCM) rather than Global Climate Models (GCMs) was applied as a downscaling tool. PRECIS (Providing Regional Climates for Impact Studies) of the U.K. Met Office Hadley Center was used for that purpose. Various boundary data sets, that have been internationally employed, were used in our runs. The horizontal resolution was 50X50 km. A2 story line of SRES was adopted as the emission scenario.

However, down-scaling a single GCM projection does not provide enough information on how much confidence can be placed on the projection. Exploring the range or spread of projections from different GCMs may enable to gain a better understanding of the uncertainties in climate change scenarios that arise from differences in model formulation. The issue of uncertainty in climate modeling was not employed in the SNC.

Attempts have been made in this report “The Third National Communication Report (TNC)” to alleviating some of the inherent uncertainties in the GCMs projections following the “Quantifying Uncertainty in Models Projections (QUMP)” approach of Hadley center. This section of “climate Change Scenarios” illustrates the process to project the “Future Climate Change Scenarios” and address to alleviating some of the inherent uncertainties in the GCMs by using QUMP.

6.3.1 Hardware and Software Installation:

In accordance with an agreement with Hadley center, the most recently updated PRECIS model (version 2.0 with 25X25km resolution) was installed in eight work stations in April 2014 with different driving GCM data.

Boundary data were obtained from five selected GCM members out of the Perturbed-Physics Ensemble (PPE) 17 members (HadCM3Q0-16), three members from the Multi-Model Ensemble (MME); HadGEM2-ES RCP8.5, HadGEM2-ES RCP4.5 and HadGEM2-ES RCP2.6, in addition to ERA-interim data set (it is a newly conducted climate data re-analysis program over a period from 1989 to 2011 and the program is still continuing). These are tabulated with their run I.D. in table1.

Table 6.7: The Identifications of Both the Work Stations and the GCMs Runs

PC	1	2	3	4	5	6	7	8
RUN ID	Saaab	Sabaa	Sacaa	sadaa	saeaa	safaa safac	sagab	Sahib
GCM ID	HadC M3 Q0	HadC M3 Q7	HadC M3 Q14	HadC M3 Q13	HadC M3 Q1	ERA-Interi HadGE M2-ES RCP 4.5	HadGE M2-ES RCP 2.6	HadGE M2-ES RCP 8.5
Period	2006-2100	2006-2100	2006-2100	2006-2100	2006-2100	1989-2011 2006-2079	2006-2100	2006-2100

The selection of the sub-ensemble of five PPE models (Q0, Q7, Q14, Q13, Q1) that delivered by Hadley center was done in accordance with QUMP approach by the Hadley center scientists for Saudi Arabia.

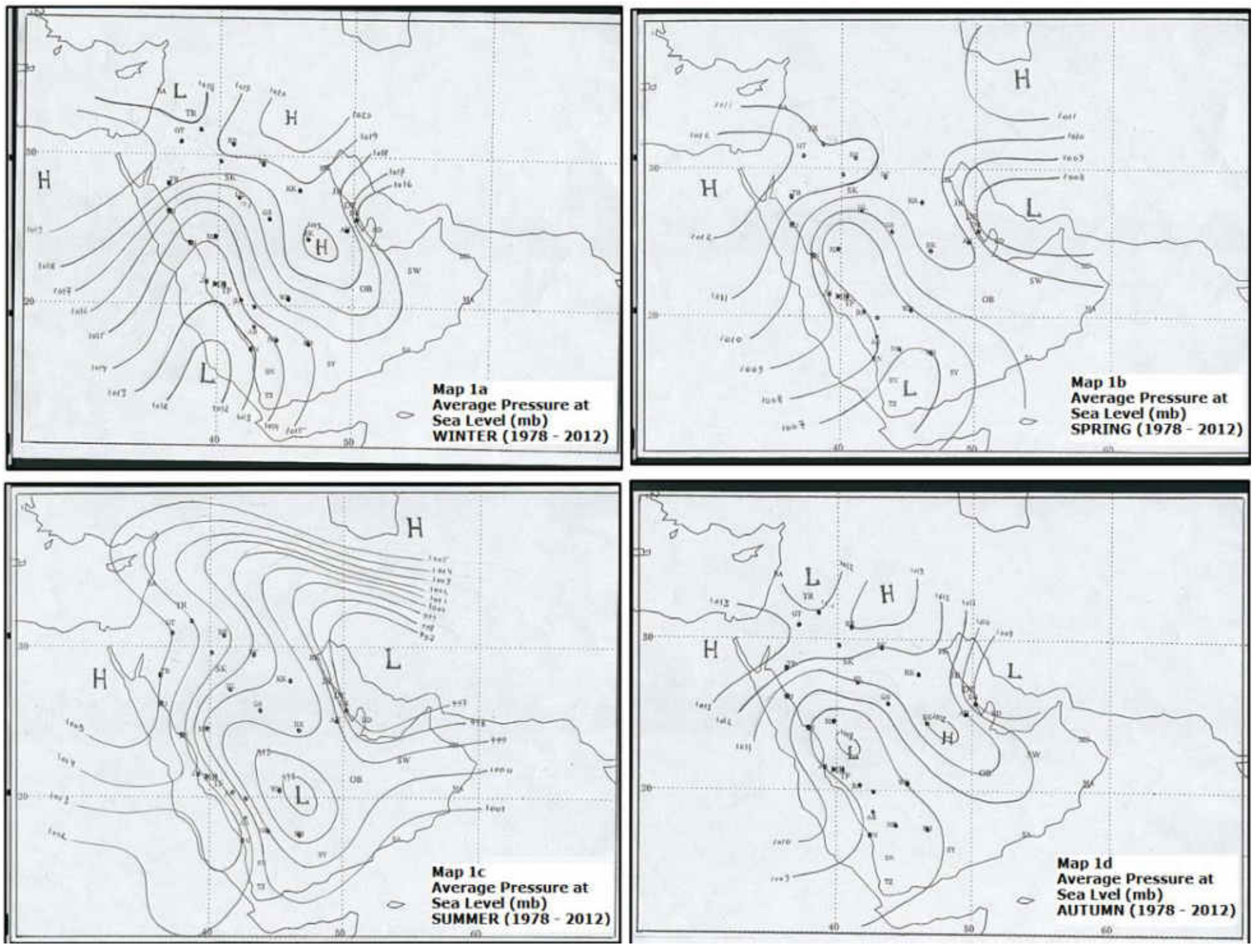
However, further refinement of the selection procedures, by assessing the performance of the selected models in simulating predefined pronounced climatic features, will be carried out. Identification of such features will be based on synoptic-climatological analysis of the large scale pressure patterns affecting the Middle East region and the local responses to these patterns in some selected areas over the Kingdom.

6.3.2 Assessing the Performance of Eight GCMs in Driving Précis:

Attempts were made to alleviate some of the uncertainties in the models projections by searching and identifying any clear synoptic- climatological feature that can be used as a criterion for testing the performance of the models at the present and the future climate.

Figure 6.10 exhibits the mean seasonal pressure at sea level for Saudi Arabia and surroundings over the baseline period (1978 – 2012). The main features affecting the region are seen to be the extension of the Siberian high in winter and the Indian monsoon in summer.

Figure 6.10: Mean Seasonal Sea Level Pressure over the Baseline Period



The regularity in seasonal alternation of these pressure patterns is expected to form a promising pathway for getting such feature.

Careful examination of the PME's climatic data base has revealed the presence of a strong negative coherence between the Monthly Mean Sea Level Pressure and Temperature. Figure 6.11 below shows this relationship for Jeddah.

Figure 6.11: Monthly Mean Sea Level Pressure and Temperature, Jeddah (1978-2013)

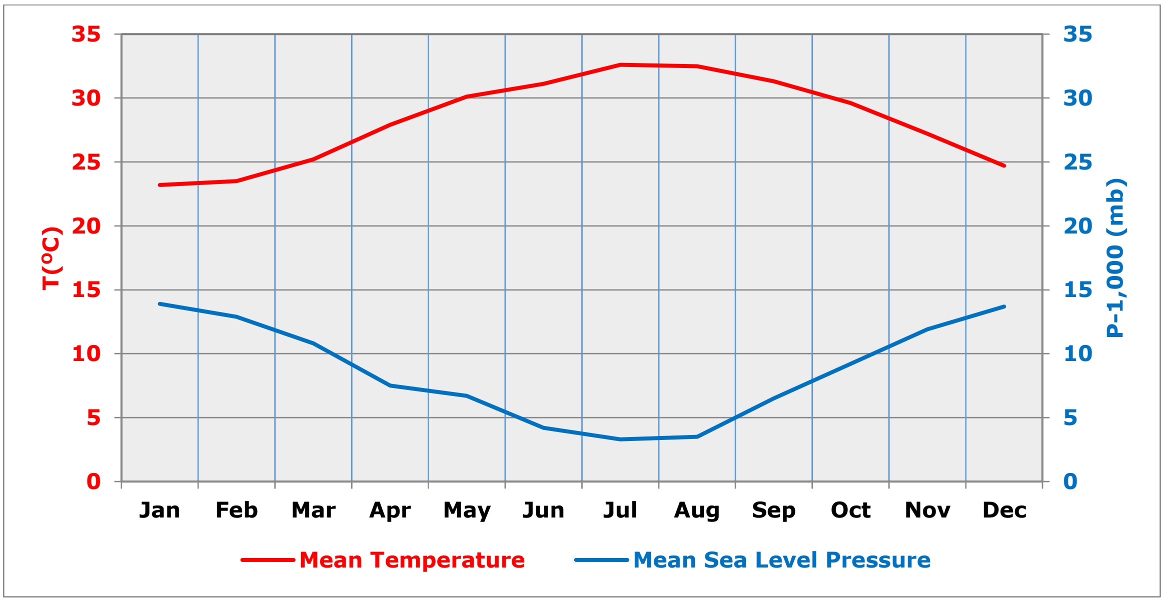
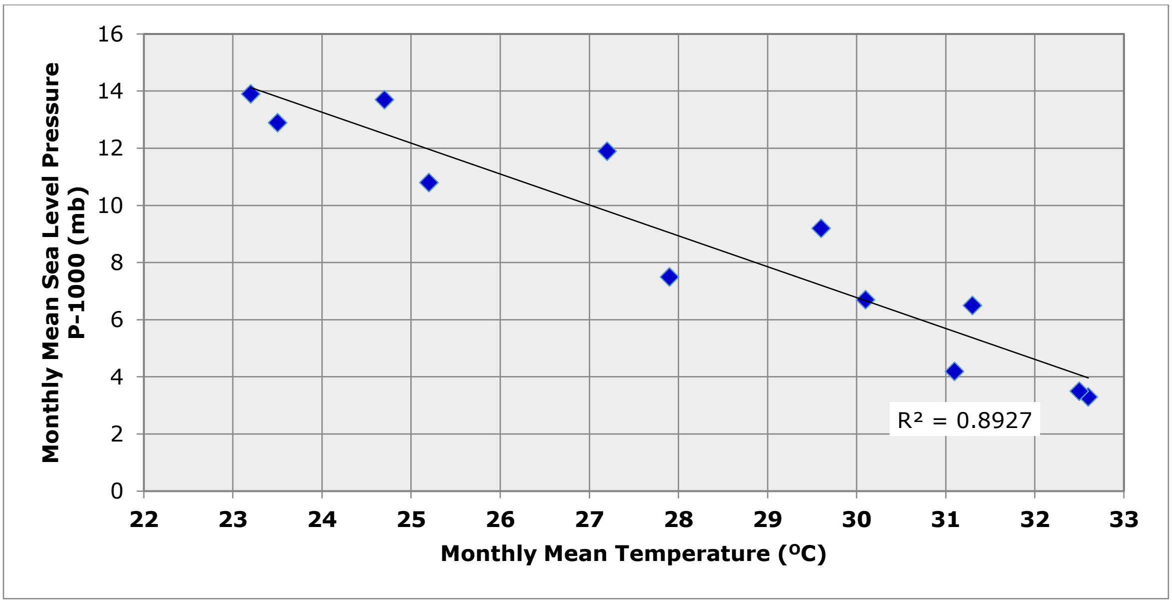


Figure 6.12: Relationship between the Monthly Mean Sea Level Pressure and Temperature, Jeddah (1978-2013)



The statistical correlation between the pressure and temperature in Jeddah was examined. As can be seen from Figure 6.12 above, there is a strong negative correlation between the two parameters with a very high coefficient of determination (R^2) estimate of 0.893.

In order to assess the sustainability of this newly established synoptic- climatic correlation, it is validated on year by year basis in Jeddah. Furthermore, extending the analyses to randomly selected stations around the country have revealed the comprehensiveness of this correlation.

Validation:

The validation process will start by applying this synoptic-climatology feature to the selected nine stations. Table 6.7 shows the values of the derived coefficient of determination R^2 from the projected data of some runs namely HadCM3Q0, Q13, Q7 and HadGEM2-ES RCP 4.5, 8.5, over the 2030-2079 period, in addition to the previously obtained values from ERA-interim run (as reference of 1990-2009 period) for the selected nine stations.

Table 6.8: Derived values of R^2 –P^T from Some Models Output for the Nine Stations

Station Name	R^2-P^T Qs			RCPs		ERA-INTERIM
Riyadh	0.943	0.914	0.925	0.940	0.948	0.924
Jeddah	0.975	0.948	0.955	0.811	0.928	0.974
Dhahran	0.936	0.905	0.924	0.942	0.945	0.943
Qassim	0.967	0.943	0.950	0.961	0.966	0.963
Qaisumah	0.960	0.936	0.945	0.955	0.962	0.949
Tabuk	0.966	0.947	0.959	0.934	0.946	0.963
Arar	0.967	0.946	0.955	0.953	0.958	0.964
Khamis Mushayt	0.567	0.498	0.569	0.485	0.562	0.611
Sharourah	0.941	0.916	0.933	0.940	0.944	0.949
Period	2030-79	2030-79	2030-79	2030-79	2030-79	1990- 2009
Model ID	**Q0**	**Q13**	**Q7**	**RCP4.5**	**RCP8.5**	**PRECIS**

**Remark on R^2: It indicates how well data points fit a line or curve. It is such that $0<R^2<1$ and denotes the strength of the linear association between X and Y.*

It is clear from Table 6.8 above that the obtained values of R^2 for all nine stations (except Khamis Mushayt) and for all five testing runs are very high and highly identical to the ERA run, which means that the models have projected equally well the outstanding correlation between the monthly mean sea level pressure and temperature in the future climate of the country. From synoptic-climatology consideration, the sustainability of this clear correlation in future forms strong evidence that the large scale atmospheric circulation over our region will not experience any significant changes in its configuration in this century.

Having this large scale P^T correlation, search was continued to identify any sustainable peculiarity in the climatic records, preferably at the local scale, that could be used as checking criterion.

Validation of Rainfall Trend from Historical Data:

Thorough inspection of the climate data available at GAMEP database reveals the existence of an interesting local climatic feature over central and north eastern provinces of the Kingdom. Monthly data analysis of six stations in this region viz Riyadh, Hail, Qassim, Qaisumah, Rafha and Ahsaa showed a clear, common and sustainable drop of rainfall amount in the month of February (Table 6.9).

Table 6.9: Monthly Mean Rainfall Over Central and Eastern Province (1978-2013)

Month	Qaisumah	Qassim	Riyadh	Rafha	Hail	Ahsa	Average
1	24.3	20.8	16	13.2	13.7	14.9	17.2
2	12.8	11.4	8.9	9.7	10	10.9	10.6
3	18.5	27.3	21	17	17.9	15.7	19.6
4	15.3	25.9	26.7	12.7	17.9	12.6	18.5
5	5.6	12.9	5.8	3	9.4	3.1	6.6
6	0.1	0	0	0.1	0.2	0	0
7	0	0.1	0	0	0.1	0	0
8	0.1	0.1	0	0	0.1	0.8	0.2
9	0.1	0.1	0	0	0.1	0	0
10	6.3	3.8	1.2	4.2	7.7	0.5	4
11	23.4	24	13.1	12.4	20.6	6	16.6
12	17.8	14.5	17.1	9.8	7.3	20.7	14.5

Figures 6.13 and 6.14 show the results of this analysis for both single and combined stations. This outstanding climatic feature forms our first testing criterion at the local scale.

Figure 6.13: Monthly Mean Rainfall Over Central and Eastern Province (1978-2013)

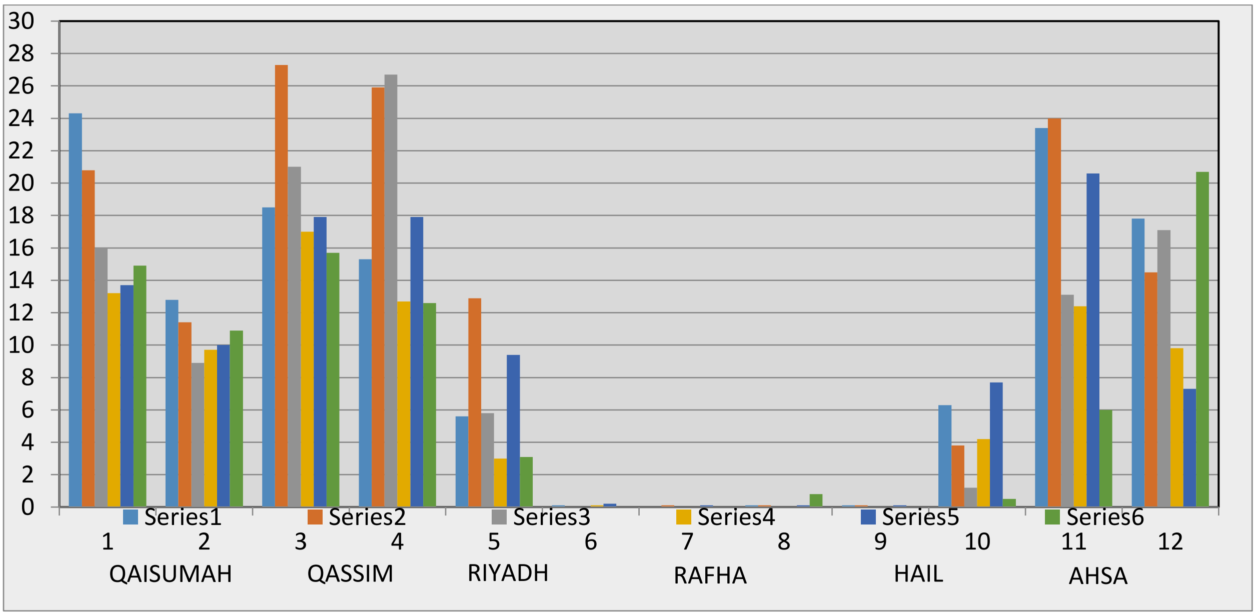
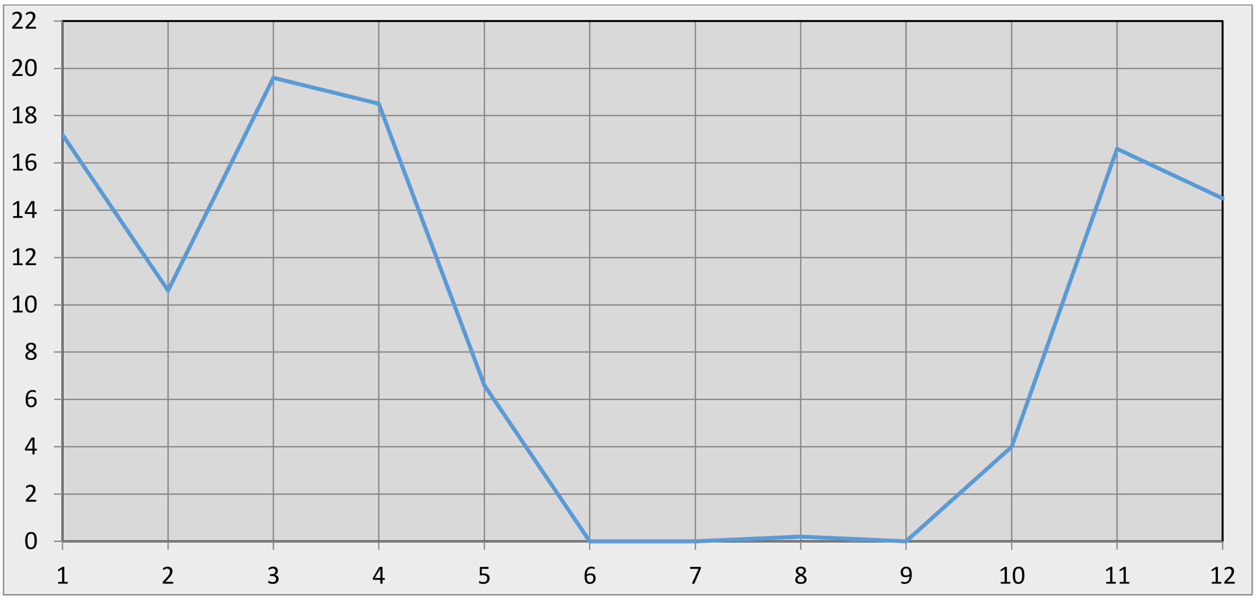
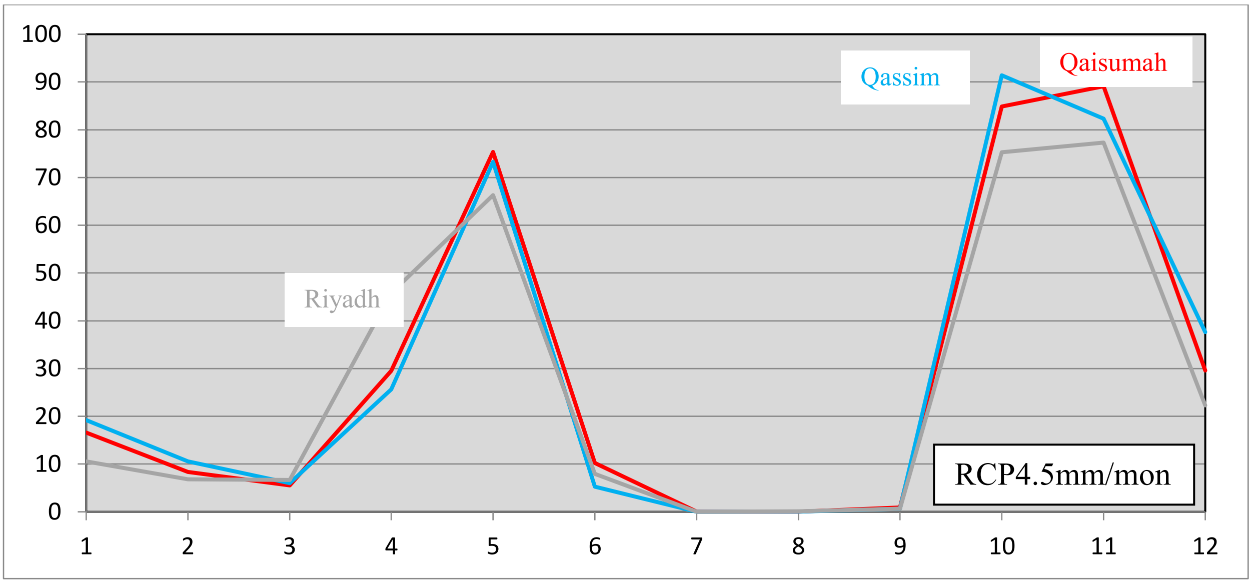


Figure 6.14: Average Monthly Rainfall for the Combined Six Stations (1978-2013)



This observed sustainable drop in February rainfall over the central and eastern regions of the Kingdom will form our next validation process. Figure 6.15 shows the analyses of the projected rainfall by the RCP4.5 model at the three considered stations (Qassim, Qaisumah and Riyadh) over 2030-2079 periods.

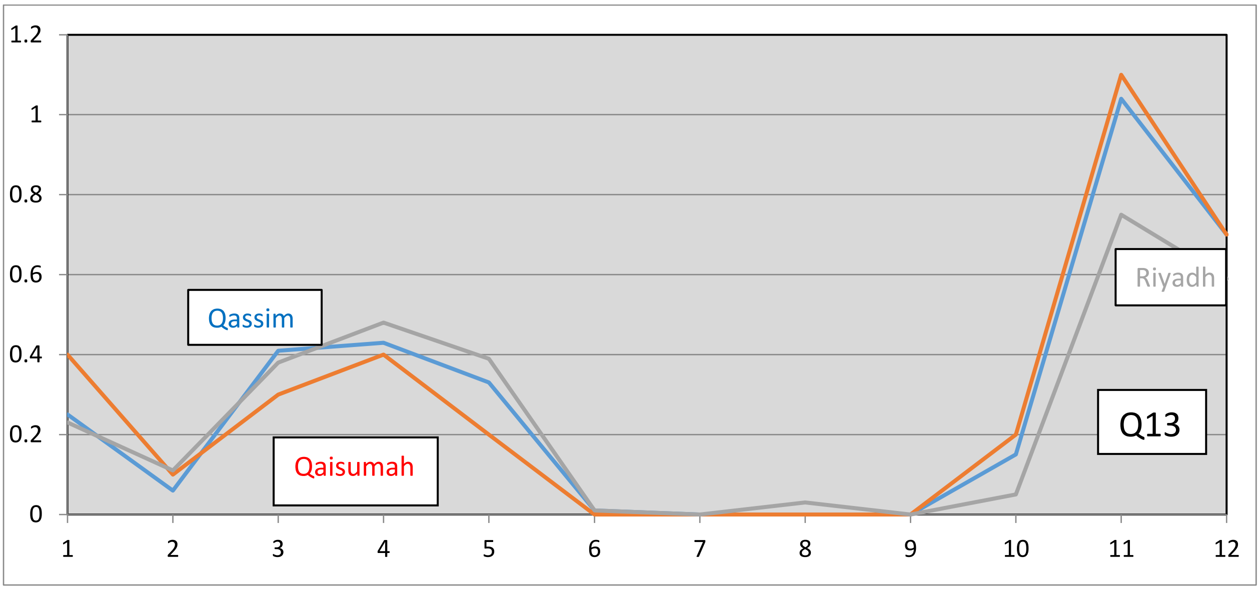
Figure 6.15: Projected Rainfall by the RCP4.5 Model at the Three Stations

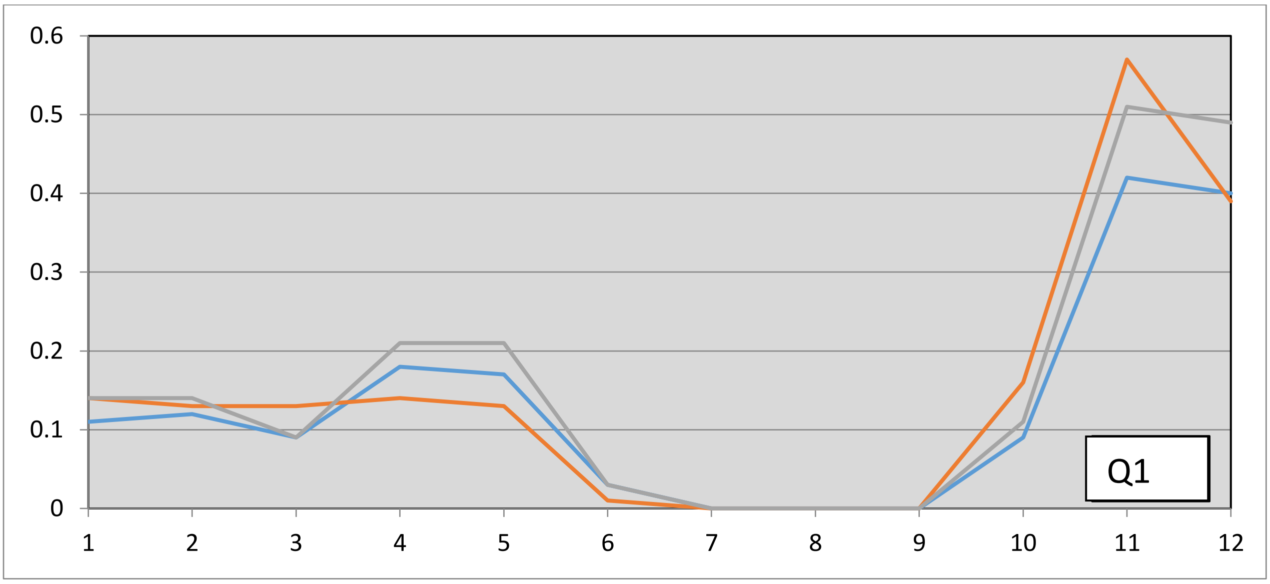


The analysis shows that all three RCPs models (2.6, 4.5 and 8.5) have failed to project this sustainable local feature. This result will negatively affect these models in the final rating process for selecting the optimum scenario for KSA.

Considering the Qs models, Figure 6.16 shows the analyses of the projected rainfall by two models from this group at the above mentioned three stations over 2030-2079 periods.

Figure 6.16: Projected Rainfall by the Q13 and Q1 Models at the Three Considered Stations

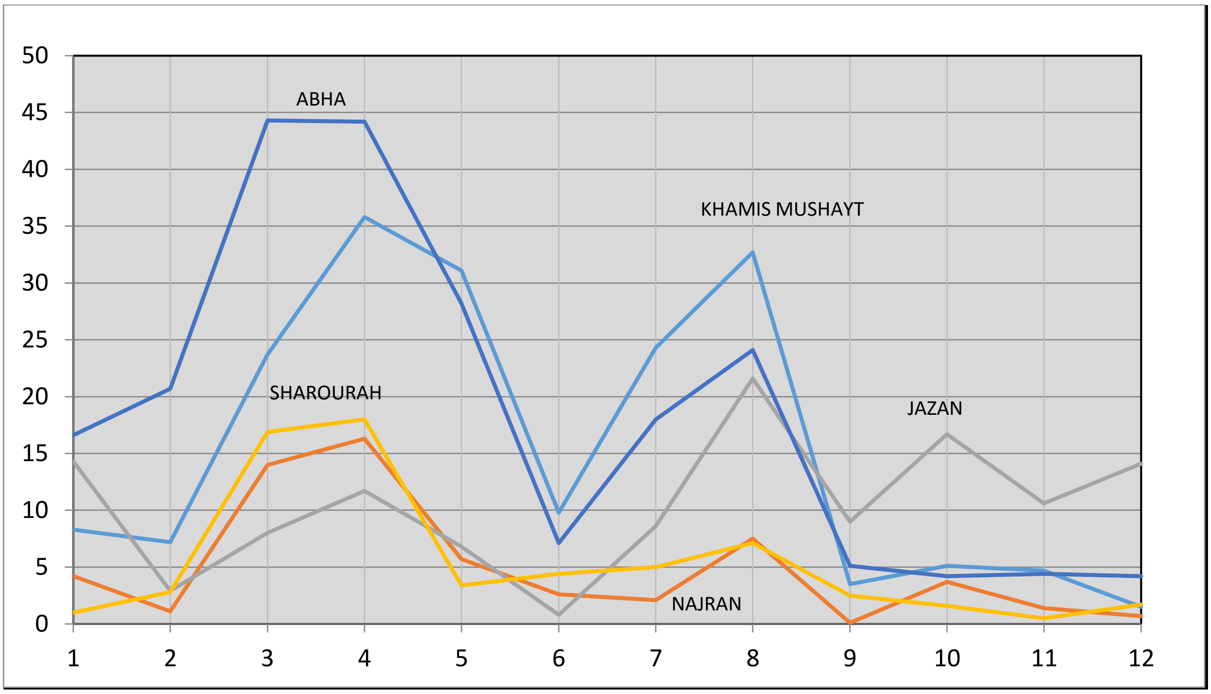




Results of this analysis show that three Qs models (Q13, Q14 and Q0) have projected correctly the drop in February rainfall amount, which will be accounted as a merit for these models in the final rating process. The other two models (Q7 and Q1) have failed to project this event and hence will be negatively rated.

Following the same line of exploration, inspection of the southwestern province rainfall data reveals a totally different régime from those experienced elsewhere in the Kingdom. It is characterized by rainy summer season and drier winter season as can be seen from Figure 6.17 of the monthly mean rainfall in stations encountered in the region: Abha, Khamis Mushayt, Najran, Jazan and Sharourah.

Figure 6.17: Monthly Mean Precipitation Over the Southern Province 1978-2012



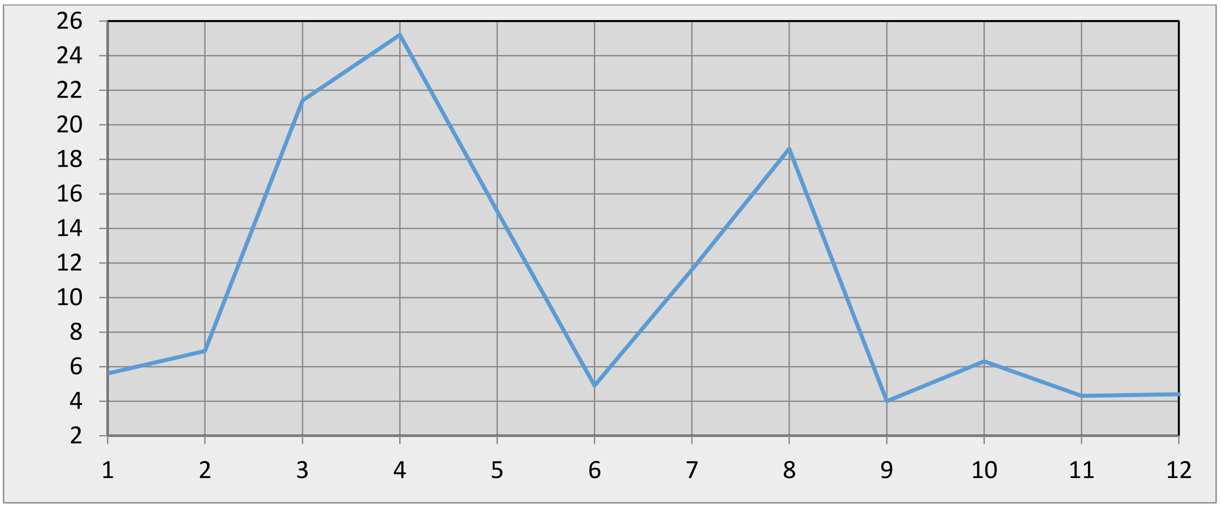
Summer rain is known to be associated with the movement of the so-called "Inter Tropical Conversion Zone (ITCZ)" from the south that affects this region at locally different strengths during summer (strongest in Khamis Mushayt and least in Sharourah further to the east). The rainfall in the last four months of the year is generally less than 5mm/month, except in the coastal city of Jazan. This figure together with Table 6.4 shows a quite clear drop in rainfall in the month of June, with two peaks in March-April and August.

Table 6.10: Monthly Mean Rainfall Over Asir and Southern Provinces (1978-2013)

Month	Khamis Mushayt	Najran	Jazan	Sharourah	Abha	Average
1	8.3	4.2	14.3	1	16.6	5.6
2	7.2	1.1	2.9	2.8	20.7	6.9
3	23.7	14	8	16.9	44.3	21.4
4	35.8	16.3	11.7	18	44.2	25.2
5	31.1	5.7	6.8	3.4	28.2	15
6	9.8	2.6	0.8	4.4	7.1	4.9
7	24.3	2.1	8.6	5	18	11.6
8	32.7	7.5	21.6	7.1	24.1	18.6
9	3.5	0.1	9	2.5	5.1	4
10	5.1	3.7	16.7	1.6	4.2	6.3
11	4.7	1.4	10.6	0.5	4.4	4.3
12	1.5	0.7	14.1	1.7	4.2	4.4

This is even more apparent in Figure 6.18 of the average monthly rainfall for the combined five stations.

Figure 6.18: Average Monthly Rainfall for the Combined Five Stations (1978-2013)

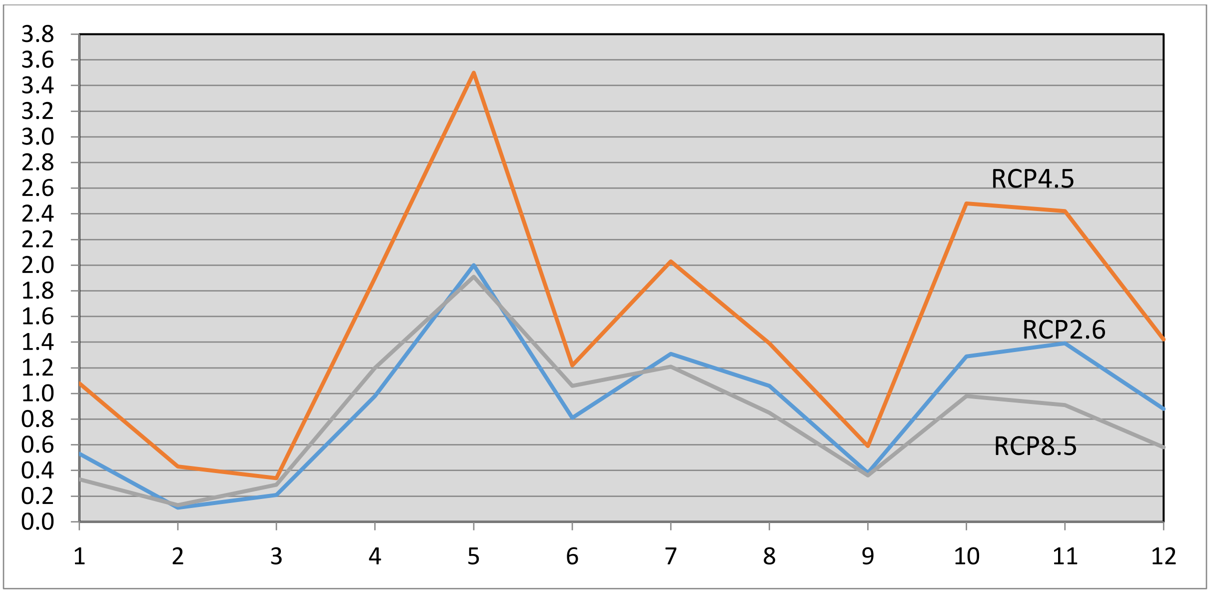


This drop in June rain can be looked at as a separation between two rainy seasons; spring and summer.

This climatic feature forms our second testing criterion at the local scale.

Figure 6.19 shows the analyses of the projected rainfall by the RCPs models at Khamis Mushayt over 2030-2079 periods.

Figure 6.19: Projected Rainfall by the RCPs Models at Khamis Mushayt Station over 2030-2079 Period

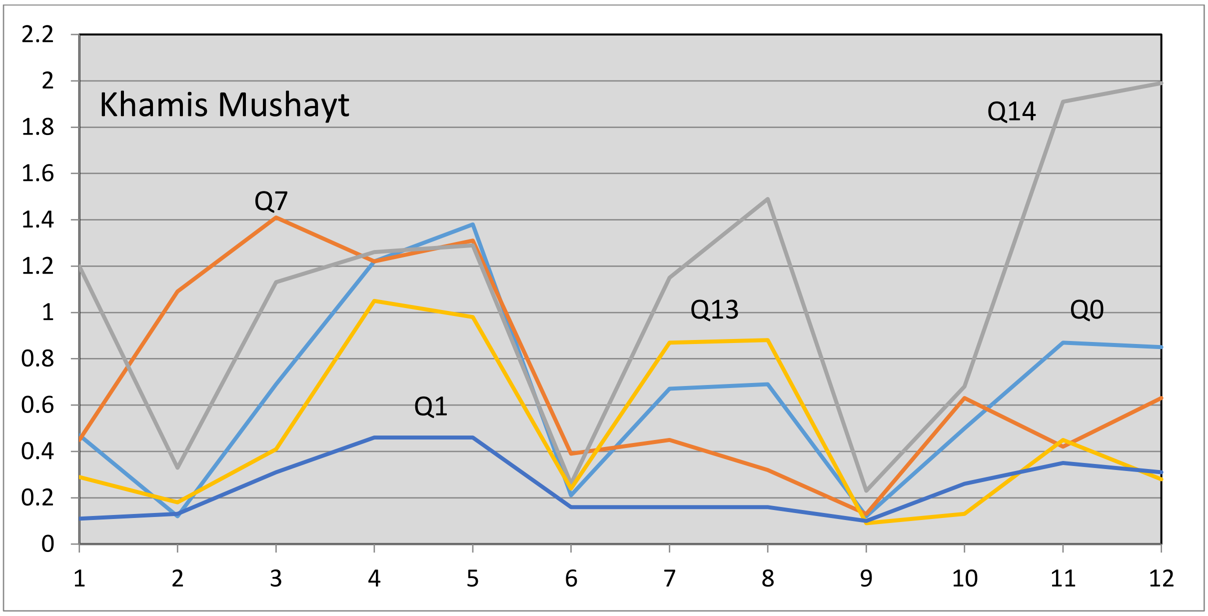


This graph indicates that the projected rainfall by the RCPs models at Khamis Mushayt are fairly good in capturing both spring and summer peaks but with shifting the spring peak from March-April to May and the summer peak to July rather than August. The reduced rainfall in June is also well projected especially by RCP2.6 and RCP4.5.

6.3.3 Performance of the Qs Models

Figure 6.20 shows the analyses of the projected rainfall by these models at Khamis Mushayt over 2030-2079 periods.

Figure 6.20: Projected Rainfall by the Qs models at Khamis Mushayt over 2030-2079 Period

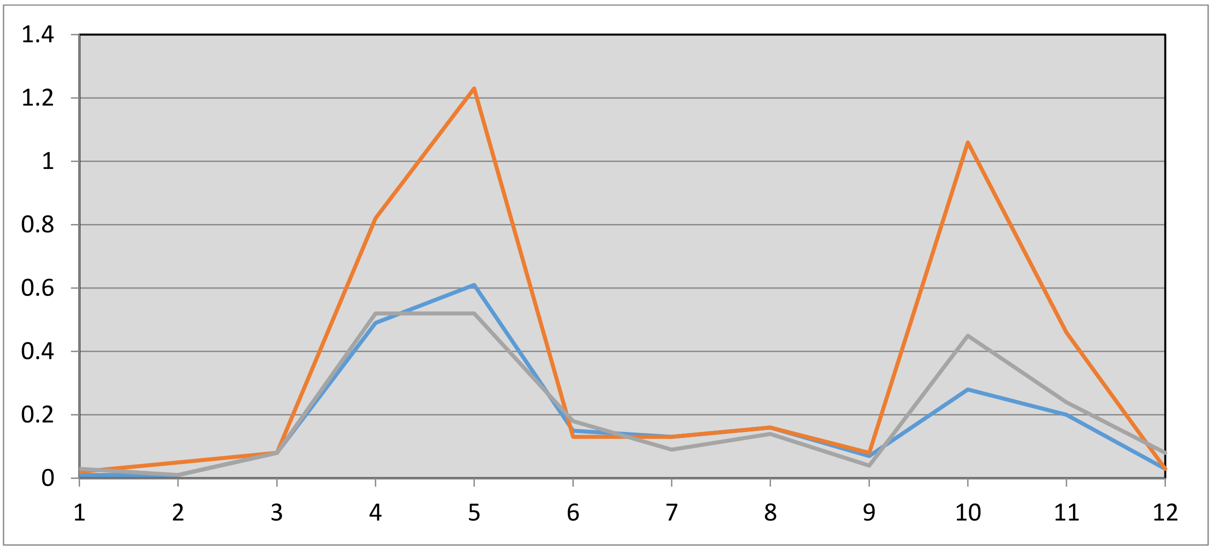


It can be seen from this graph that three Qs models (Q13, Q14 and Q0) have projected correctly the two rainy periods in spring and summer with the pronounced drop in June rainfall amount. The other two models (Q7 and Q1) have failed to project this event.

An interesting feature was observed in the results of many models, both RCPs and Qs that there will be appreciable increase in rainfall amount during autumn season (mainly in October and November). This may indicate a possible future interference of other than the existing régime. This could be due to more frequent tropical cyclone and hurricanes events hitting the region from the Arabian Sea.

Figure 6.21 shows the analyses of the projected rainfall by the three RCP models over 2030-2079 period for Sharourah.

Figure 6.21: Projected Rainfall by the RCP Models at Sharourah Station over 2030-2079 period



It is clear from this graph that all three RCP models (2.6, 4.5 and 8.5) have completely failed to project the summer season rainfall feature, which will contribute negatively to its rating score.

Performance of the Qs models: Figure 6.22 shows the analyses of the projected rainfall by these models at Sharourah over 2030-2079 period.

Figure 6.22: Projected Rainfall by the Qs Models at Sharourah Station over 2030-2079 Period

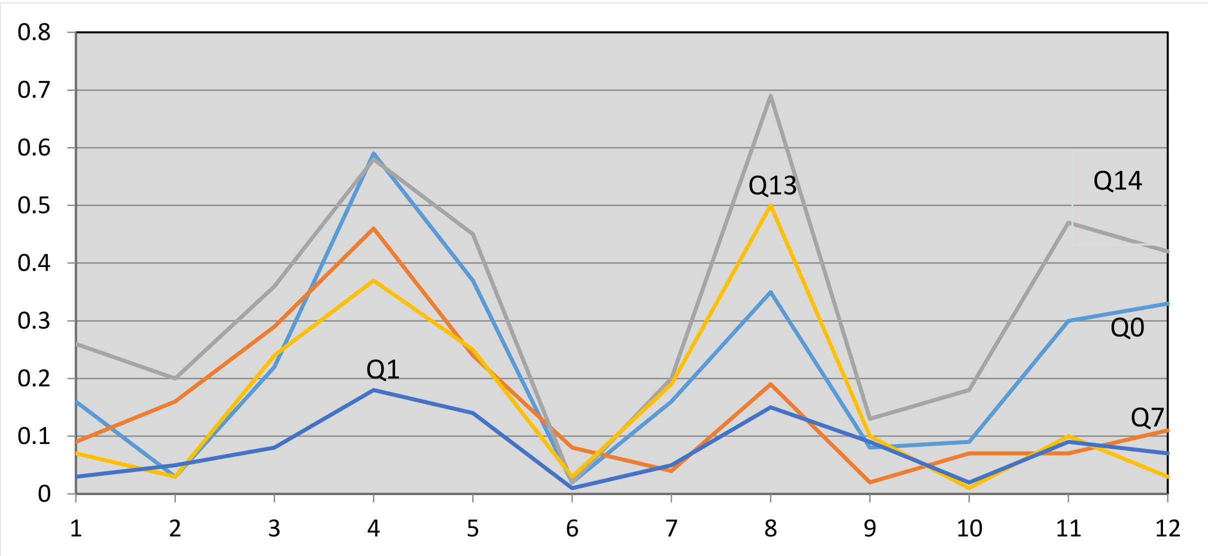


Figure 6.22 indicates that the Qs models have projected excellently the two rainy periods in spring and summer with the pronounce drop in rainfall amount in June except for Q7.

The interesting observation mentioned in the analysis of Khamis Mushayt above for the autumn rain is also valid for Sharourah.

6.3.4 Conclusions Drawn from Validation Procedures:

Summing up the results of the validation procedures as described above, it can be concluded that the précis run using HadCM3Q13, followed by HadCM3Q14 exhibit the best performance in projecting the outstanding climate features (adopted as criteria) for the future period of 2030-2079. These two models can be adopted to produce the future climate change scenarios for Saudi Arabia with more confidence due to less uncertainty in the selected models.

Having reached this conclusion, the analysis of the future climate scenario will focus accordingly on the HadCM3Q13 and to less extent on HadCM3Q14 to obtain the climate parameters during the period 2030-2079. It should be mentioned here that HadCM3Q13 identified by Hadley center as a model with high sensitivity (larger temperature changes).

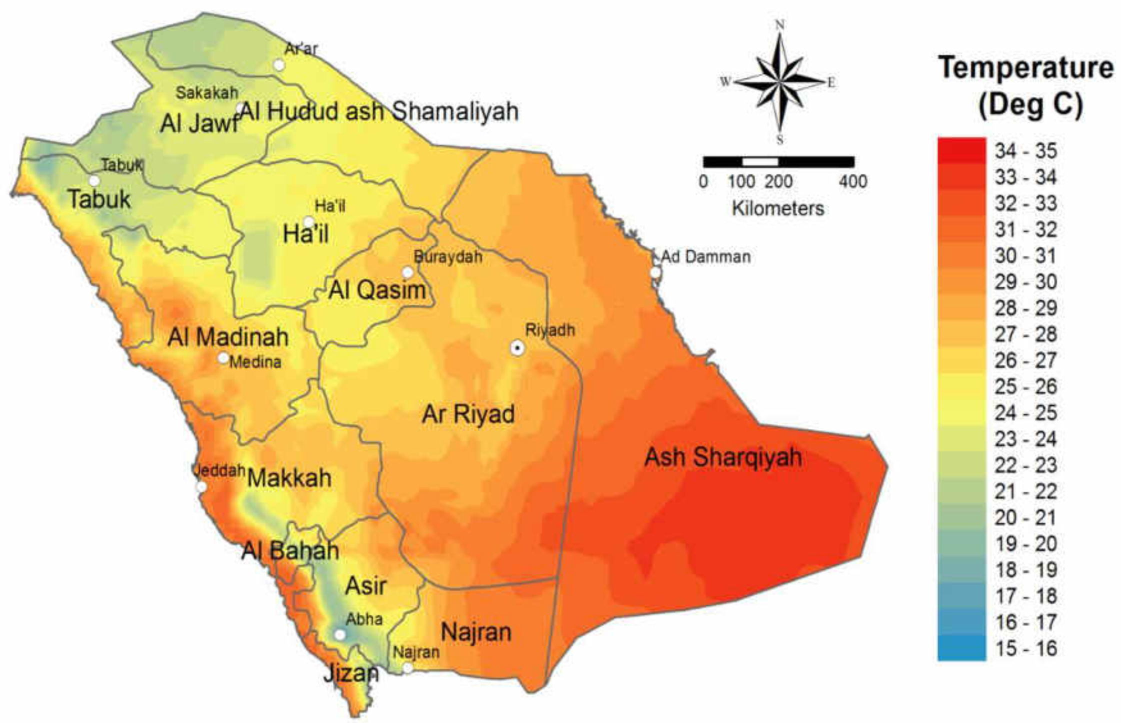
Results of HadCM3Q13 and HadCM3Q14 Models Runs

Based on the validation procedures followed above in subsection 3.3.2 and based on the above mentioned conclusions, HadCM3Q13 and HadCM3Q14 models were used to produce the future climate change scenarios for the three important climate factors namely temperature, precipitation and humidity.

(a) Temperature:

The spatial distribution of the projected Annual mean temperatures by HadCM3Q13 is shown in Figure 6.23 (it is worth to remember that the resolution of the model is 25x25 km).

Figure 6.23: Annual Mean Temperatures from HadCM3Q13 (2030-2079 Period)



As expected, the highest temperature is seen over the Empty Quarter and along the Red Sea coastal strip. The coolest areas are those of Asir Mountains and the northern border province.

Table 6.11 lists the projected mean annual temperatures using HadCM3Q13 and HadCM3Q14 models in comparison with those of the baseline period.

Table 6.11: Mean Annual Temperatures using HadCM3Q13 and HadCM3Q14 Models

Station Name	Mean Annual Temperature		
Riyadh	26.6	27.6	27.0
Jeddah	28.4	29.0	29.0
Dhahran	26.6	29.6	29.4
Qassim	25.1	27.1	27.0
Qaisumah	25.4	27.5	27.4
Tabuk	22.1	23.1	22.8
Arar	22.2	23.9	23.9
Khamis Mushayt	19.5	18.7	18.9
Sharourah	28.6	30.8	30.8
Period& ID	1978-2013	2030-2079	2030-2079
	Actual	**sadaa Q13**	**sacaa Q14**

Except the projected cooling in Khamis Mushayt of about 0.8ºC, all other stations will experience general annual warming ranging from 0.6-2.9ºC.

The projected mean annual temperatures for the nine stations are shown in Table 6.11, in comparison with their actual counterparts of the baseline period.

It can be noticed from Table 6.5, the strongest warming is occurring in Summer (July-August) and the weakest is in Winter (December-January) in most of the nine stations. Figure 6.24 exhibits the spatial distribution of the projected Mean temperature in January as representing the winter season, while Figure 6.25 is for July as representing summer season.

The coolest January is prevailing in the Northern Province with gradual increase in temperature as going south towards the Empty Quarter. The warmest January is seen to be stretching along the Red Sea coast from Jazan to Yanbu.

The hottest July is seen to be over the Empty Quarter and with the temperature decreasing gradually northwestwards to Tabuk. The coolest July is projected correctly over Asir Mountains from Najran to Taif.

The spatial distribution pattern of the annual maximum temperature is similar to that of July with slight difference in values.

Figure 6.24: Mean Temperature in January from HadCM3Q13 (2030-2079 Period)

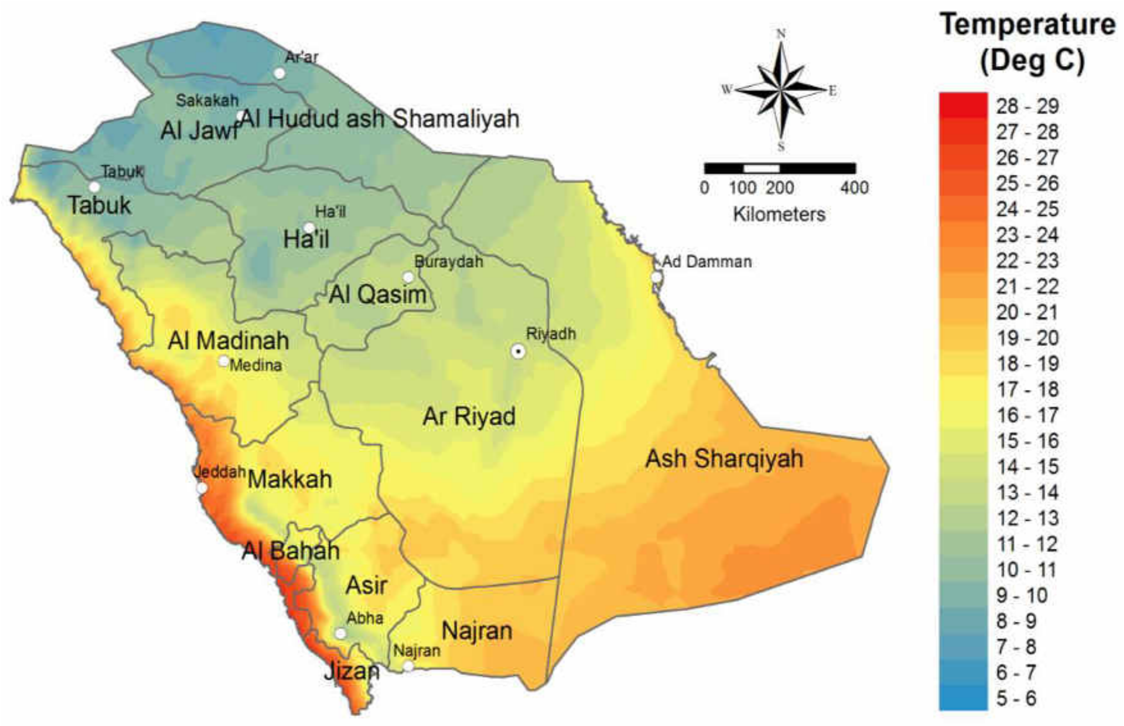
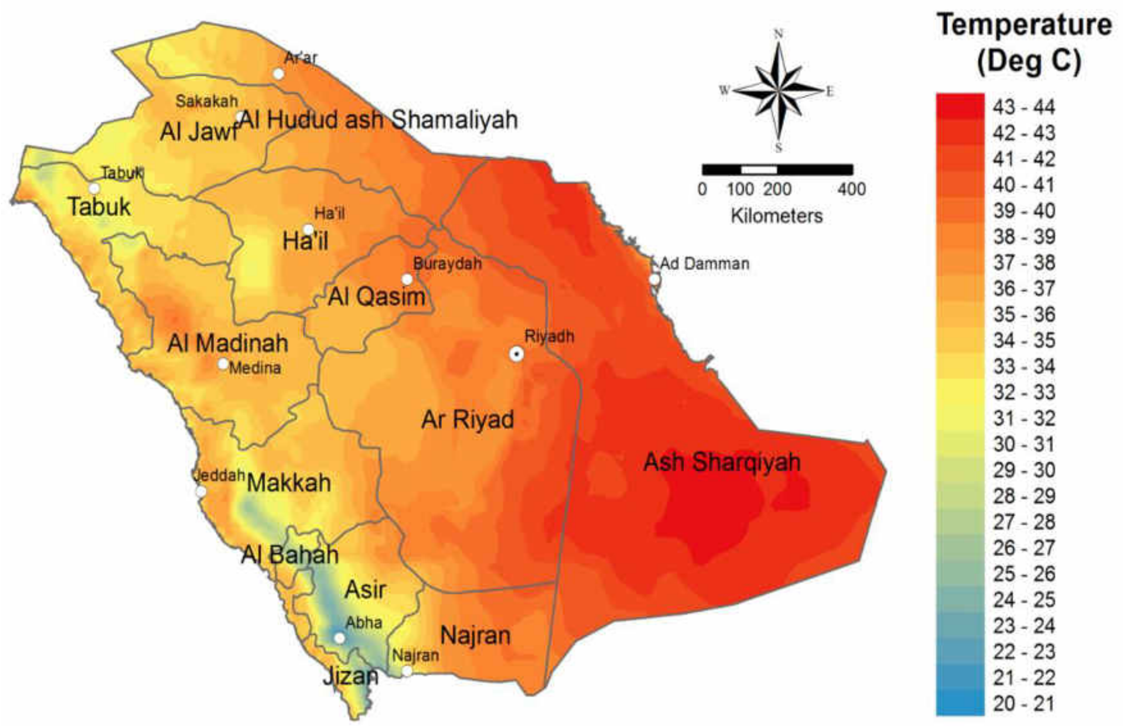


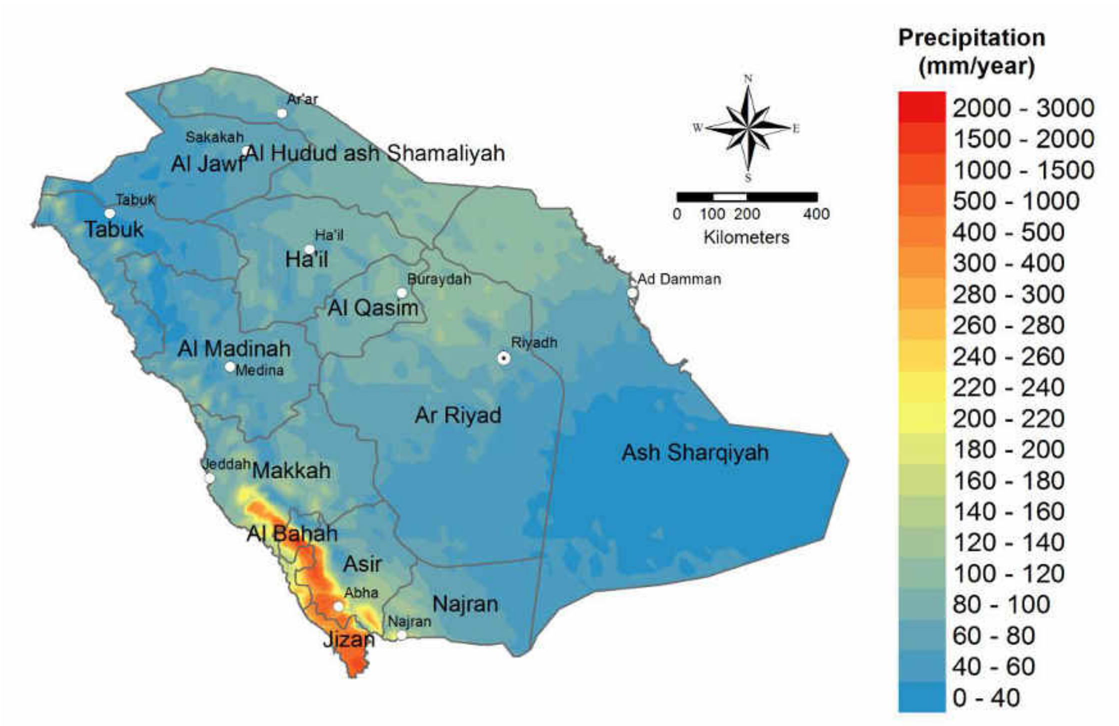
Figure 6.25: Mean Temperature in July from HadCM3Q13 (2030-2079 Period)



(b) Precipitation:

The spatial distribution of the projected Annual total precipitation by HadCM3Q13 is shown in Figure 6.26.

Figure 6.26: Annual Total Precipitation from HadCM3Q13 (2030-2079 period)



The least precipitation (less than 45 mm/yr) is projected over the Empty Quarter and the northwestern province around Tabuk. The higher amount of rainfall (morethan150mm/yr) is confined to the Jazan-Najran region and Asir Mountains.

Table 6.12 lists the projected total annual precipitation using HadCM3Q13 and HadCM3Q14 models in comparison with those of the baseline period.

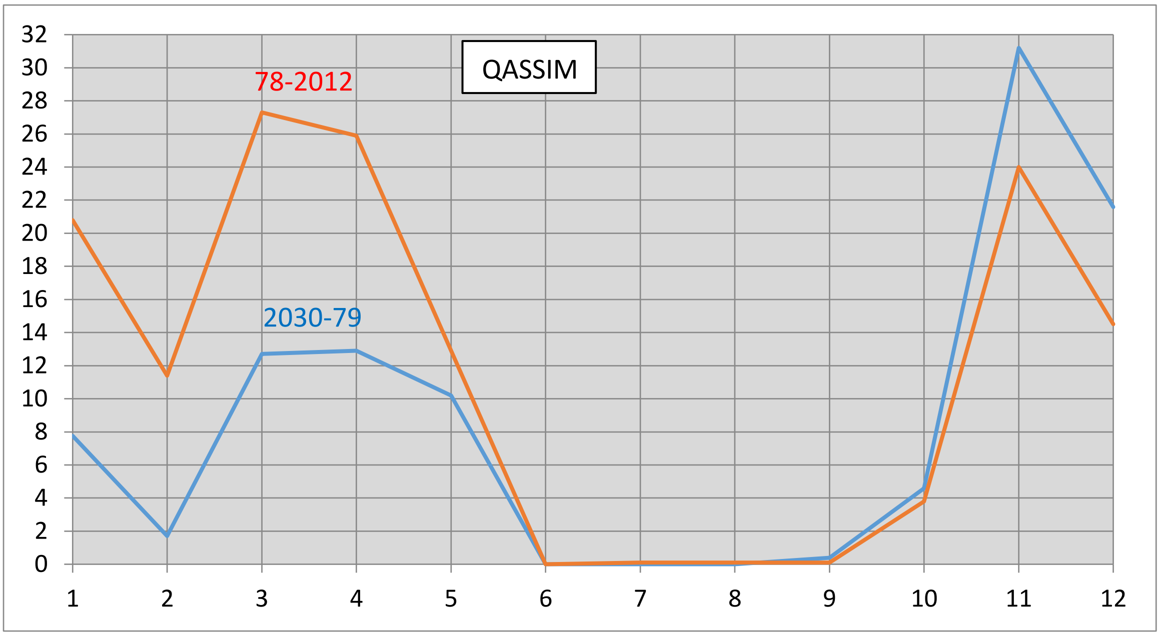
Table 6.12: Total Annual Precipitation Comparison: Q13, Q14 and GAMEP Corresponding Data

Station name	Mean Annual Rainfall(mm)		
Riyadh	110.4	91.8	154.1
Jeddah	55.2	38.1	65.7
Dhahran	87.6	72.4	122.2
Qassim	134.4	102.8	132.8
Qaisumah	117.6	100.9	139.8
Tabuk	30.0	37.1	42.0
Arar	55.2	69.9	77.5
Khamis Mushayt	187.2	177.8	392.8
Sharourah	64.1	58.4	120.4
Period & ID	1978-2014	2030-2079	2030-2079
	Actual	**sadaa Q13**	**sacaa Q14**

According to Q13 model, except the predicted increase in rainfall at Tabuk and Arar of about 25%, there will be a general decrease in rainfall ranging from a lower amount of 5% in Khamis Mushayt up to about 31% in Jeddah and 23% in Qassim. Model Q14 in the other hand, predicted an increase rather than decrease in all stations except in Qassim which shows minor decrease of 1.2%. The highest increase of about 100% is predicted in Khamis Mushayt and Sharourah. Results of these two models can be combined to span the range of change in predicted rainfall over the 2030-2079 period.

The projected total monthly precipitation for the nine stations is shown in Table 6.12 in comparison with their actual counterparts of the baseline period. The general outcome in this comparison is that the model projected reduction in the monthly average rainfall during the first four months of the year in most of the selected stations, in contrast to the last three months when an increase of the rain amount is projected in these stations. An example of single station comparison is shown in Figure 6.27 for Qassim.

Figure 6.27 Example of Monthly Total Precipitation Comparison for Single Station.

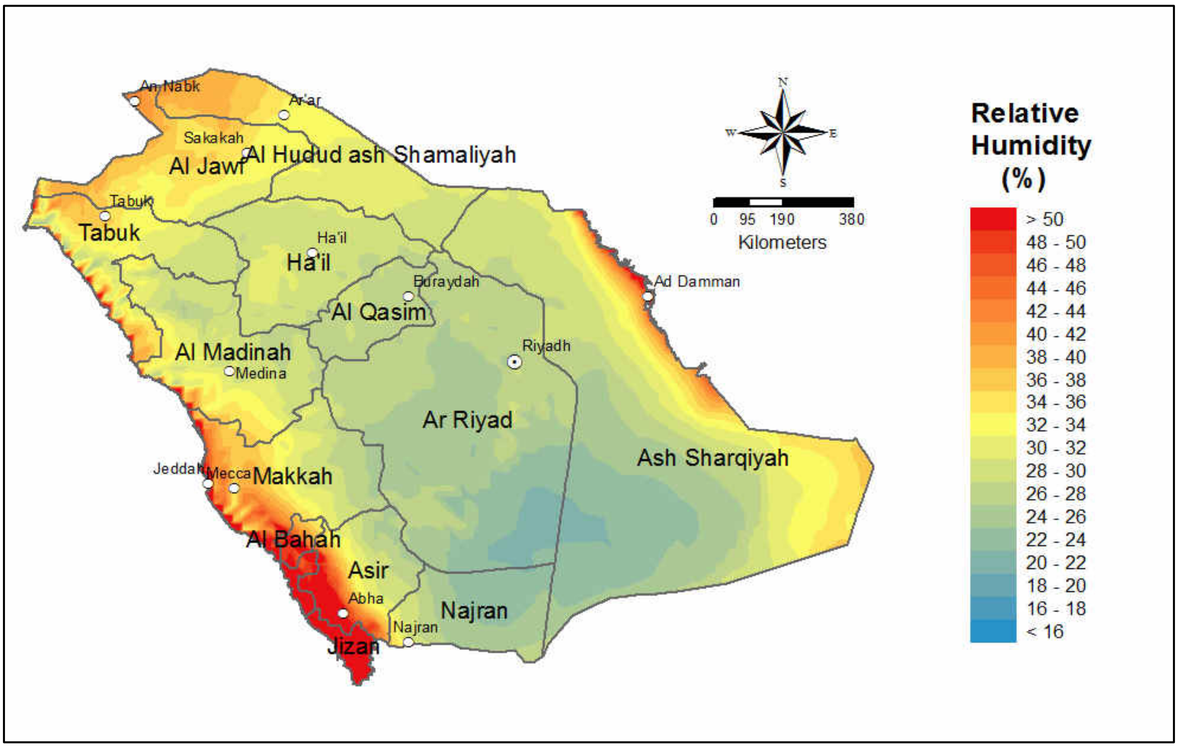


It shows that the first four months of the year will experience a significant decrease (about 13mm/month) in the projected rainfall amounts. On the other hand, there will be an appreciable increase in November and December rain (about 7mm/month). No summer rain is projected.

(c) Humidity

The spatial distribution of the projected Annual mean relative humidity by HadCM3Q13 is shown in Figure 6.28

Figure 6.28 Annual Mean Relative Humidity from HadCM3Q13 (2030-2079 Period)



The low humidity values are found in general over the southern and central provinces, while the high values appear along the coasts of the Arabian Gulf and the Red Sea but with the highest values are extending from Jazan northward to Jeddah.

Table 6.13 lists the projected mean annual relative humidity as obtained from HadCM3Q13 model run in comparison with those of the baseline period.

Table 6.13 Comparison of Relative Humidity of the Q13 run and GAMEP corresponding Data

Station Name	Mean Annual	R. H. (%)
Riyadh	27	26
Jeddah	60	81
Dhahran	53	45
Qassim	31	28
Qaisumah	32	30
Tabuk	33	38
Arar	38	33
Khamis Mushayt	51	50
Sharourah	28	26
Period & ID	1978-2013	2030-2079
	Actual	**sadaa Q13**

All stations will face reduction in air humidity over the assumed period ranging from a maximum of 8% in Dhahran to 1% in Riyadh and Khamis Mushayt except Tabuk in the northwest of the country. The exceptionally high increase in Jeddah value is a result of the averaging process over the grid box containing Jeddah. It seems that most of the involved grids are located over the sea.

The model projected reduction in the monthly average R.H. during the first ten months of the year in most of the selected stations. The annual increase in humidity in Tabuk and Jeddah is seen to be a reflection to the increase in almost all months. In contrast to this general trend, an increase in Relative Humidity is projected over the last two months in all the nine stations.

6.4 Conclusion and Recommendations:

In order to obtain more reliable model/models for producing future climate change scenarios, the issue of uncertainty in climate modeling has been addressed in this report. Sub-ensemble of eight GCMs (five Perturbed-Physics Ensemble “PPE” and three members from the Multi-Model Ensemble “MME”) were recommended by Hadley Center to be examined for their performance in driving the RCM model (précis-2) over Saudi Arabia. The assessments have been carried out by testing the capability of these models to reproduce a set of outstanding sustainable synoptic-climatological features found in the available data records of the country over the last 4-5 decades. Thorough analyses of the testing results have led to the conclusion that the top rated models are HadGM3 Q13 and HadGM3 Q14. These two models have simulated successfully the outstanding features and hence, adopted to produce the expected future climate scenarios for the Kingdom of Saudi Arabia with less uncertainty.

The output data and information from the HadGM3 Q13 and HadGM3 Q14 will be stored in special data base and made available for the other TNC scientific teams and investigators upon their specific requests (location, period, spatial and temporal resolution etc.).

References:

1 Stephenson DB. (2008) Chapter 1: Definition, diagnosis and origin of extreme weather and climate events, CLIMATE EXTREMES AND SOCIETY, Cambridge, UK, Cambridge University Press, 11-23.

2 Australian Research Council, Climate System Science (2015), what is Heat Wave?

3 First National Communication Report of the Kingdom of Saudi Arabia (2005)

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5 McSweeney C. et al, (2012) Selecting Ensemble Members to Provide Regional Climate Change Information, Journal of Climate, October 2012.

Vulnerability Assessment and Adaptation Measures

SECTION – 7

Impacts of Climate Change on Water Resources

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Section 7: Impacts of Climate Change on Water Resources

7.1 Introduction

The Kingdom of Saudi Arabia is located in an arid region (latitude: 16.4°N–32.2°N; longitude: 34.6°E–55.7° E) which has an average annual rainfall of less than 150 mm (Abderrahman, 2001). It has an area of approximately 2.15×10^6 km^2 and an estimated population of about 30 million in 2013. The maximum summer temperature often exceeds 45°C, the relative humidity is usually low except in coastal regions and the skies are clear most of the time. High temperatures and low precipitation as well as a high degree of variability of these factors increase evapotranspiration, reduce soil moisture and erode the soil by weathering. These conditions have a negative impact on agriculture and water resources.

The Kingdom's population has increased from 6.9 million in 1972 to 29.9 million in 2013. (Population & Housing Census, 2013). This population growth has been coupled with increasing water consumption in the agricultural, domestic and industrial sectors. As a result, the Kingdom is experiencing an extreme water shortage condition (Abderrahman, 2006; Vörösmarty et al., 2000; Ukayli and Husain, 1987).

The Kingdom is characterized by a low annual rainfall and is without perennial rivers. Past studies on water demand and water resources indicate that a rapid population growth has exerted tremendous pressure on existing water resources. This stress has been further compounded by agricultural and industrial development, as well as by the rising living standards (Zaharani, Al-Shayaa and Baig, 2011). In KSA, renewable water resources per capita are dropping at an annual rate of 2%. Its per capita renewable water share decreased from 281 m^3 in 2005 to 240 m^3 in 2010, which is even less than 25% of the global average (Water Sector of Saudi Arabia, 2010). By 2025, it will further reduce to 105 m^3 per person per year (Husain and Danish, 2013).

The revenue from crude oil exports in Saudi Arabia is reported to have been approximately US$1,034 billion between 1972 and 2001. This has accelerated development and improvement in the living standards (SAMA, 2002; Elhadj, 2004). The population increased from 6.9 to 21 million during these 29 years. Water use has increased significantly in the past 20 years. A steady increase in water demand from 1997 to 2005 was observed in this study. The Kingdom's annual water demand of 20,740 MCM in 2000 and 22,480 MCM in 2005 indicates an average increase of 1.7% per year (Shareef et al., 2005; Chowdhury and Champagne, 2006). At this rate of increase, water demands for 2080 are estimated to be 93,010 MCM and approximately 5,250 billion cubic meters (BCM) will be needed in Saudi Arabia to meet the demands through 2010 to 2100, while the total estimated current reserves (non-renewable and renewable groundwater sources) and future contributions through recharges and surface-water sources will be approximately 2,700 BCM (Earth Trends, 2003). However, these estimates of water availability are also associated with a high degree of uncertainty and it is unlikely that all of the reserved water from non-renewable and renewable groundwater sources will be extractable.

Extreme heat and aridity are characteristic of most parts of Saudi Arabia. It is one of the few places in the world where summer temperatures above 50°C (122°F) have been recorded, with

51.1°C (124°F) being the highest temperature ever recorded in Saudi Arabia, at Dhahran, in 1956. In winter, frost or snow can occur in the interior and on the higher mountains, although this occurs only once or twice in a decade. The lowest recorded temperature is -12.0°C (10.4°F), at Turaif. The average winter temperature ranges from 8° to 20°C (47° to 68°F) in January in interior cities such as Riyadh and 19° to 29°C (66° to 83°F) in Jeddah, on the Red Sea coast. The average summer temperature range (in July) is 27° to 43°C (81° to 109°F) in Riyadh and 27° to 38°C (80°F to 100°F) in Jeddah. Nighttime temperatures in the central deserts can be chilly even in summer, as the sand gives up daytime heat rapidly once the sun has set. Annual precipitation is usually sparse (up to 100 mm or 4 inches in most regions), although sudden downpours can lead to violent flash floods in wadis. The annual rainfall in Riyadh averages 100 mm (4 inches) and falls almost exclusively between January and May; the average in Jeddah is 54 mm (2.1 inches) and occurs between November and January.

The main objective of this study is to assess changes in water supply and demand and in the hydrological cycles due to climate change and to recommend adaptation measures. To accomplish this objective, the following tasks are proposed:

- Assess water quality and quantity likely to be affected in KSA by global warming by developing projection models.
- Study the changes in the hydrological cycles due to global warming which will impact the human health and ecosystems due to drought, desertification, temperature rise and humidity changes.
- Introduce multi-criteria decision-making tools for sustainable water resource planning by integrating conservation measures, wastewater treatment and use and aquifer recharge.
- Assess KSA's overall water situation and develop a decision support system for integrated water resource management through stakeholder participation.

This report includes a detailed compilation of data on water supply and demand in the Kingdom. It also describes changes in hydrologic cycles due to global climate changes on water quality and quantity. An integrated water resource management plan, including reclaimed wastewater, is introduced and various multi-criteria decision-making tools and techniques are discussed.

7.2 Water Resources in Saudi Arabia

Water resources in the Kingdom can be classified as surface water, groundwater, desalinated sea water and reclaimed wastewater. Conventional water resources, including groundwater and surface water are the major sources of water supply, while non-conventional water resources, such as treated wastewater and desalinated sea water, contribute only a small percentage of the total supply. Groundwater resources have been used extensively in the last three decades to support its comprehensive agricultural, industrial and socio-economic development (Husain and Danish, 2013; Ouda, 2013).

7.2.1 Surface Water

In the Kingdom of Saudi Arabia, precipitation is extremely low and infrequent and varies significantly from year to year. This low rainfall has resulted in limited renewable surface-water resources. In the north, the average annual rainfall is below 150 mm/year, while in the south an average of approximately 500 mm/year annual rainfall has been recorded. Surface-water resources are scarce except in the mountainous area in the southwest, where rainfall is relatively high and regular and runoff occurs mainly in the form of intermittent flash floods. The surface runoff in the western region is approximately 60% of the country's total runoff (AQUASTAT Survey-2008, 2009).

A small fraction of the surface runoff percolates through the sedimentary layers in the valleys and recharges the groundwater, while most is lost through evaporation. Evaporation rates vary and depend mainly on the seasons and the regions: they are lower in winter (2.5 mm/day) and higher in summer (17 mm/day). These values are lower in the coastal areas (2,500 mm/yr) but higher in the central part of the desert (4,500 mm/yr) (Supporting Documents for King Hassan II Great World Water Prize 2012, 2012). Saudi Arabia's annual runoff has been estimated to be 2.2 BCM, most of which infiltrates and recharges shallow aquifers such as Khuf, Tuwail, Aruma, Jauf, Sakaka and Jilh in basalt and alluvial areas (Abderrahman, 2000a).

To facilitate the storage of surface runoff water and to prevent flash floods, several dams have been constructed by the Ministry of Water and Electricity (MOWE). These dams mainly store runoff water, reduce surface water evaporation and increase infiltration to recharge aquifers (Tuinhof and Heederik, 2002). It is estimated that approximately 1.4 BCM of surface runoff are stored annually through a total of 302 dams across the Kingdom (The Ninth Development Plan [2010–2014], 2010). Among those dams, 275 are used for groundwater recharge and control, recharging approximately 992.7 MCM water per year. A total of 25 dams store 303.5 MCM water per year annually for the drinking-water supply, while two dams store 51.5 MCM/year for agricultural irrigation (Chowdhury and Al-Zahrani, 2013).

7.2.2 Groundwater

Groundwater, the most reliable source of water in the Kingdom, provides over 84% of its water supply. Groundwater resources exist in shallow alluvial and deep rock aquifers. The shallow alluvial aquifers are the main sources of renewable groundwater resources and are located mostly in the western and southwestern parts of the Kingdom. These renewable groundwater resources are stored in basalt layers of varying thickness and width, usually under major valleys within the coastal mountains. Groundwater in these unconfined alluvial aquifers can be replenished more frequently and rapidly than in the deep sedimentary, mostly confined, aquifers. Those renewable groundwater resources are utilized for domestic and agriculture purposes and sometimes for a drinking-water supply in rural areas. It is worth mentioning that these aquifers are sensitive to human activities especially when they are located in the vicinity of major cities and towns with high populations (Ouda, 2013). The aquifer is estimated to store 84 BCM with an average annual recharge of 1,196 MCM. However, those estimates were based mostly on investigations carried out over 15 years ago and will be updated with more recent studies (Supporting Documents for King Hassan II Great World Water Prize 2012, 2012). Groundwater recharge is important for sustainable groundwater management and planning, especially for Saudi Arabia's water-scare regions.

The main source of water for Saudi Arabia is non-renewable fossil groundwater in sedimentary aquifers. This groundwater is estimated to have been formed approximately 10,000 to 32,000 years ago, based on isotopic analyses (Water Atlas of Saudi Arabia, 1984). Aquifer water is generally brackish and confined in sand and limestone formations of a thickness of approximately 300 m at depths from 150 m to 1500 m (Chowdhury and Al-Zahrani, 2013).

Total dissolved solids in the water vary from 300 ppm to more than 10,000 ppm. Sedimentary aquifers can be classified as either primary or secondary, based on their areal extent, groundwater volume, water quality and developmental potential. The principal aquifers include Saq, Wajid, Tabuk, Minjur, Dhruma, Biyadh, Wasia, Dammam, Umm Er Radhuma and Neogene (Ukayli and Husain, 1987; Chowdhury and Al-Zahrani, 2013). Secondary aquifers include Al-Jauf, Al-Khuff, Al-Jilh, the upper Jurassic, Sakaka, the lower Cretaceous, Aruma, Basalts and Wadi Sediments (Ouda 2013).

It is estimated that the approximate groundwater reserve to a depth of 300 m below ground surface is 2,185 BCM, with a total recharge of 2,762 MCM (Water Sector of Saudi Arabia, 2010). The Ministry of Planning estimated that approximately 141.1 BCM of groundwater reserve was used from these principal aquifers from 1984 to 1996, which resulted in significant drops in the water level (Proceedings of the Second Expert Consultation on National Water Reform in the Near East, Cairo, Egypt, 1997). It is estimated that approximately 28.6 BCM and 15.4 BCM of non-renewable groundwater were used in 1992 and 1997, respectively (Abderrahman, 2000b). MOEP (2010) reported in its Ninth Development Plan that approximately 13.5 and 11.6 BCM of non-renewable groundwater resources were used in 2004 and 2009. Recent studies indicated that water demand in the Kingdom exceeded the sustainable water resources yield and the resulting gap is bridged through groundwater depletion (Chowdhury and Al-Zahrani, 2013; Ouda, 2013; Zaharani et al., 2011).

7.2.3 Desalinated Water

Desalination plants convert brackish sea water from the Arabian Gulf coast and the Red Sea coast into potable water by applying mainly Multistage Flash Systems (MSF) and Reverse Osmosis (RO) techniques. Large desalination plants have been constructed on the Gulf and Red Sea coasts in the last few decades to satisfy the Kingdom's growing need for potable water. It is estimated that 70% of the required drinking water as well as 5% of the electricity demands in the Kingdom are met by desalination plants ("Water and National Strength in Saudi Arabia," 2011).

Saudi Arabia is the largest producer of desalinated water, accounting for about 30% of the global capacity. Since the 1970s, more than US$25 billion have been invested in desalination plants and 2,500 miles of pipeline to convey the desalinated water from the coast to various coastal and inland cities in the Kingdom. According to a MOWE report (2012), 30 desalination plants are situated on the western and eastern coasts, of which 24 are on the Red Sea and six on the Arabian Gulf coast (Chowdhury and Al-Zahrani, 2013). The Saline Water Conversion Corporation (SWCC), a government corporation, is responsible for desalinating sea water. To meet the growing demand, two major plants are being constructed in Jeddah and Ras AlKhair and six plants are under study (Actual Water and Electicity Production, 2013). Desalinated water production is expected to reach approximately 1,921 MCM in 2015 and more than 2,144 MCM in 2020.

7.2.4 Reclaimed Wastewater

In Saudi Arabia, a small fraction of wastewater is reclaimed for agricultural, landscaping and industrial use. This wastewater is treated in around 70 sewage treatment plants (Chowdhury and Al-Zahrani, 2013). Wastewater collection and treatment systems currently cover 42% of the Kingdom's urban area and is expected to increase to 60% by 2020 (Ouda, 2013). About

1,460 MCM of wastewater is generated, of which about 671 MCM (46%) is collected and treated. This treated wastewater has been extensively used in many cities (e.g., Riyadh, Jeddah and Jubail) for municipal park irrigation and urban area landscaping which is estimated to be 240 MCM. Septic tanks and cesspits are used for wastewater disposal in areas without wastewater infrastructures, causing the shallow water table to rise and possible pollution of the groundwater.

Sustainable water resources planning (SWRP) has become a crucial tool in the development of areas where renewable freshwater resources are highly constrained (Husain, 2009; Husain and Khalil, 2013). To meet an increasing demand for water, many countries are developing alternative sources including desalination as a potable source and treated wastewater effluent for landscaping, restricted irrigation and aquifer recharge (Ukayli and Husain, 1988; Husain and Ahmed, 1997). Under climate-change conditions, even temperate regions face certain risks of droughts and occasional extreme flooding causes serious damage. To address these major challenges, the projection of both the whole hydrologic regime with high resolution and the long-term environmental consequences resulting from changes in that regime are needed (Husain and Danish, 2012).

7.3 Assessment of Climate Change Impacts on Water Resources

7.3.1 Description of Model

The effects of climate change in Saudi Arabia were studied using PRECIS, which adds high-resolution information to large-scale projections of a global climate model and generates more accurate climate scenarios for Saudi Arabia. In the Second National Communication Report, a PRECIS model was used to describe past (1960–1990) and future (2070–2100) climate scenarios on a global scale, including changes in wind speed, temperature, relative humidity and precipitation. In this report, a PRECIS model has also been used to project the same parameters, in addition to the mean sea level pressure from 2030 to 2080 in a regional scale setting.

Global warming is anticipated to increase crop evapotranspiration rates and crop water requirements and reduce water recharge to aquifers. The reduction of groundwater recharge in the Kingdom will result in a reduction of groundwater resources and a deterioration of water quality and will affect communities, agriculture and the industries that rely on groundwater supplies. In addition, an increase in temperature and evapotranspiration will further lead to an increased water demand for domestic, industrial and agricultural uses (Second National Communication, Kingdom of Saudi Arabia, 2011).

Although it is difficult to project evapotranspiration perfectly under variable climatic conditions due to simplifications in formulation and errors in boundary conditions, the FAO's Expert Consultation Group agreed to use the hypothetical reference definition of the FAO Penman-Monteith approach as the definition for grass reference evapotranspiration (ET_0) when deriving and expressing crop coefficients (Allen et al., 1998). The FAO Penman-Monteith approach is a close, simple representation of the physical and physiological factors governing the evapotranspiration process (Allen et al., 1998). In this approach, evapotranspiration is estimated as follows:

$$\lambda ET = \frac{\Delta(R_n - G) + \rho_a c_p \frac{(e_s - e_a)}{r_a}}{\Delta + \gamma\left(1 + \frac{r_s}{r_a}\right)} \quad (3.1)$$

where,

R_n = net radiation;
G = soil heat flux;
e_s = vapor pressure at saturation;
e_a = actual vapor pressure;
ρ_a = mean air density at constant pressure;
c_p = specific heat of the air;
r_s = bulk surface resistance;
r_a = aerodynamic resistance;
γ = psychrometric constant;
Δ = slope of the saturation vapor pressure temperature relationship;
ET = evapotranspiration; and
λ = latent heat of vaporization.

The aerodynamic resistance is estimated using the following equation:

$$r_a = \frac{\ln\left(\frac{z_m - d}{z_{om}}\right)\ln\left(\frac{z_h - d}{z_{oh}}\right)}{k^2 u_z} \quad (3.2)$$

where,

r_a = aerodynamic resistance (s/m);
z_m = height of wind measurements (m), (~2 m);
z_h = height of humidity measurements (m), (~2 m);
d = zero plane displacement height (m), estimated as 0.667 h, where h = crop height (~0.12 m);
z_{om} = roughness length governing momentum transfer (m), estimated as 0.123 h;
z_{oh} = roughness length governing transfer of heat and vapor (m), estimated as $0.1z_{om}$;
k = von Karman’s constant, 0.41 (-); and
u_z = wind speed at height z (m/s).

Substituting these values, Equation 3.2 can be simplified to:

$$r_a = \frac{208}{u_2} \quad (3.3)$$

where u_2 is the wind speed (m/s) at 2 m.

The estimation of bulk surface resistance can be performed as:

$$r_s = \frac{r_1}{LAI_{active}} \quad (3.4)$$

where

r_s = bulk surface resistance (s/m)
r_l = bulk stomatal resistance of the well-illuminated leaf (s/m), which is approximately 100 s/m under well-watered conditions
I_{active} = active (sunlit) leaf area index (m^2(leaf area)/m^2(soil surface)), which is approx. 0.5LAI
LAI = 24 h, where h = height of grass (~ 0.12 m)

Substituting these values, r_s can be estimated as:

$$r_s \cong 70 \text{ s/m} \tag{3.5}$$

Latent heat of vaporization (λ) is the energy required to change a unit mass of water from liquid to water vapor in a constant pressure and constant temperature process. It is estimated to be approximately 2.45 MJ/kg.

The psychrometric constant (γ) is estimated as:

$$\gamma = \frac{c_p P}{\varepsilon \lambda} = 0.665 \times 10^{-3} P \tag{3.6}$$

where,

γ = psychrometric constant (kPa/°C);
P = atmospheric pressure (kPa);
λ = latent heat of vaporization, 2.45 (MJ/kg);
c_p = specific heat at constant pressure, 1.013×10^{-3} (MJ/kg/°C); and
ε = ratio molecular weight of water vapor/dry air = 0.622.

The mean air density at constant pressure (ρ_a) can be estimated as:

$$\rho_a = \frac{P}{T_{kv} R} \tag{3.7}$$

where,

ρ_a = mean air density at constant pressure (kg/m^3);
T_{kv} = virtual temperature, estimated as T_{kv}= 1.01 (T+273); and
R = specific gas constant = 0.287 kJ/kg/K.

Equation 3.1 was simplified through substitution of the parameters (Equations 3.3–3.7) as:

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34 u_2)} \tag{3.8}$$

where,

ET_o = reference evapotranspiration (mm/day);
Rn = net radiation at the crop surface ($MJ/m^2/day$);
G = soil heat flux density ($MJ/m^2/day$);
T = mean daily air temperature at 2 m height (°C);
u_2 = wind speed at 2 m height (m/s);
e_s = saturation vapor pressure (kPa);
e_a = actual vapor pressure (kPa);
Δ = slope vapor pressure curve (kPa/°C); and
γ = psychrometric constant (kPa/°C).

Adaptation to the changing water availability and demand due to climate change has been considered an important part of water resource management. Historically, water management has mainly concentrated on meeting the increasing water demand. However, conventional assumptions such as a constant water resource base and stationary hydrology are no longer valid due to the impact of climate change (Parry et al., 2007). Therefore, there is an increasing need to improve the projection of the potential impact of climate change on water quantity and quality in order to identify appropriate adaptation strategies.

To construct more reliable scenario projections on water resources in the Kingdom, more research is needed to develop precise and reliable climate and hydrological forecasting tools and an improved coupling between the projection models. Since uncertainties in future hydrological conditions due to climate change pose a challenge to water resource management, it is important to develop adaptation measures to the impact of climate change (Bates et al., 2008).

Trends in precipitation (i.e., the annual total precipitation in the past and the difference of annual total precipitation in the future), temperature, wind speed, relative humidity and mean sea level pressure across Saudi Arabia from 2030 to 2080 were analyzed. Changes in evapotranspiration for each of the 28,000 grids in Saudi Arabia were estimated using the FAO-approved Penman-Monteith approach. In addition, the information on key parameters (wind speed, relative humidity, temperature, evapotranspiration and precipitation) from the PRECIS Regional Climate Modeling System was also downscaled. Soil moisture data from the IPCC Data Distribution Centre show that there will be no soil moisture in any of the grids across the Kingdom in 2080, which means that, due to aridity, the soil surface will be perfectly dry and/or sandy/rocky for each grid.

The seasonal settings of the model are as follows:

1) Winter: December to February
2) Spring: March to May
3) Summer: June to August
4) Fall: September to November

7.3.2 Results and Analysis

Wind speed

The annual wind speeds for the first (2030) and the last (2080) years of simulation are shown in Figure 7.1. The difference between the annual values from the first and last years of simulation is plotted in Figure 7.2, with the corresponding trend values in Figure 7.3. The annual wind speeds are almost the same. The winds are relatively more evenly distributive in the fall and more varied in the winter. The strongest wind usually occurs in the coastal area and the southeast area of Ash Sharqiyah, especially in winter whereas the lowest wind usually occurs in Hail, Al Qassim and Jazan areas. Relative significant reductions occur in winter and spring from 2030 to 2080.

In winter, wind speed will decrease in the northeast and the Makkah regions by 0.5 m/s to 1 m/s and increase in some areas of Makkah, Asir, Al Madinah and Ash Sharqiyah by 0.1 m/s to 0.6 m/s. In spring, wind speed will increase throughout the southwest by 0.1 m/s to 0.5 m/s. In the northeast, wind speed will decrease from 0.1 m/s to 0.3 m/s respectively. A significant increase in wind speed will be observed in the northeast of Ash Sharqiyah in the fall (0.6 m/s to 0.9 m/s); a considerable decrease will be observed in Tabuk during the fall (0.6 m/s to 1.2 m/s).

The annual trend indicates little change in wind speed during 50 years. The most significant increasing trends occur in the southeast of Ash Sharqiyah during winter and the Makkah area during fall. The most significant decreasing trends occur in the north during fall, the central area and Makkah coastal area during summer, as well as the northeast during spring and winter. The trends of wind speed from 2030 to 2080 range from -0.7% to 0.7%.

Figure 7.1: Annual Wind Speeds in 2030 (Left) and 2080 (Right)

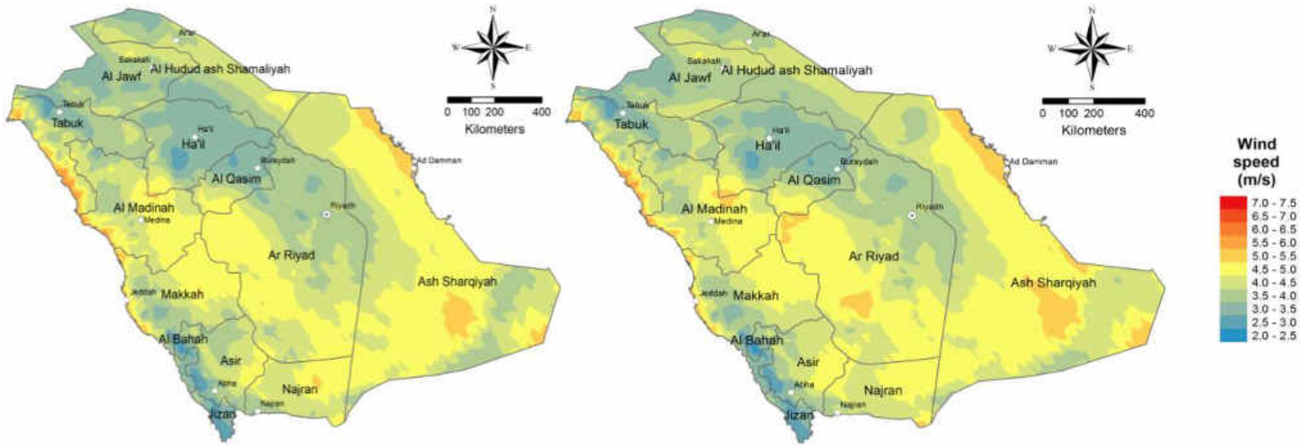


Figure 7.2: Difference of Annual Wind Speed from 2030 to 2080

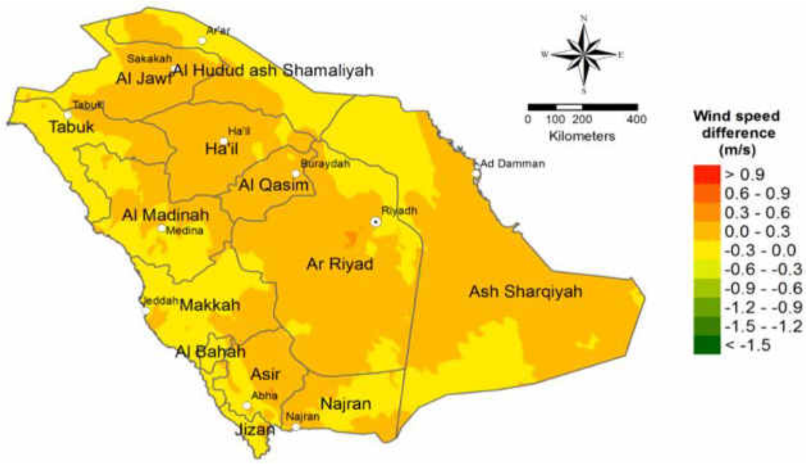
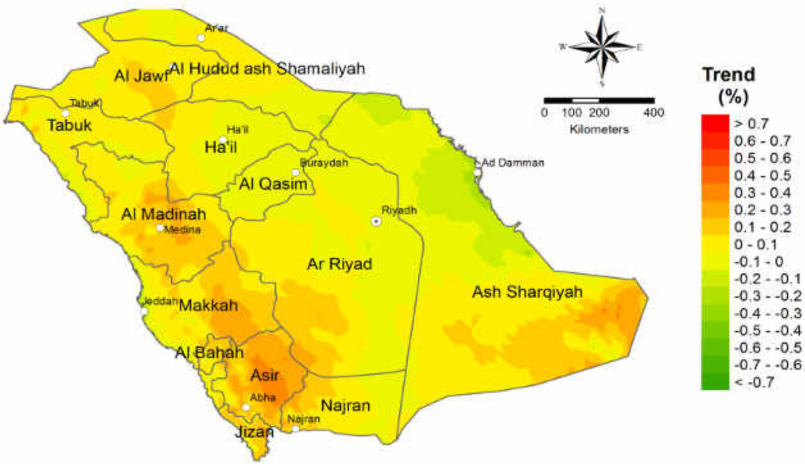


Figure 7.3: Trend of Annual Wind Speed from 2030 to 2080



Relative Humidity

The annual relative humidity for the first (2030) and the last (2080) years of simulation runs is shown in Figure 7.4 and the differences plotted in Figure 7.5. The corresponding trend values are presented in Figure 7.6. As shown in these plots, high relative humidity is observed in the coastal area and the northeast; the lowest is observed in the south-central part of the Kingdom. Comparing the relative humidity from 2030 to 2080, an overall increase is noticed in the entire Kingdom in winter and a decrease in spring. An increase in humidity is observed in the southwest and a decrease in the northeast. In the fall, most areas of the Kingdom, especially the Al Madinah, Hail and Al Jouf areas, experience a decrease in humidity; the Asir and Najran areas have a slight increase in relative humidity.

The relative humidity trend from 2030 to 2080 ranges seasonally from -12% to 18%. A significant increase occurs in Al Qassim, south Hail, north Ash Sharqiyah and Riyadh, Asir and Jazan during winter. In contrast, a 2–4% decrease was observed in Tabuk and Al Jouf. A significant increase occurs in the south (8–14%); a slight decrease occurs in the north (-2% to -5%) during spring.

Figure 7.4: Annual Relative Humidity in 2030 (Left) and 2080 (Right)

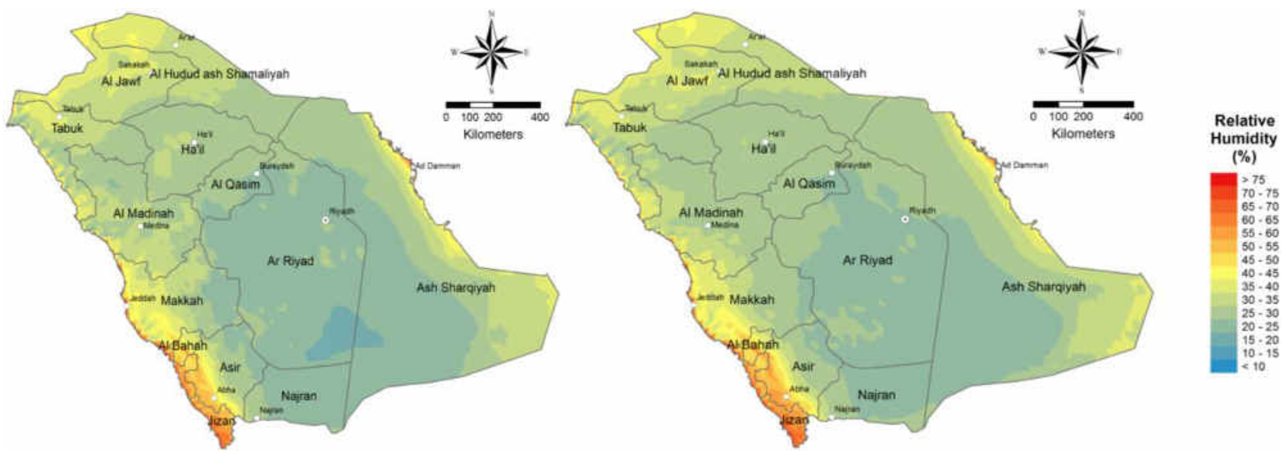


Figure 7.5: Difference of Annual Relative Humidity from 2030 to 2080

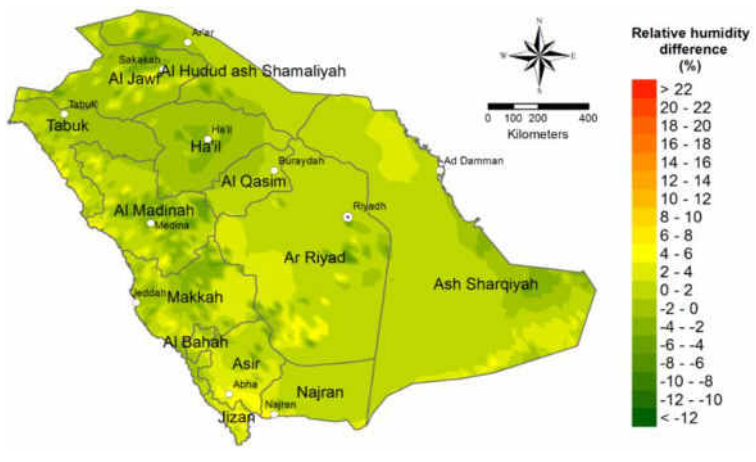
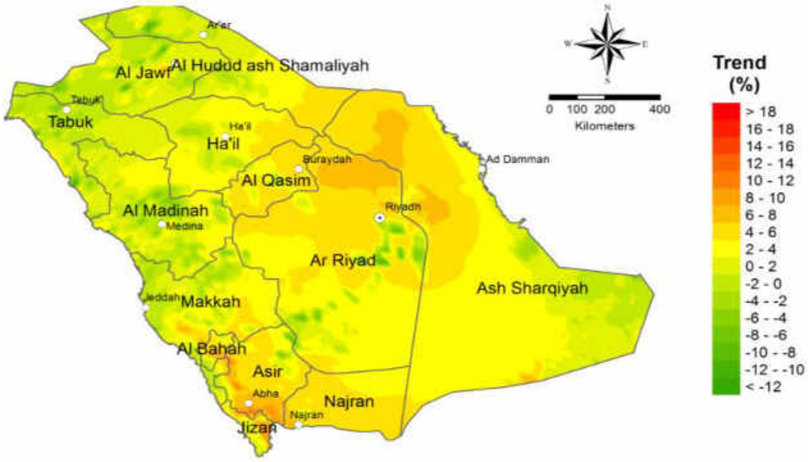


Figure 7.6: Trend of Annual Relative Humidity from 2030 to 2080



Precipitation

The annual precipitation for the first (2030) and the last (2080) years of simulation are shown in Figure 7.7. The difference between the annual values from the first and last year of simulation are listed in Figures 7.8, while the corresponding trend values are presented in Figures 7.9. In addition, the plots regarding the seasonal scenarios are listed in Appendix 7A. The total precipitation of the year is in a range of 2 – 879 mm in 2030 and 0.5 – 2275 mm in 2080. The highest precipitation appears in the southwest of the Kingdom. The second highest amount of precipitation is observed in the northeast area. The annual precipitation in most of the southeast and northwest areas are lower than 50 mm. Comparing the precipitation in the first and the last year of the simulation period, the annual total precipitation have somehow increase from 2030 to 2080, especially in the southwest corner of the Kingdom. Slight increase is observed in the most parts of the Kingdom by 10 – 20 mm from 2030 to 2080. Significant increases up to 1000 mm are observed in the southwest area, while decreases up to 100 mm are also observed in some central areas.

There is almost no precipitation in the Kingdom except the southwest area (100 – 200 mm) in winter season in 2030. Some precipitations appear in the central and southwest area of the Kingdom in spring, however, only 50 – 100 mm. Precipitation with higher than 200 mm is only observed in the southeast corner of the Kingdom in summer in 2030, while the amount and coverage is increased in 2080. The precipitation in fall occurs in the southwest and northeast of the Kingdom.

By comparing the precipitation in 2030 and 2080, the precipitation is increase across the Kingdom during winter (30 - 70 mm in the east coastal area and up to 1000 mm in the southwest area), slight decrease is observed in the northwest and southeast areas by about 1 - 10 mm. In spring, some areas in the southwest coastal, central, and southeast areas have slight increase by about 50 mm, while some areas in the south part of Riyadh decrease by about 50 mm; the other areas do not have significant changes. The precipitation has relatively significant increase across the Kingdom in summer when compared with the other seasons, especially in the southwest area (more than 1000 mm). Most area have no change in precipitation during fall except some areas in northeast and southwest part of the Kingdom appearing slight increase, and the central Ha’il appearing slight decrease. The trends of the precipitation are significant varying across the Kingdom in annual periods (-50% to 60%). In Spring, significant increasing trends are observed in the south areas, while decrease trends are observed in the north area. In summer and fall, significant increase trends appear in the central areas while slight decrease is observed in the other areas.

Figure 7.7: Annual Total Precipitations in 2030 (Left) and 2080 (Right)

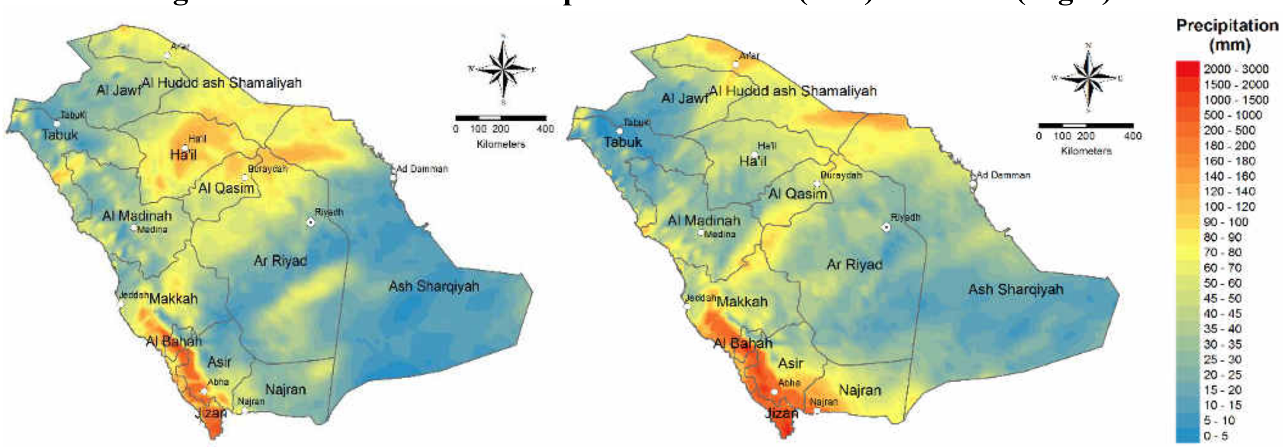


Figure 7.8: Difference of Annual Total Precipitation from 2030 to 2080

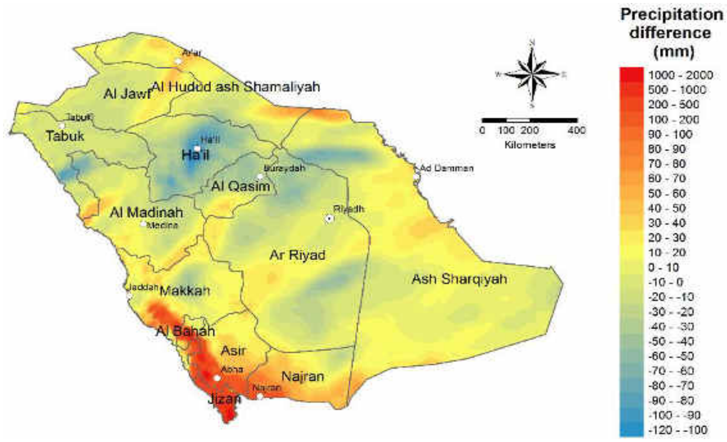
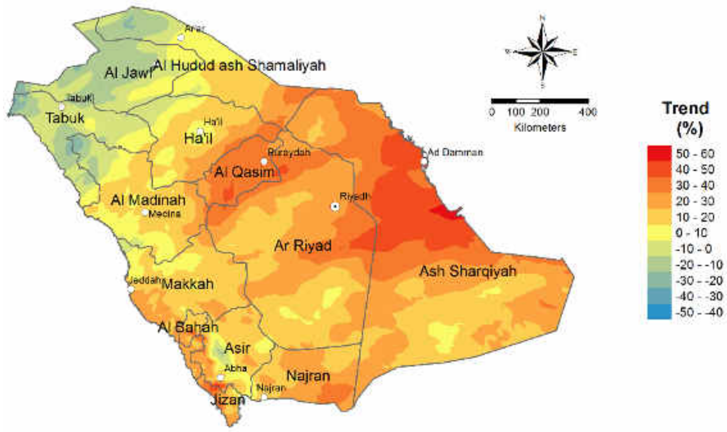


Figure 7.9: Trend of Annual Total Precipitation from 2030 to 2080



Temperature

The annual temperatures for the first (2030) and the last (2080) years of the simulation runs are presented in Figure 7.10. The difference between the annual values is plotted in Figure 7.11 and the corresponding trend values presented in Figure 7.12. Temperature distributions in 2030 and 2080 indicate that the temperature has a clear gradient across the Kingdom from southeast (highest) to northwest (lowest), except for the southeast corner, which usually has the lowest temperatures in the Kingdom. The temperature varies considerably in different seasons. Winter has a temperature range of 6°C to 26 °C; summer, 24°C to 42°C.

The change of temperature in 50 years' simulation is in the range of -0.6°C to 5°C. The most significant decrease appears in the northeast (up to -0.6°C) in winter and the most significant increase (up to 5°C) also occurs in the northeast during the fall. A significant increase is observed in the southwest during spring; the maximum decrease, in the eastern part of Ash Sharqiyah.

An increase in temperature is projected in most parts of the Kingdom during summer, except in the eastern part of Ash Sharqiyah. The temperature ranges from 0.8% to 5.4%. Such a positive trend is more significant in the southeast during winter and less significant in the northwest. The trend in the spring is the most significant, especially for the northwest and the southern coastal areas.

Figure 7.10: Annual Temperatures in 2030 (Left) and 2080 (Right)

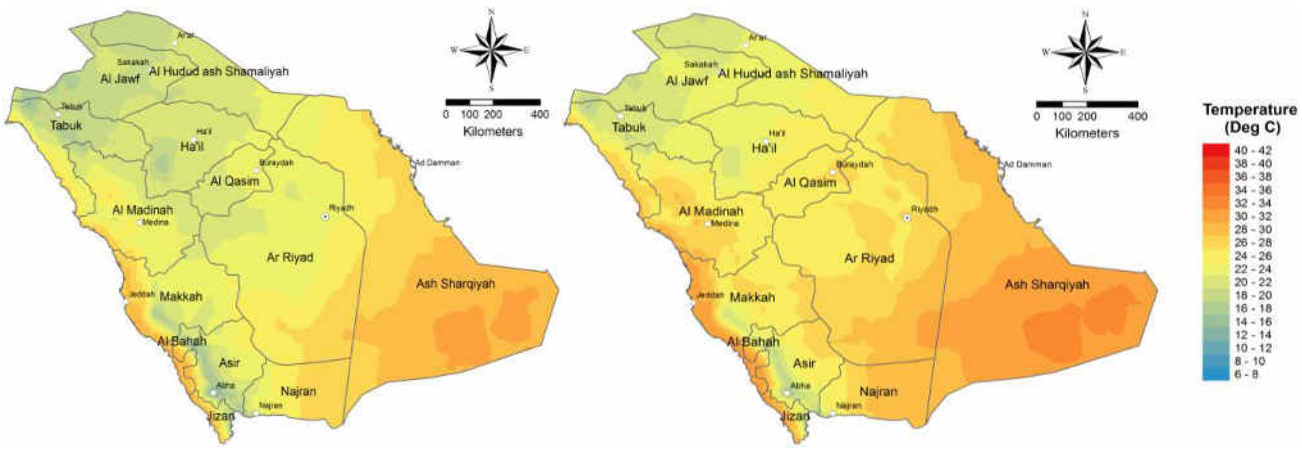


Figure 7.11: Difference of Annual Temperatures from 2030 to 2080

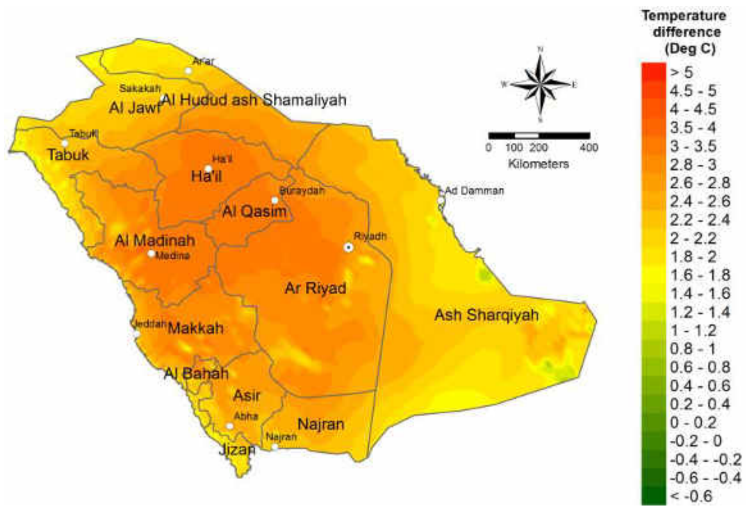
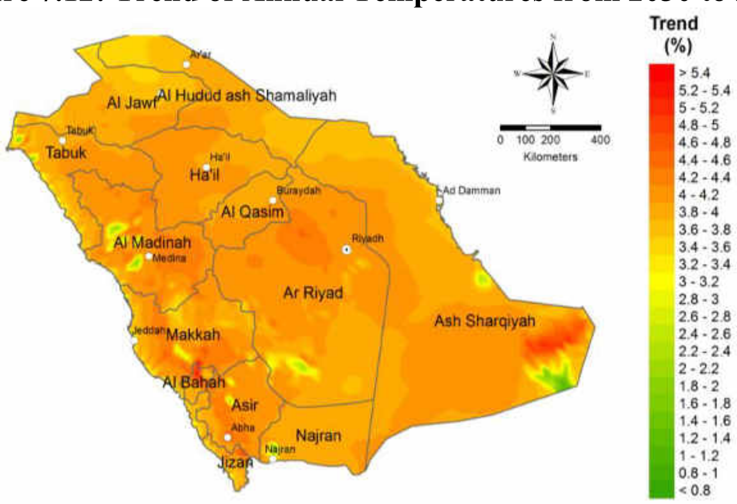


Figure 7.12: Trend of Annual Temperatures from 2030 to 2080



7.4 Changes in the Hydrological Cycle

7.4.1 The Hydrological Cycle in KSA

The hydrological cycle is intimately linked with changes in atmospheric temperature and radiation balance. Various components in the hydrological cycle and systems are affected by the global warming observed over the past decades, such as changes in precipitation patterns, intensity and extremes, increased atmospheric water vapor and evaporation and changes in soil moisture and runoff.

The robust correlations between temperature and precipitation observed in many regions provide evidence that processes controlling the hydrological cycle and global warming are closely related (Bates et al., 2008). Almazroui and his associates (2012) studied recent climate change in the Arabian Peninsula through an analysis of the rainfall and temperature in Saudi Arabia for the 1978 to 2009 period. This study showed a significant decreasing trend in the annual rainfall for the last half of the analysis period, with a relatively large inter-annual variability, while the maximum, mean and minimum temperatures increased significantly at a rate of 0.71ºC, 0.60ºC and 0.48ºC per decade, respectively. The lowest annual rainfall throughout the analysis period was observed in the southeastern region of the Arabian Peninsula and the highest rainfall over the southwest of the Peninsula. The temporal analysis of rainfall over Saudi Arabia indicates a large inter-annual variability for the study period. The observed rainfall for Saudi Arabia showed a linear decreasing trend of 6.2 mm per decade between 1978 and 2009 and a statistically significant decreasing trend of 47.8 mm per decade between 1994 and 2009. A comparison of the rainfall for 2000–2009 and 1980–1989 shows an increased rainfall in the southern part of the Peninsula and along the Red Sea coast and a decreasing trend in most parts of the Kingdom (Almazroui et al., 2012).

In Saudi Arabia, it is important to study the effects of global warming on irrigation water demand because this amounts up to 90% of the total water consumption (Abderrahman, 2000a). Irrigation water demand is determined initially by identifying the ET_0 an agro-climatic property that involves temperature, humidity, solar radiation and wind speed. A change in ET_0 reflects changes in other climate parameters, including temperature, radiation, humidity and wind speed. It directly affects crop water requirements and hydrological water balance. A recent study conducted by Elnesr and Alazba (2013) showed changes in ET_0 values with time throughout the Kingdom in order to quantify the future water demand. Historical daily ET_0 in Saudi Arabia was analyzed for 29 meteorological stations distributed over the Kingdom for the 1980–2008 period. A contour map was plotted for each month with a decreasing or increasing ET_0 trend.

The time series analysis of ET_0 revealed an overall increasing trend during the study period. Increasing ET_0 trends prevail in the northern and southwest areas along the longitudinal line of 45 degrees. Decreasing trends prevail in the northwest along the Red Sea and the southeast along the Arabian Gulf. The study concluded that an increase in ET_0 is likely to be affected by global warming or an increase in temperature in the Arabian Peninsula (Elnesr and Alazba, 2013). The increase in evapotranspiration and decline in precipitation in recent decades due to global warming intensifies the water problem in Saudi Arabia.

Groundwater flow in shallow aquifers is part of the hydrological cycle and is affected by climate change through a recharge process. In arid areas, evaporation usually exceeds the amount of rainfall. Therefore, groundwater recharge mainly occurs during high intensity rainfall events and is due to an accumulation of rainwater in low-lying areas, or percolation through cracks, fissures or channels (Vries and Simmers, 2002). A decrease in rainfall over Saudi Arabia and an increase in evapotranspiration due to global warming is envisaged to reduce net groundwater recharge and hence a reduction in the availability of groundwater resources.

7.4.2 Modelling of Hydrological Cycle

Changes in evapotranspiration (ET) across the Kingdom of Saudi Arabia from 2030 to 2080 have been estimated using grid wise climatic data of the Hadley model from IPCC data distribution centre in Equations 3.1 to 3.8 as discussed in Section 7.3.1. The seasonal and annual evapotranspiration for the first (2030) and last (2080) years of simulation is shown in Figure 7.13. The difference between the seasonal and annual values from these years is listed in Figure 7.14; the corresponding trend values are presented in Figure 7.15. The distribution of evapotranspiration temporally and spatially varies across the Kingdom. Evapotranspiration has a range of 3.5–15 mm/day during the modelling period. Usually, the highest evapotranspiration appears in the southeast, the lowest in the northwest and the southwest, during all four seasons. The highest evapotranspiration is observed in the east and central-southeast parts of the Kingdom, with up to 15 mm/day; the lowest is observed in winter, with as low as 3.5 mm/day.

Evapotranspiration varies from -1.2 to 2 mm/day from 2030 to 2080. A major decrease appears in winter across the Kingdom, with an up to -1.2 mm/day decrease in the northeast. Increasing evapotranspiration is dominant during the spring, except for the southeast part and the west coastline. The increase in evapotranspiration in the central area in this season can be up to 1.4 mm/day. Evapotranspiration would decrease in the south and increase in the north (especially the northeast) during summer. It significantly increases in the central and southeast parts of the Kingdom, but decreases in the northwest and the southwest. Overall for the year, evapotranspiration mainly increases across the Kingdom, especially in the central area. However, a decrease is also observed on the west coastline and in the southeast. Most areas in the north and the southwest have a relatively significant decreasing trend in winter (up to -0.6% near Buraydah); the southeast has a slight increase. The most significant increasing trend appears during the spring in the northwest, especially in the Al Madinah region (up to 2%). The southeast and the southwest corners have a slightly decreasing trend in this season. The trend distribution varies during the summer. A significant increase occurs in the northeast and the south-central area; the central part has a slightly decreasing trend. The situation in fall is almost in contrast to that in the summer. Overall for the year, a decreasing trend is observed in the central-east and the southwest; a relatively significantly increasing trend is observed in the central-west part of the Kingdom.

Figure 7.13: Annual Evapotranspiration in 2030 (Left) and 2080 (Right)

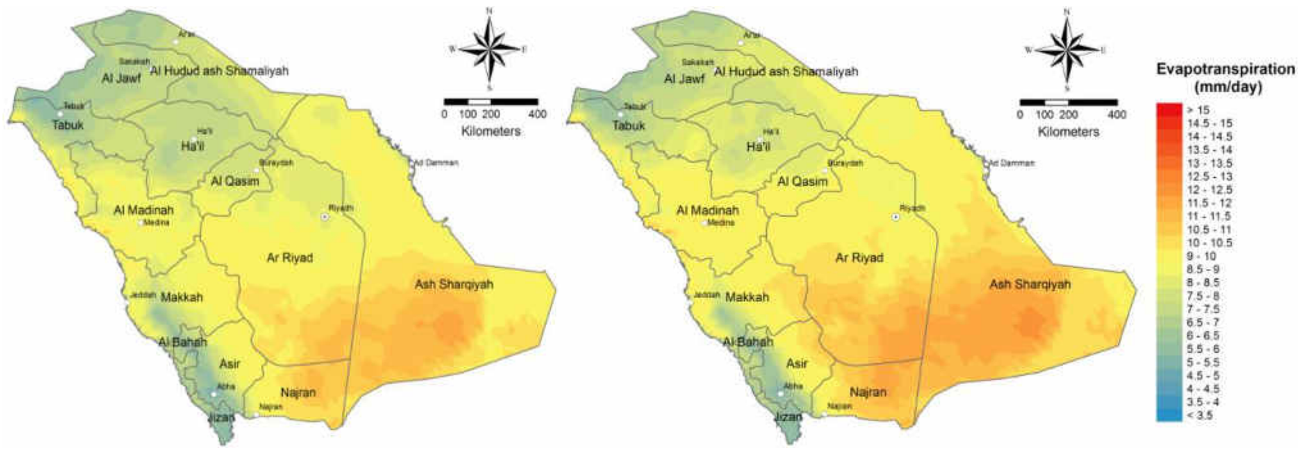


Figure 7.14: Difference of Annual Evapotranspiration from 2030 to 2080

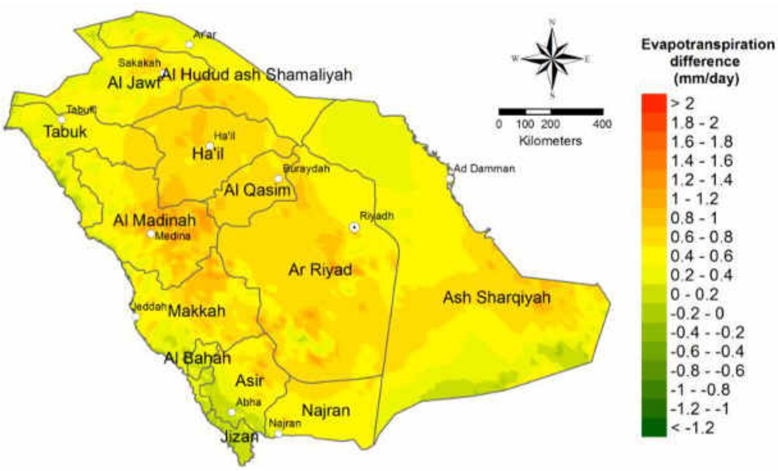
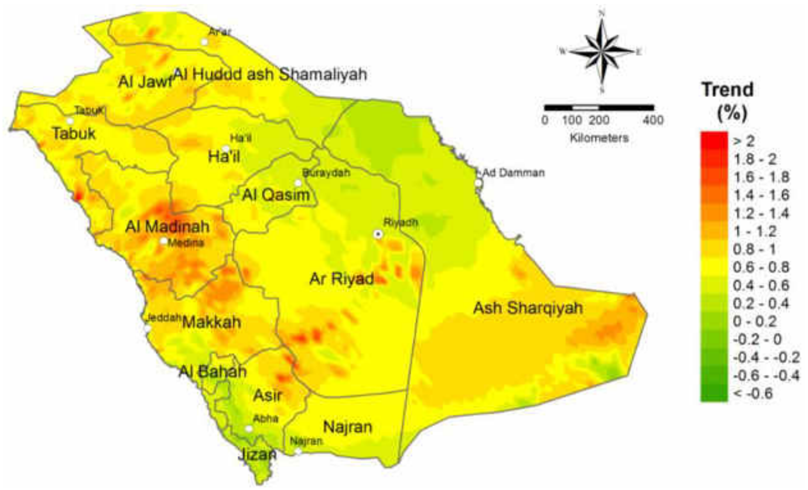


Figure 7.15: Trend of Annual Evapotranspiration from 2030 to 2080



7.5 Impact of Climate Change on Water Supply

Limited water resources (groundwater and surface water) and a sensitive desert environment are major features of the ecosystems of arid regions such as Saudi Arabia. Any increase in air temperature and change in other meteorological parameters will affect the reference crop evapotranspiration, crop water requirements and water recharge to aquifers. Groundwater resources are the major water supply source for the Kingdom. More than 90% of the national water use is satisfied from groundwater which is pumped from local aquifers. Surface water is very limited due to a low annual precipitation. The annual aquifer recharge from the low average rainfall has been very significant in partially compensating the water withdrawal from the aquifers. Furthermore, irrigation demands more than 90% of the total water demand. These demands are satisfied mostly from groundwater resources. Any increase in air temperature and change in other meteorological parameters will affect the availability of groundwater and surface water by enhancing evaporation rates from open water bodies, soil and plants and by reducing water recharge to aquifers. This recharge reduction will result in a deterioration of water quality and aquifer yield and will not be able to meet the growing water demand. Consequently, the urban, industrial and agricultural water supplies from groundwater and the survival of cultivated and desert plants and desertification will be greatly affected. Serious socio-economic impacts will result. Thus, any increase in ET_0 will result in an increase in evaporation rates and a decrease in the available water supplies from annual precipitation by lowering the annual recharge to aquifers and by lowering the surface runoff.

Simultaneously, the increase in ET_0 results in increasing water demands for urban, industrial and agricultural uses. Normally, in the domestic and industrial sectors an ET_0 increase of about 20% to 30% occurs from winter to summer. This increase is expected to be aggravated by a temperature rise, especially in summer. Irrigation water demands will be elevated by increasing the ET_0 and crop water requirements in various agricultural regions. Consequently, the available water resources to meet these increasing demands will be under stress due to a decrease in the water recharge and surface runoff and an increase in domestic, industrial and agricultural demands.

7.5.1 Impacts on Groundwater Recharge and Surface Water

Necessary geological, hydrological and hydrogeological data and information, including maps for KSA's main aquifers, have been reviewed. The calculated total annual recharge to all aquifers in the Arabian Shelf is about 2,762 MCM, based on several hydrogeological studies as given in KFUPM/RI (1988) and Al Alawi and Abdulrazzak (1993). The annual recharge to shallow aquifers in the Arabian Shield is 1,196 MCM (BAAC, 1980). Thus, the total annual recharge to all aquifers is about 3,958 MCM. The average increase in ET_0, as calculated and explained in Section 3.4, which reduces the recharge to all aquifers, has been defined as 2.3% and 12% of the total annual recharge at a 1°C and a 5°C increase in temperature respectively. The calculated reduction in the total annual recharge is about 91.4 MCM and 475 MCM at 1°C and 5°C increases in temperature respectively. A reduction in annual surface runoff of 5,000–8,000 MCM at ET_0 increases of about 2.3% and 12% at a 1°C and a 5°C increase in temperature respectively have been calculated. At a 1°C increase, an increase in ET_0 of 2.3% will result in decreasing the annual surface runoff by about 115–184 MCM (with an average of 150 MCM);

at a 5ºC increase, an ET_0 increase of 12% will decrease the annual surface runoff by about 600–960 MCM (with average of 780 MCM). The total annual reduction in water resources equals a reduction in recharge and surface runoff. Thus, the total water resource reduction will be about 241 MCM and 1,435 MCM at 1ºC and 5ºC increases in temperature respectively.

A reduction in water recharge to aquifers and surface water runoff will result in a deterioration of water quality and will not be able to meet the growing water demand. Consequently, the urban, industrial and agricultural water supplies from groundwater and limited surface water will be affected. Serious socio-economic impacts will result.

7.5.2 Impacts on Future Irrigation Water Supply

A calculated increase in ET_0 and irrigation requirements (IR) have been used to calculate an increase in irrigation requirements of various crop types in different regions of the Kingdom at 1ºC and 5ºC increases in temperature. The total irrigation demands for cultivated crops have been calculated using a specially developed model for different types of crops in different regions considering the effect of temperature increase. The domestic and industrial water use increase at 1ºC to 5ºC has been assumed to be about 5% and 25% respectively. Thus, the expected rise in domestic and industrial demands will range between 75 MCM and 390 MCM at 1ºC and 5ºC increases in temperature respectively. The total water stress is equal to the total decrease in groundwater recharge and surface runoff, increase in irrigation requirements and domestic and industrial demands at 1ºC and 5ºC increase in the temperature. The calculated total water stress ranges between 1,520 and 4,947 MCM at 1ºC and 5ºC increases in temperature, respectively. This will represent a serious challenge on the domestic, industrial, agricultural and natural vegetation in the different land forms in the Kingdom. Early monitoring and warning systems and appropriate contingency plans should be developed to protect national interests and to minimize desertification-induced processes in various regions of the Kingdom.

Saudi Arabia has an average annual rainfall of less than 150 mm throughout the year (Abderrahman, 2001; Elhadj, 2004). The available water sources are already in stress. Further effects from climatic change may worsen it. This study estimates an annual reduction of water levels in the range of 1.04 m to 1.37 m in 2080, which may have severe implications on water supplies. Water demands are currently satisfied by non-renewable groundwater sources, renewable surface and groundwater sources, desalinated water and treated wastewater; non-renewable groundwater sources supply the most, followed by renewable surface and groundwater sources, desalinated water and treated wastewater (Chowdhury and Champagne, 2006; Alhumoud et al., 2003; Shareef et al., 2005). The quantity of renewable groundwater found in sediments and in weathered and fractured rocks depends on the frequency and intensity of rainfall, which is poor in Saudi Arabia; thus, renewable groundwater sources, especially the shallow groundwater sources and valley basins, dry up frequently (Alkolibi, 2002). A major portion of the non-renewable groundwater is used primarily for agricultural purposes; many parts of the Kingdom also use it for drinking purposes (Shareef et al., 2005). In addition to these conventional sources, sea water is desalinated, primarily to satisfy a significant portion of drinking water in the Kingdom's main cities. Surface water and precipitation is stored in the approximately 185 dams which have been constructed across the Kingdom to recharge the water basins (Abderrahman, 2001). A portion of domestic wastewater is treated and recycled for agricultural use.

This study has projected a decrease in water levels by 1.04 m to 1.37 m per year by 2080. Reductions by such amounts may reduce the natural flow into shallow and deep groundwater resources, thus the renewable and non-renewable sources may become vulnerable. These may make the water supply systems unsustainable throughout the Kingdom. The salinity of sea water may increase significantly due to higher levels of evapotranspiration (Elhadj, 2004). Thus, the ecological balance may be at risk. In addition, implications associated with the disposal of desalination byproducts may become an issue (Elhadj, 2004). The use of treated wastewater is very low (less than 15% of domestic wastewater); it is typically used for agricultural and landscaping purposes (Abderrahman, 2001; Shareef et al., 2005; Chowdhury and Champagne, 2006). Its use will provide dual benefits: (i) a reduction of freshwater extraction from non-renewable water sources and (ii) a reduction of environmental implications associated with wastewater disposal (Chowdhury and Champagne, 2006). However, a social and religious motivation may be helpful in obtaining better results for using treated wastewater in the Kingdom. To provide better water-supply systems, it is important that the water resources are effectively managed. Management of these resources will require a proper understanding of future water storage, availability, hydrologic cycles, water consumption and socio-economic developments. Future research may address these particular issues for better water supplies and management.

7.6 Conclusions and Recommendations

7.6.1 Conclusions

The possible effects of climate changes on water resources, water quality, water supply, agriculture, human health and ecological systems in Saudi Arabia have been investigated in this study. Changes in wind speed, precipitation, temperature and relative humidity for this period were estimated from the PRECIS model projections. Using these data, changes in evapotranspiration and water levels for 28,000 grids covering Saudi Arabia (latitude: 16.5°N–32.5°N; longitude: 33.75°E–56.25°E) were estimated. Wind speed and direction will vary spatially and temporally throughout the Kingdom. The temperature will increase by -0.6°C to 5°C, with trends of 0.8–5.4%. Relative humidity will have variable effects depending on the region; however, an overall decrease will be observed. Estimates of climatic parameters show that the Kingdom may suffer from increased droughts, more communicable diseases, less production of agricultural food and insufficient water.

Because of aridity and the low reserves of water in underground aquifers, Saudi Arabian water resources are already under stress. Climate changes may add further stress. This study estimated the change of evapotranspiration in the range of -1.2 to 2 mm/day from 2030 to 2080 with trends of -0.6 to 2%. An increase in evapotranspiration will decrease water levels. It is likely that the water level decreases will affect hydrologic cycles, flow directions and salinity conditions, which will ultimately affect the amount and quality of water stored in shallow and deep underground aquifers. Thus, water supplies may face a serious challenge.

It has been documented that climatic changes can affect the spread of communicable diseases, including diarrhea, cholera, malaria and dengue in the deserts, including Saudi Arabia. These diseases have the potential to reduce human workability; thus, the possibility of an increase in medical expenses throughout the Kingdom cannot be ignored. The temperature will increase across the Kingdom by -0.6°C to 5°C with trends of 0.8–5.4% from 2030 to 2080. This increase in temperature may result in a 7.5% to 10% increase in the all-cause mortality for Saudi Arabia. In addition, an increase in temperature will affect crop yield. Based on this study, it can be reasonably argued that the quality of human life may be degraded in Saudi Arabia by 2080.

Most of Saudi Arabia has a sensitive ecosystem for any level of climate change, especially on surface and groundwater resources. An assessment of these impacts indicated clearly that most regions have high vulnerability levels for climate change impacts on water resources. These impacts as represented by a temperature increase would elevate the levels of ET_0 by about 1–4.5% at a 1°C increase and by about 6–19.5% at a 5°C increase in most regions; and crop irrigation water demands would rise by about 602 MCM and 3,122 MCM at 1°C and 5°C increases respectively. These expected yield losses of different types of field crops (including cereals, vegetables and forage crops) and fruit trees (including date palms) will range between 5% and more than 25%. Furthermore, agricultural activities represent a major support for about 25% of the national population who still live in rural areas. These problems are expected to be aggravated due to an expected reduction in water supplies from local aquifers because of less aquifer recharge and surface runoff. The total annual reduction in recharge and surface runoff will be about 241 MCM and 1,435 MCM at 1°C and 5°C increases in temperature respectively.

Climate change will also increase domestic and industrial water demands by about 75 MCM and 390 MCM at 1°C and 5°C increases in temperature respectively. Satisfying the increasing domestic, industrial and agricultural demands may lead to additional burden on water authorities. The stress on domestic water supplies will be aggravated by a possible decrease in groundwater recharge and surface runoff with temperature increases. This means that the domestic water supplies of 50% from groundwater and surface water will be replaced partially or totally with desalinated water which could lead to related costs exceeding approximately Saudi Riyals 4 Billion annually.

7.6.2 Recommendations

This study provides a guide in identifying an appropriate approach for the consideration of future water availability for water resource management. Thus, a sustainable approach can be developed to protect human health, ecological balance and the environment. To further improve this projection, the following recommendations are made for future studies:

- The impact of climate change on a possible increase in the reference evapotranspiration using data from all meteorological and climate stations.
- The impact of climate change on a possible decrease in surface rainfall runoff in different parts of the Kingdom using more detailed data and local hydrological information in the various regions.
- The impact of climate change on a possible decrease in aquifer recharge using more detailed hydrogeological data from local aquifers in different regions of the Kingdom.
- Assessment of water-use stress on natural vegetation.
- Assessment of risk associated with the use of treated wastewater effluent (Husain and Danish, 2005).
- The design of early monitoring and warning systems which should be developed to avoid consequences on recharge, runoff, soils and plants.

A multi-criteria decision-making (MCDM) tool and decision support system (DSS) for integrated water resource management (IWRM) should be developed in future studies (Husain and Chaudhary, 2008; Mofarrah and Husain, 2012), provided that more data support is available for such an initiative. Successful integrated water management will cover the following: (1) capturing society's views, (2) reshaping planning process, (3) coordinating land and water resource management, (4) recognizing water quantity and quality linkages, (5) conjunctive use of surface water and groundwater and (6) protecting and restoring natural systems (Bates et al., 2008). In addition, MCDM tools in water resource management will explicitly address impediments to the flow of information through stakeholder participation. Stakeholders are characterized as individuals or groups who may be affected by climate change or by the actions taken to manage anticipated climate risks (Husain and Chaudhary, 2008). A decision support system for water resource management shall at least include projection models (e.g., climate and hydrologic models), techniques and methods for decision analysis, as well as the support to participatory processes of stakeholders involved in the decision making. The decision support system generally integrates multi-source geographically referenced data (hydrology, climate, soil, demography, economic development etc.) and data management systems and a variety of models and optimization procedures within a customized user interface.

APPENDIX 7A: PLOTS FOR SEASONAL SCENARIOS

Figure 7A1: Wind Speed in Winter 2030 (Left) and 2080 (Right)

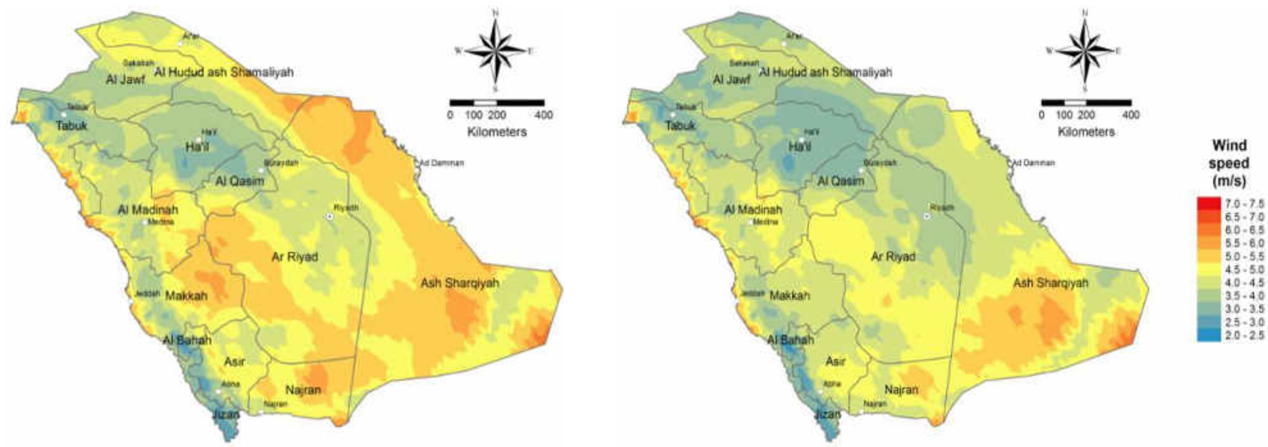


Figure 7A2: Wind Speed in Spring 2030 (Left) and 2080 (Right)

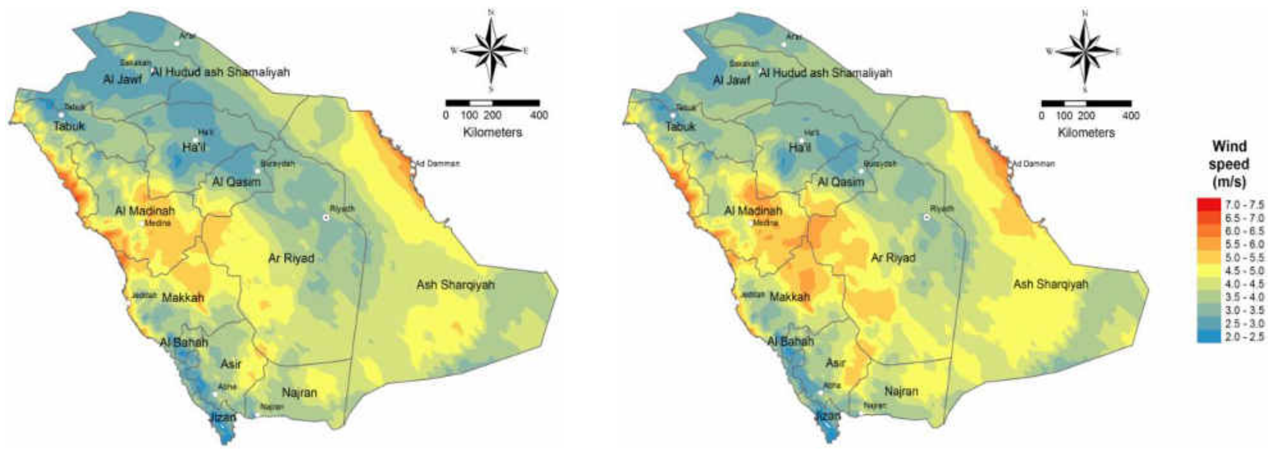


Figure 7A3: Wind Speed in Summer 2030 (Left) and 2080 (Right)

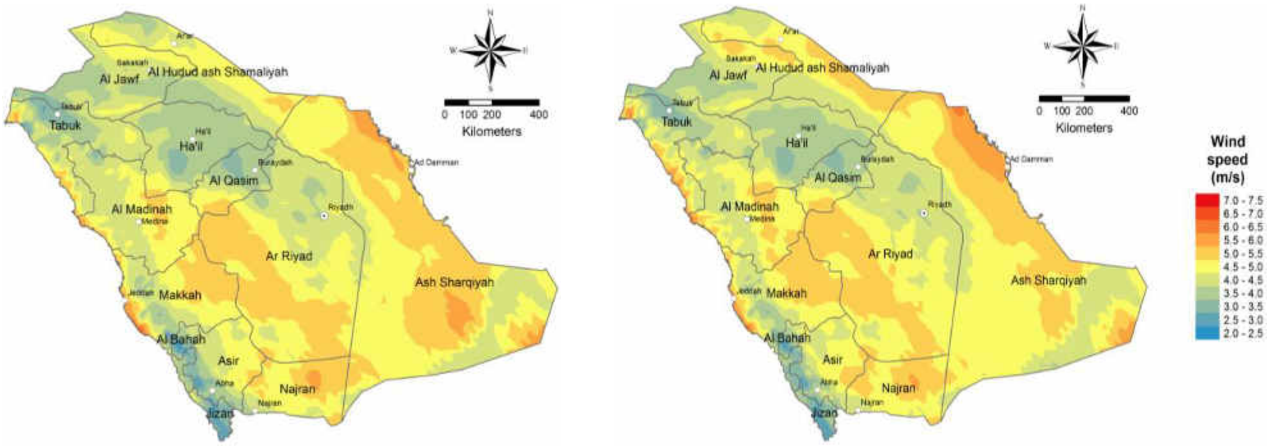


Figure 7A4: Wind Speed in Fall 2030 (Left) and 2080 (Right)

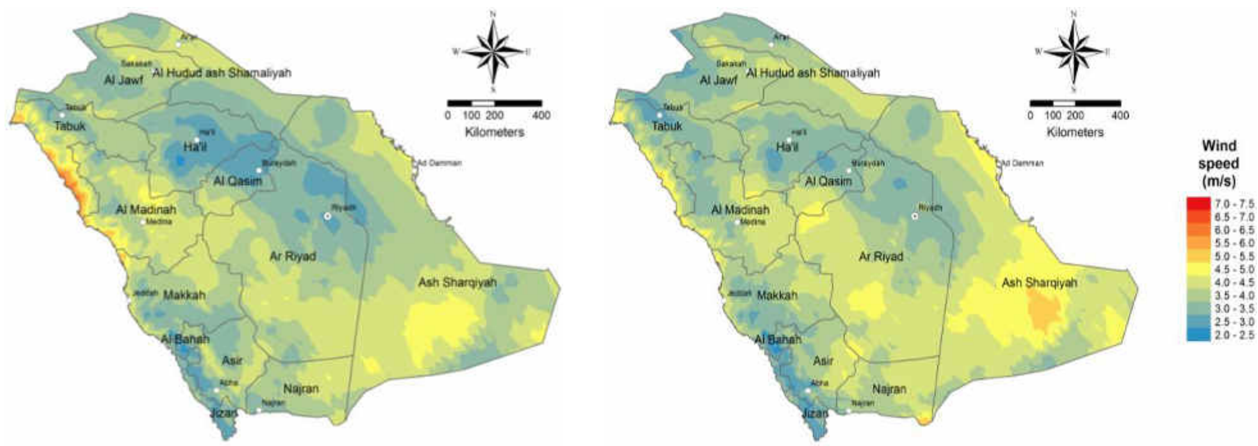
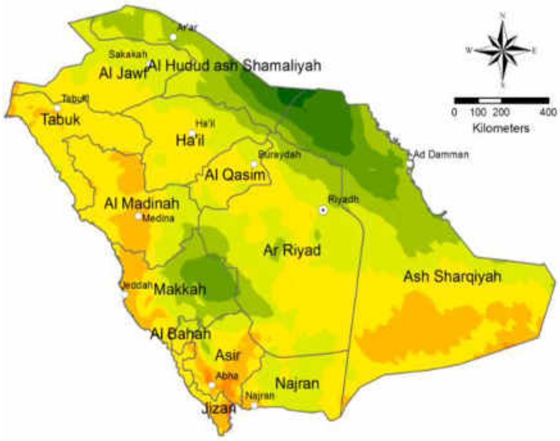
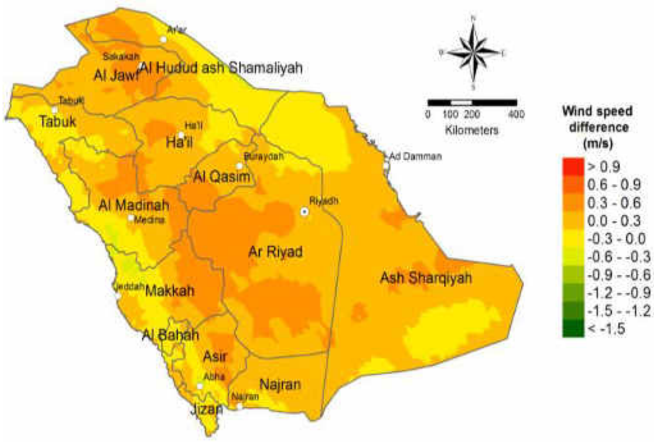


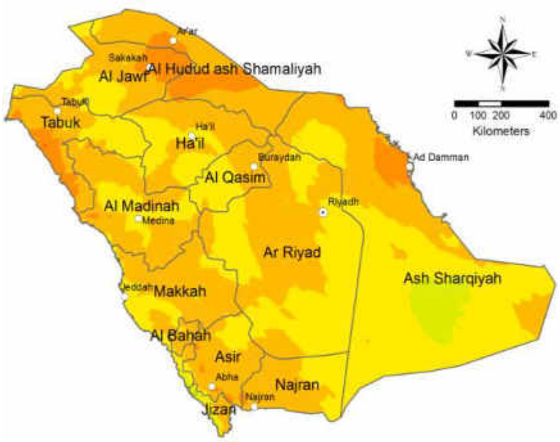
Figure 7A5: Difference in Wind Speed Between 2030 and 2080
(a) Winter, (b) Spring, (c) Summer and (d) Fall



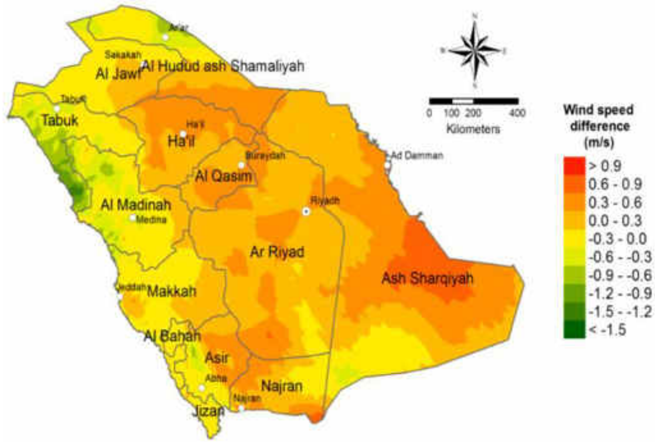
(a)



(b)

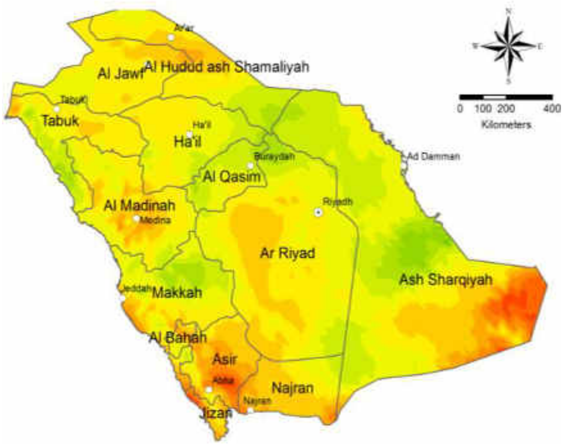


(c)

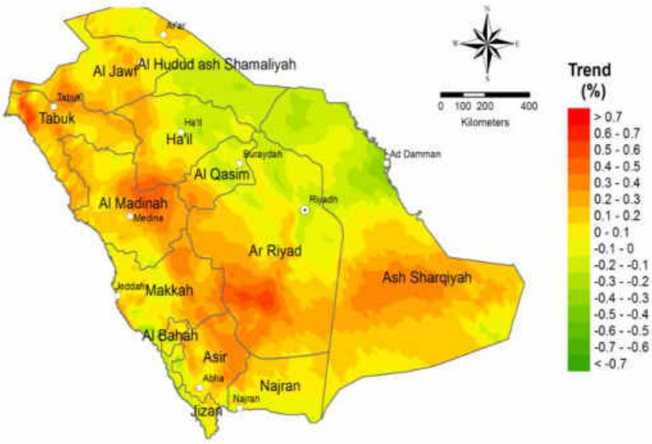


(d)

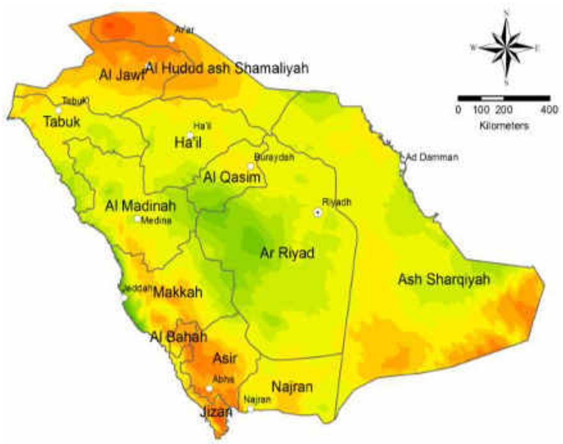
Figure 7A6: Wind Speed Trends Between 2030 and 2080
(a) Winter, (b) Spring, (c) Summer and (d) Fall



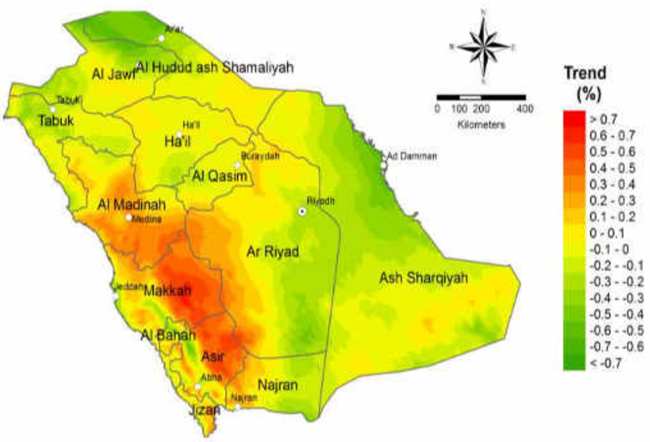
(a)



(b)



(c)



(d)

Figure 7A7: Relative Humidity in Winter 2030 (Left) and 2080 (Right)

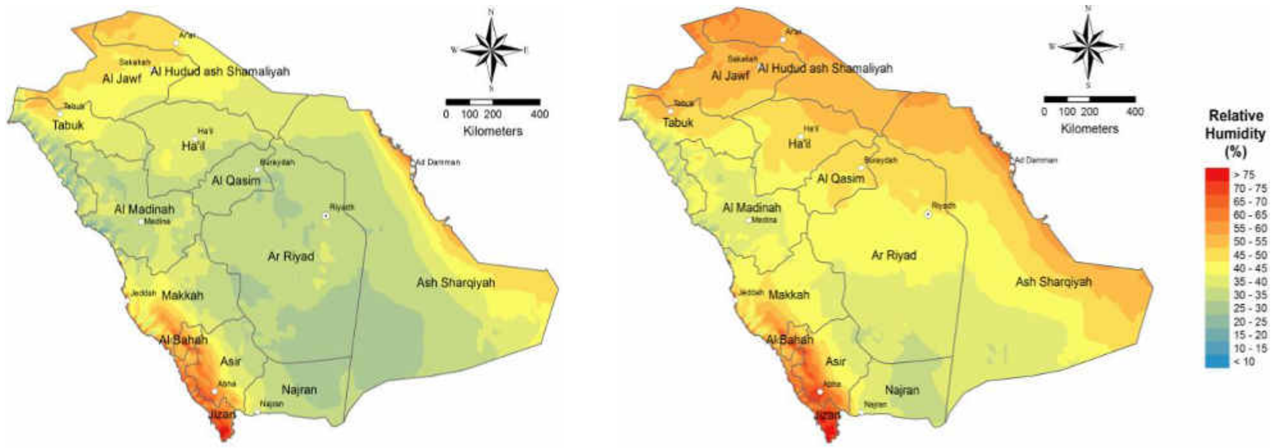


Figure 7A8: Relative Humidity in Spring 2030 (Left) and 2080 (Right)

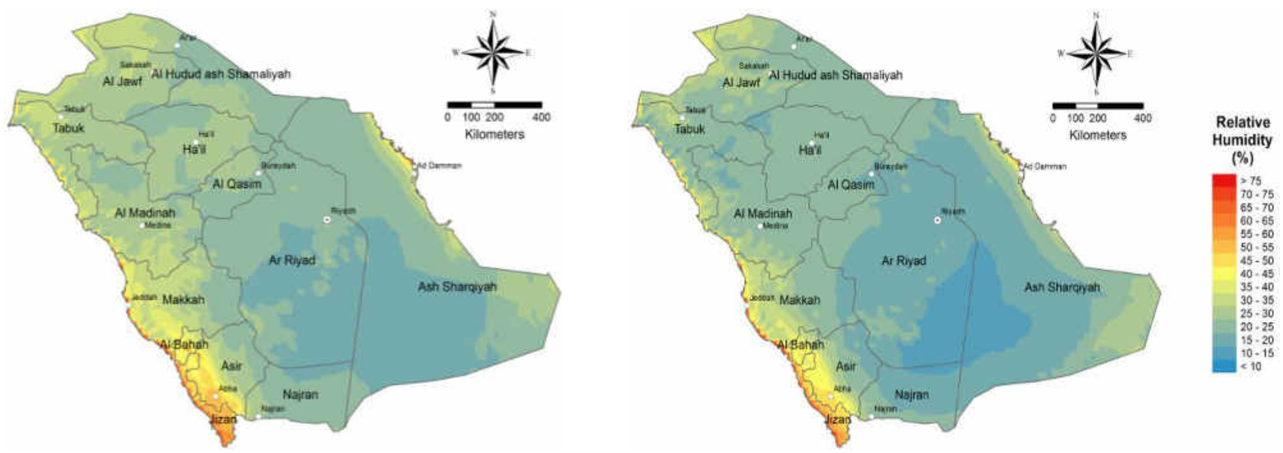


Figure 7A9: Relative Humidity in Summer 2030 (Left) and 2080 (Right)

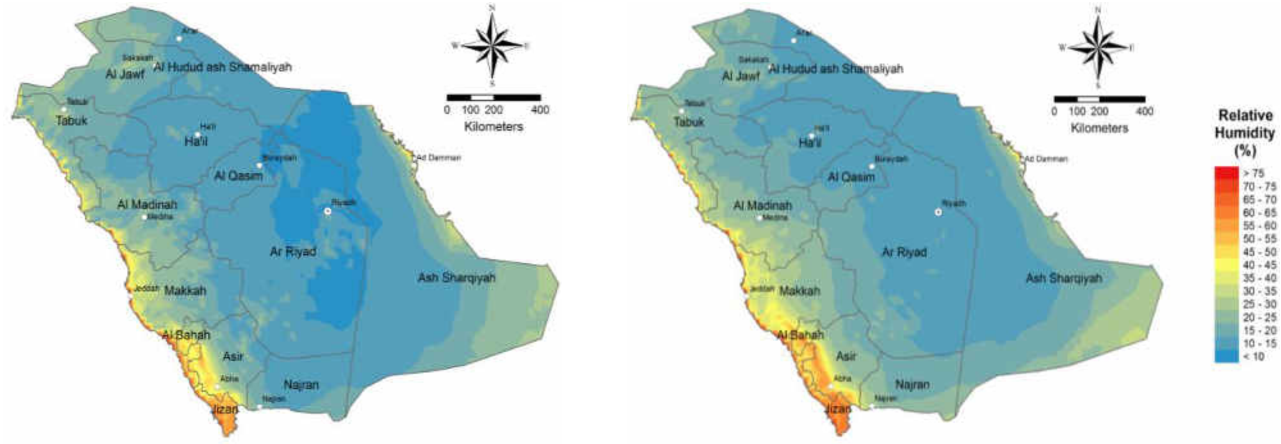


Figure 7A10: Relative Humidity in Fall 2030 (Left) and 2080 (Right)

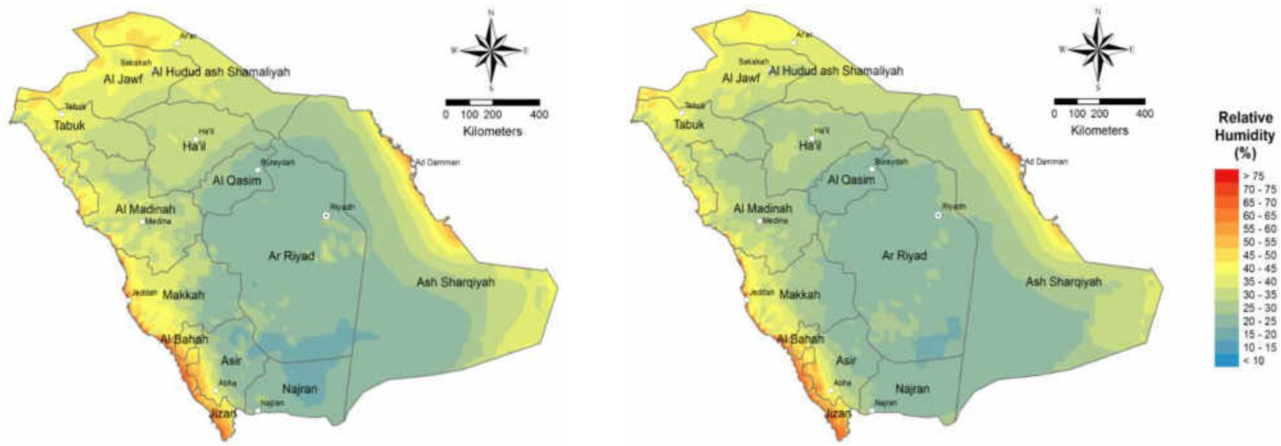
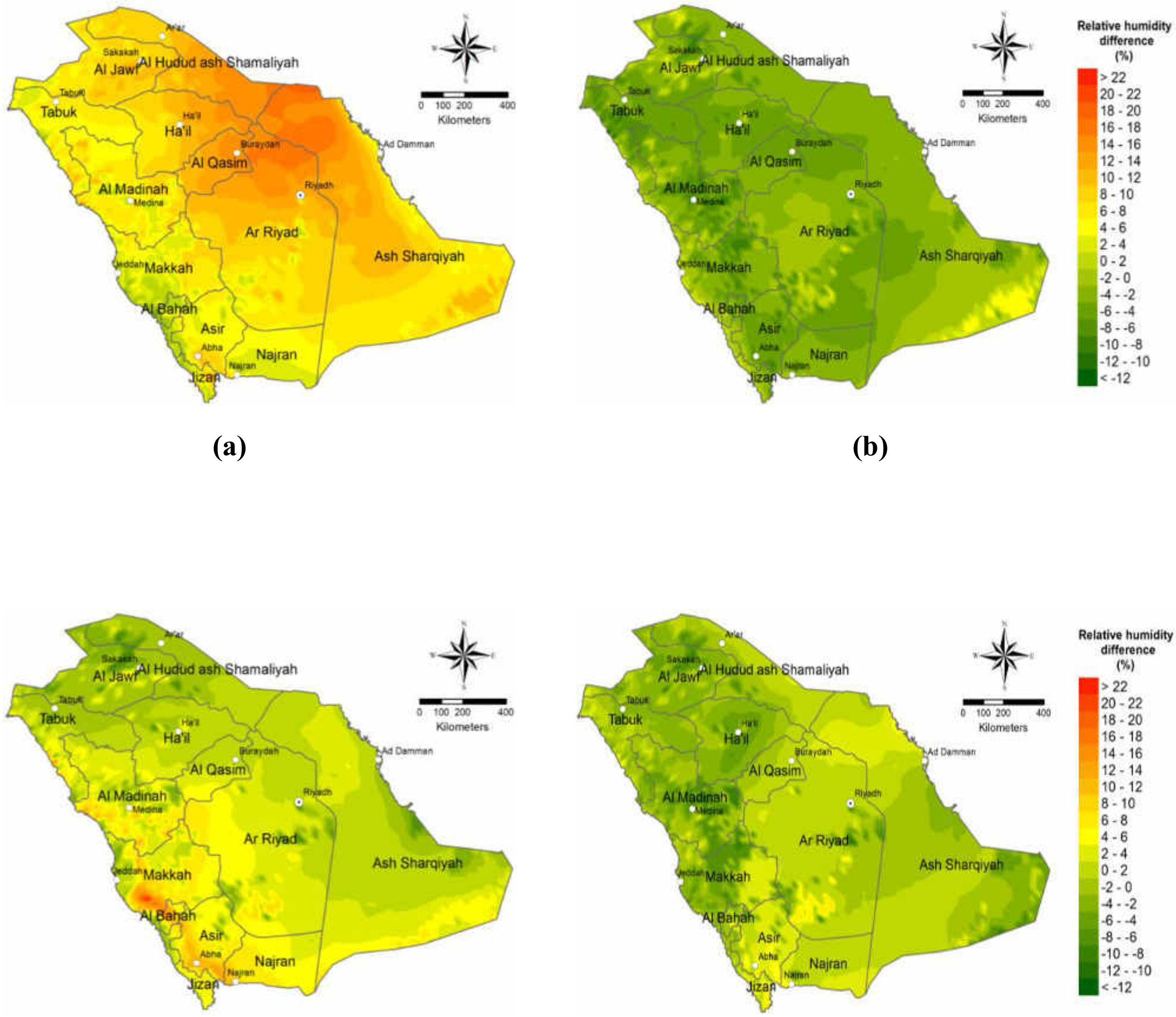
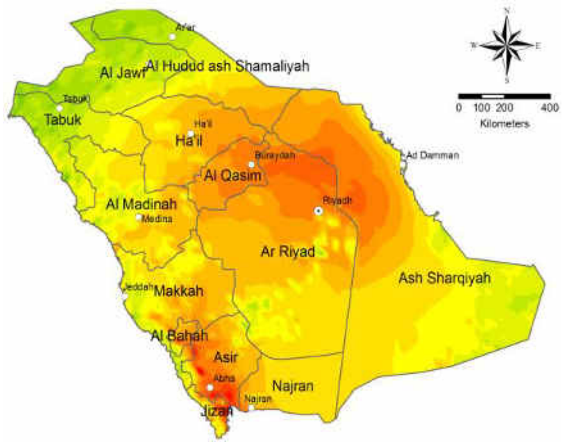


Figure 7A11: Difference of Relative Humidity Between 2030 and 2080
(a) Winter, (b) Spring, (c) Summer and (d) Fall

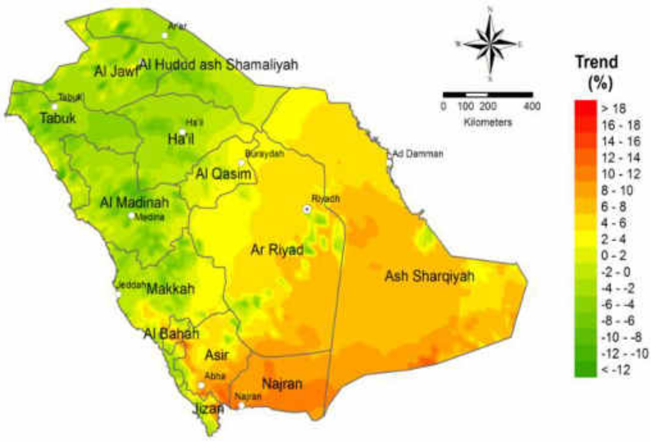


(a) (b) (c) (d)

Figure 7A12: Trend in Relative Humidity Between 2030 and 2080
(a) Winter, (b) Spring, (c) Summer and (d) Fall

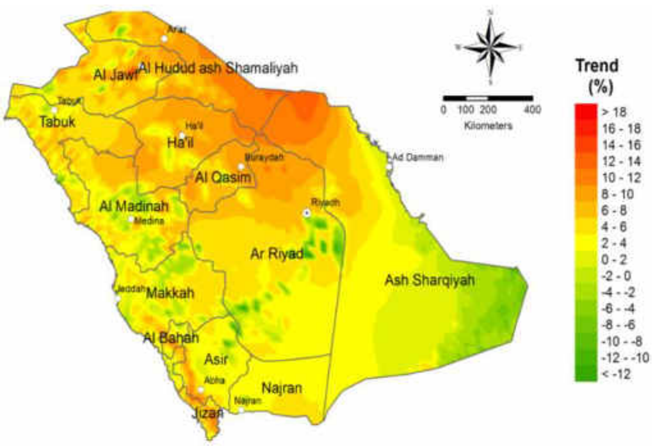


(a)



(b)

(c)



(d)

Figure 7A13: Total Precipitation in Winter 2030 (Left) and 2080 (Right)

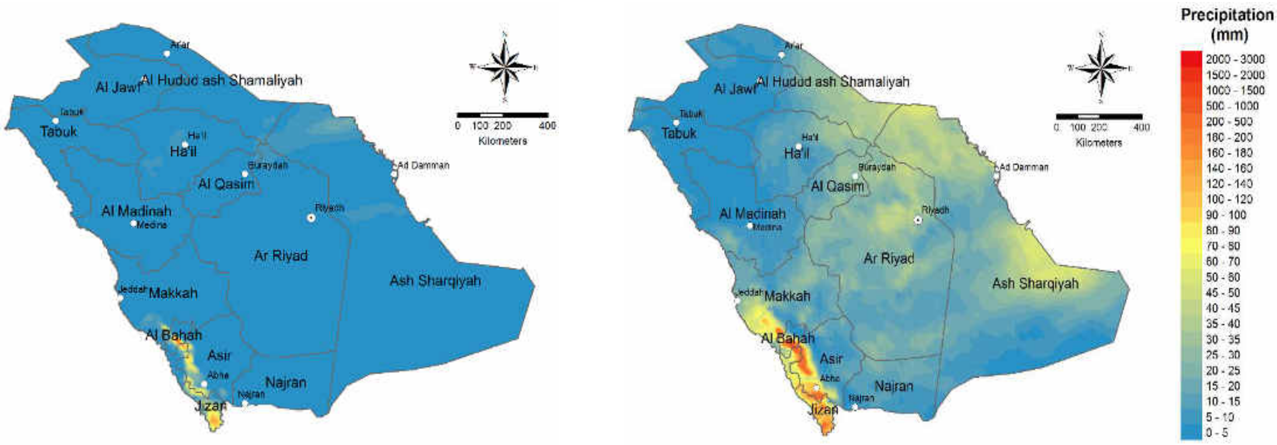


Figure 7A14: Total Precipitation in Spring 2030 (Left) and 2080 (Right)

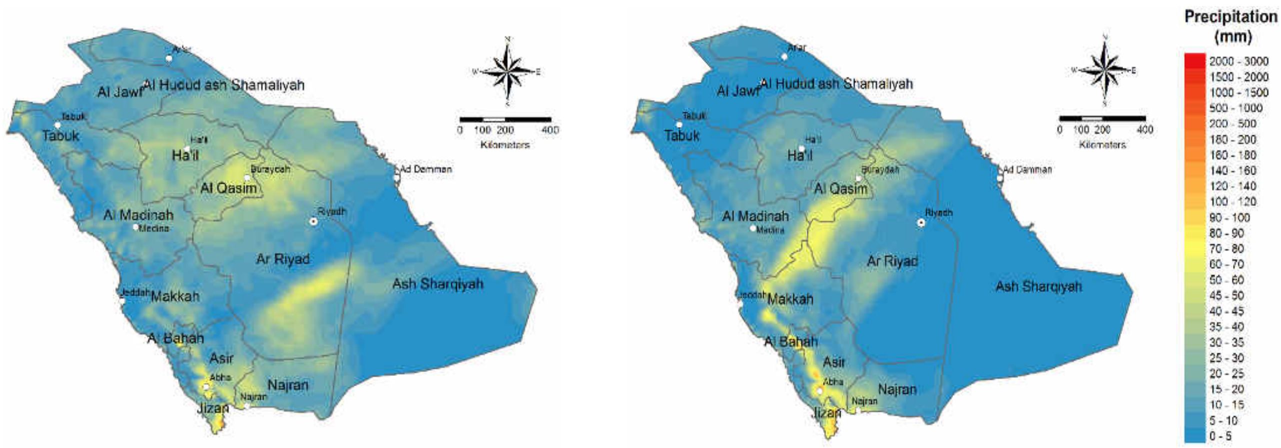


Figure 7A15: Total Precipitation in Summer 2030 (Left) and 2080 (Right)

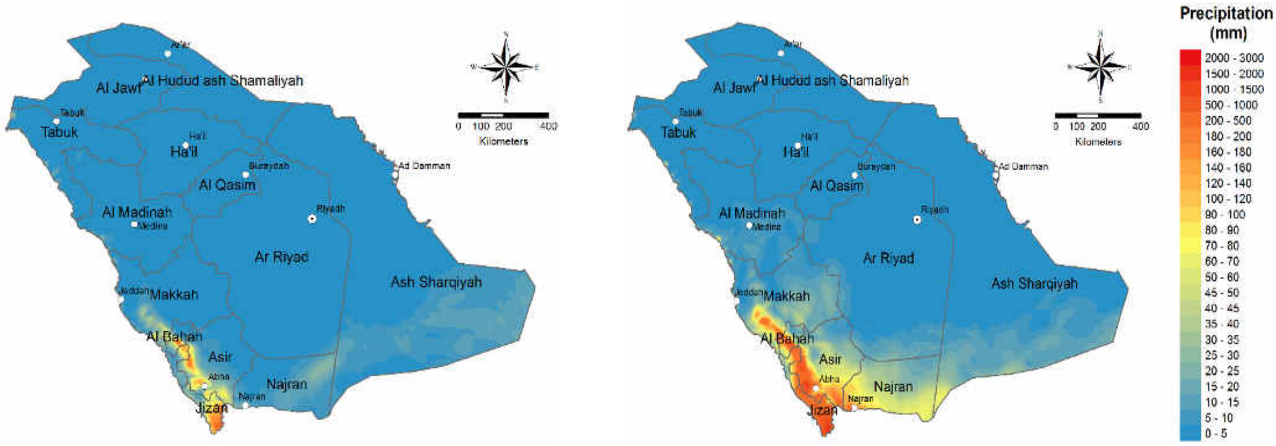


Figure 7A16: Total Precipitation in Fall 2030 (Left) and 2080 (Right)

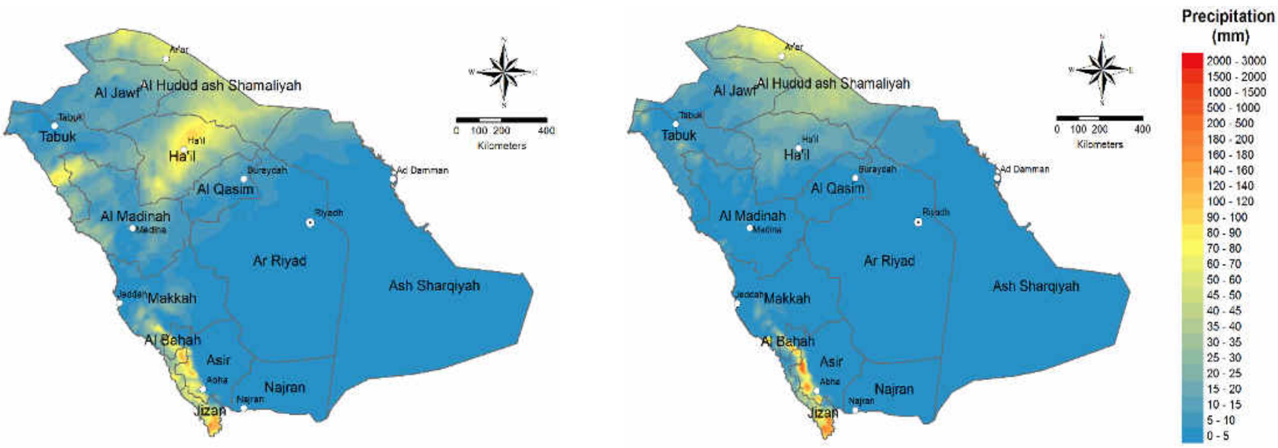
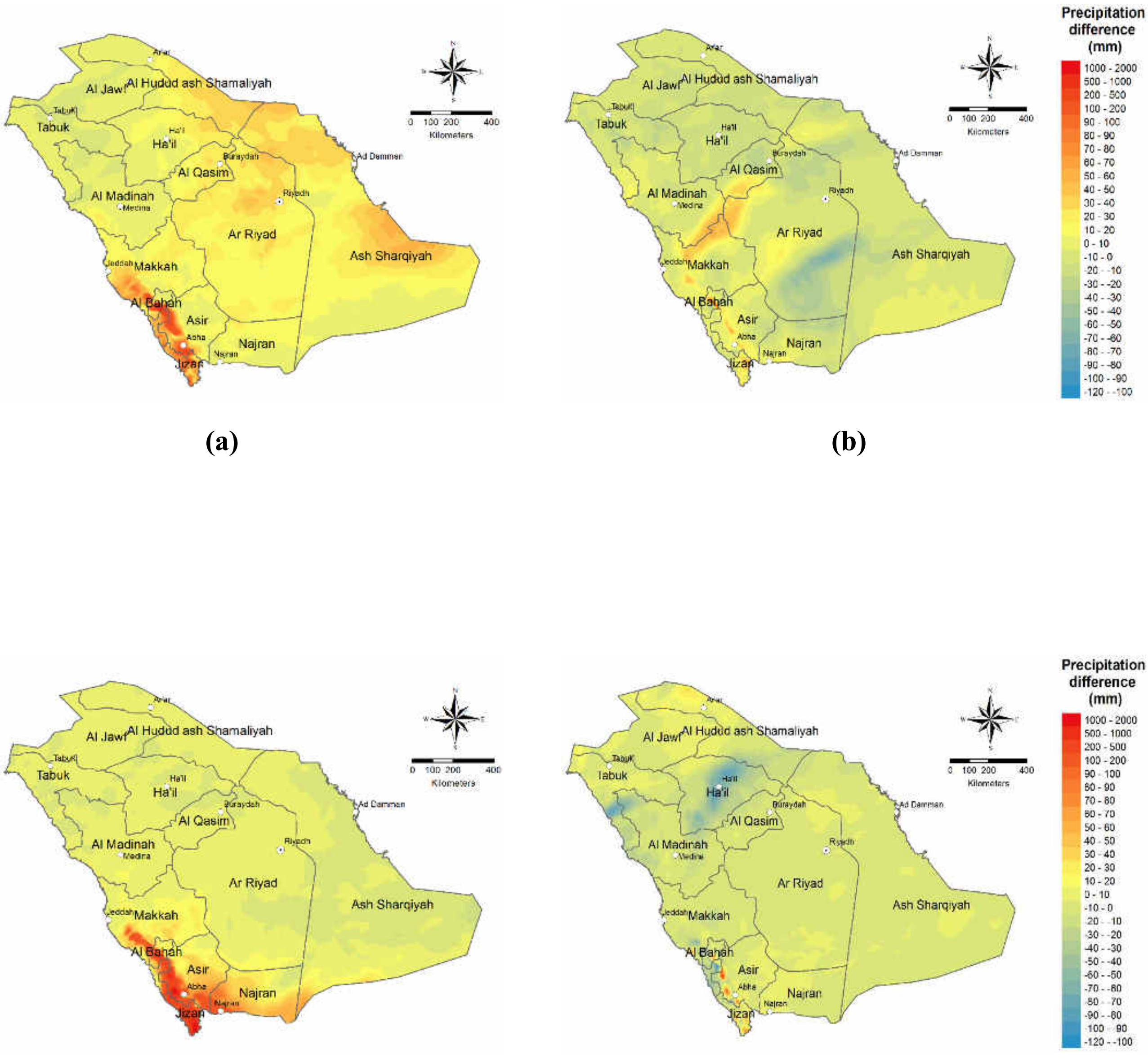


Figure 7A17: Difference in Total Precipitation in Between 2030 and 2080 (a) Winter, (b) Spring, (c) Summer and (d) Fall



(a) (b)

(c) (d)

Figure 7A18: Trend of Total Precipitation from 2030 – 2080 in (a) Winter, (b) Spring, (c) Summer and (d) Fall

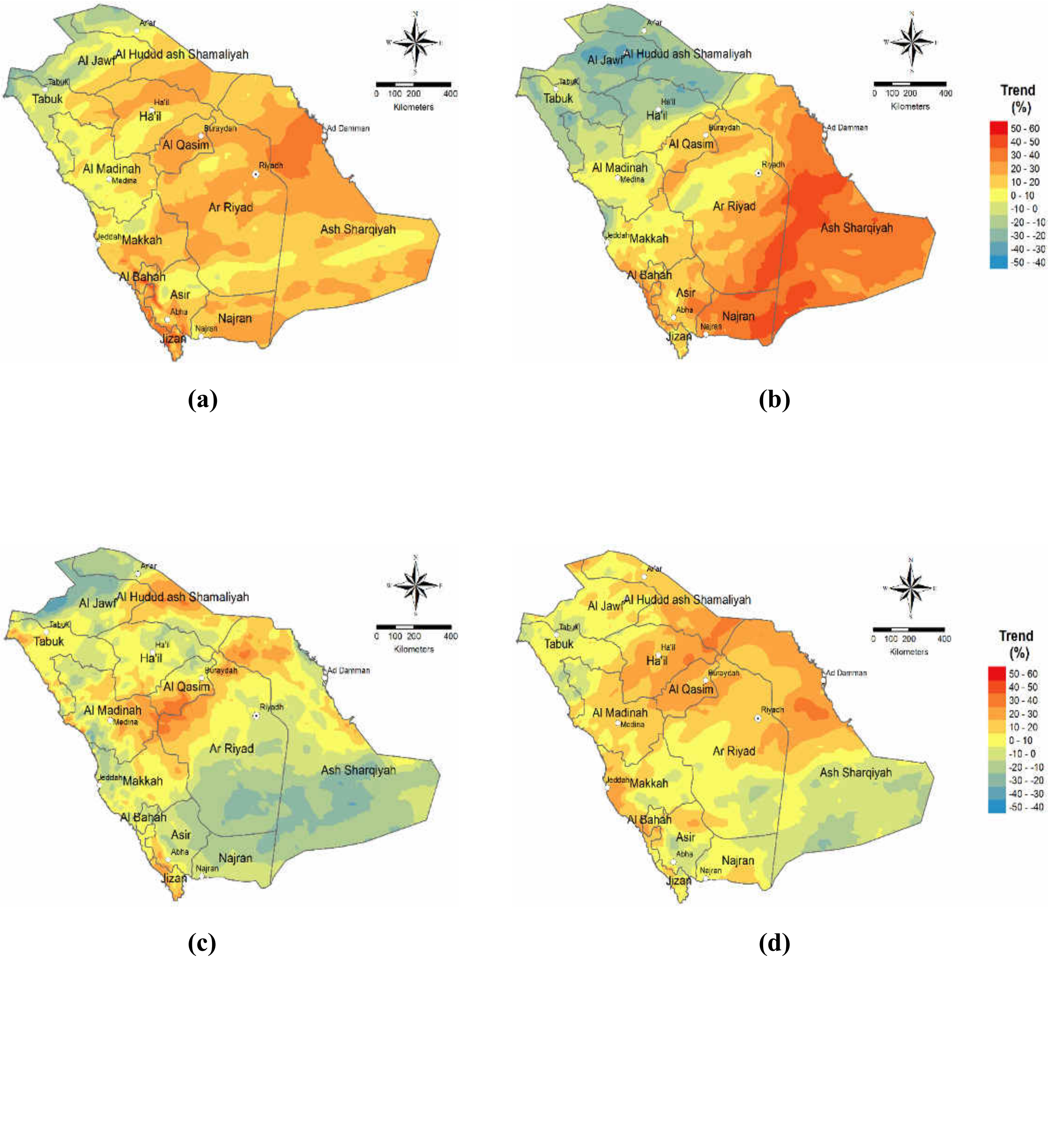


Figure 7A19: Temperature in Winter 2030 (Left) and 2080 (Right)

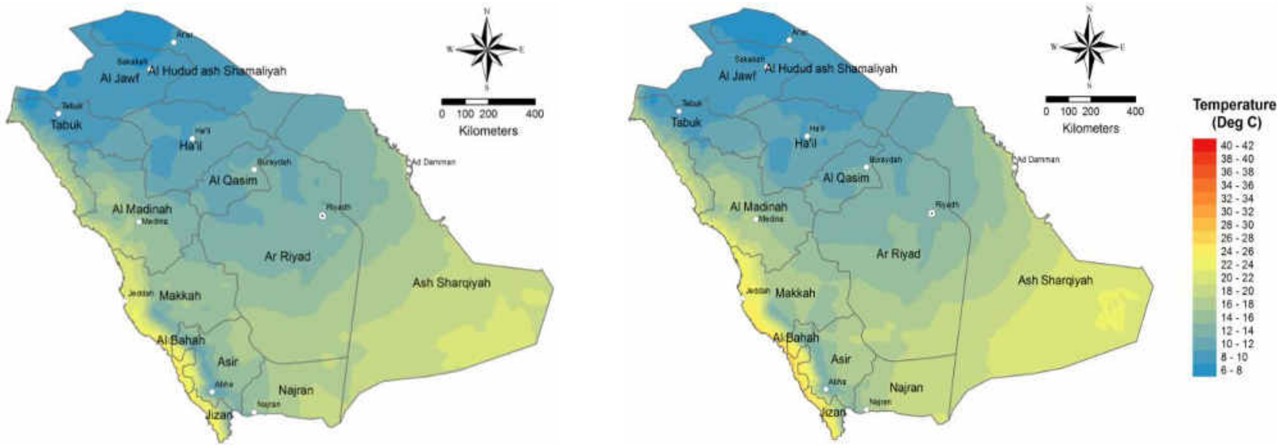


Figure 7A20: Temperature in Spring 2030 (Left) and 2080 (Right)

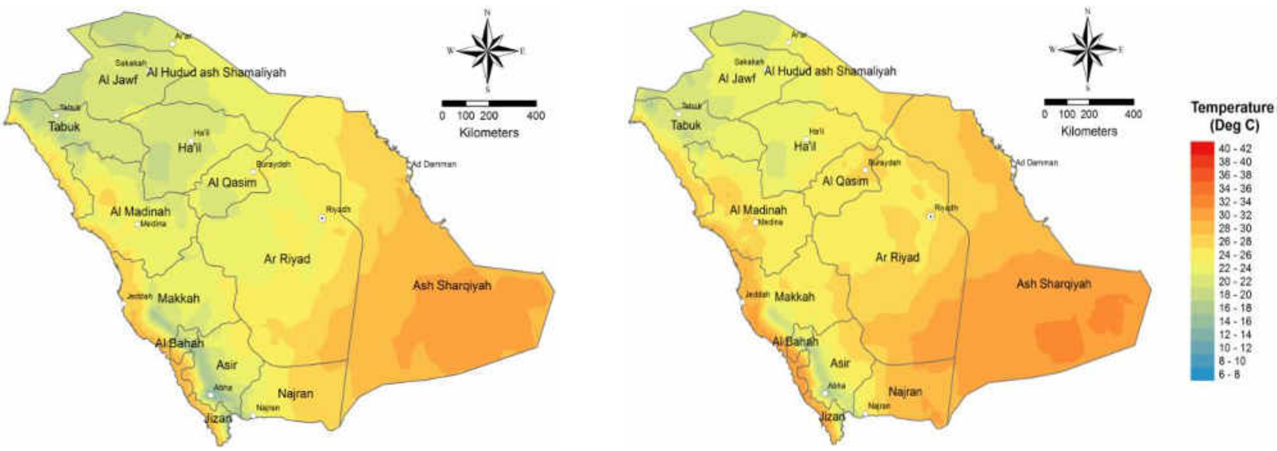


Figure 7A21: Temperature in Summer 2030 (Left) and 2080 (Right)

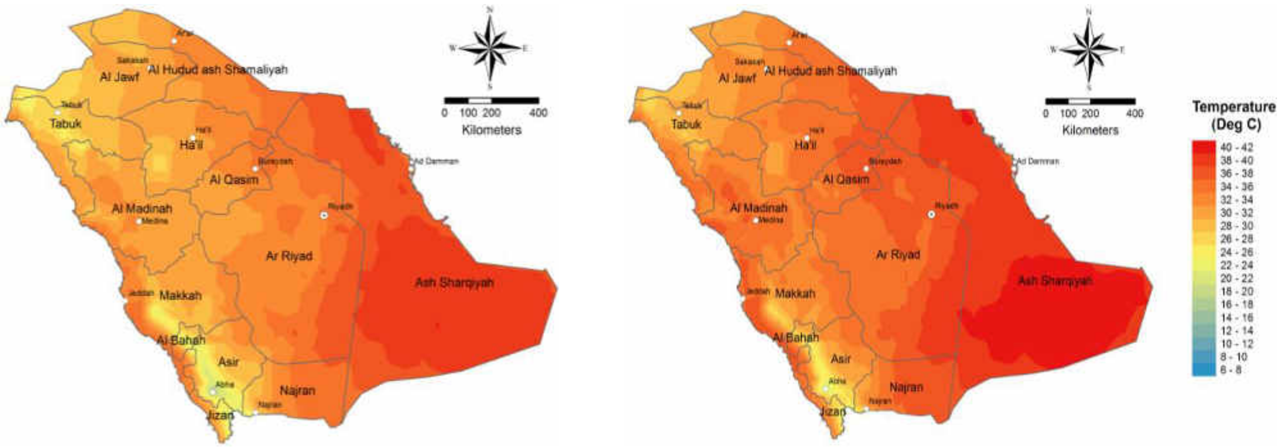


Figure 7A22: Temperature in Fall 2030 (Left) and 2080 (Right)

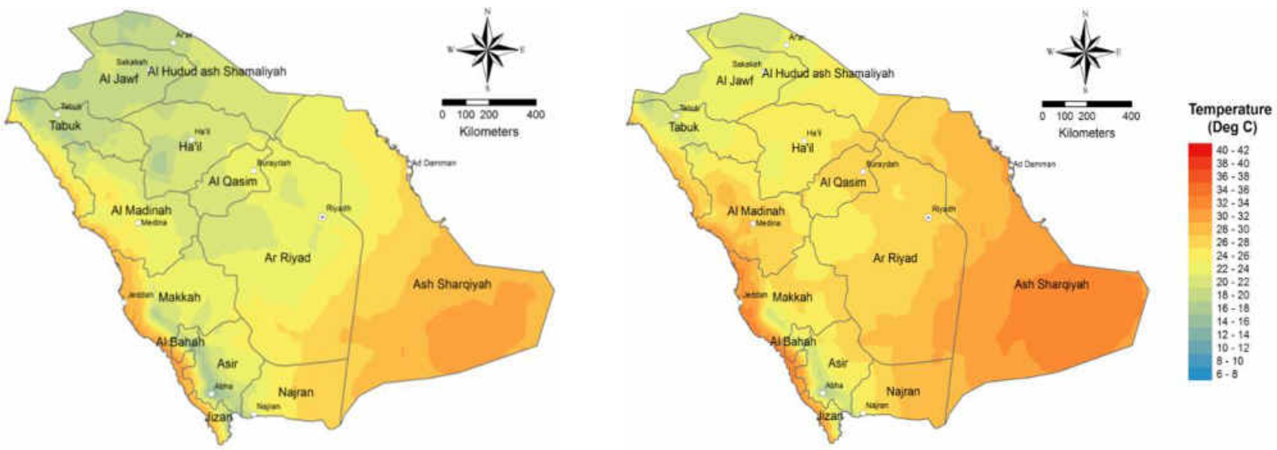
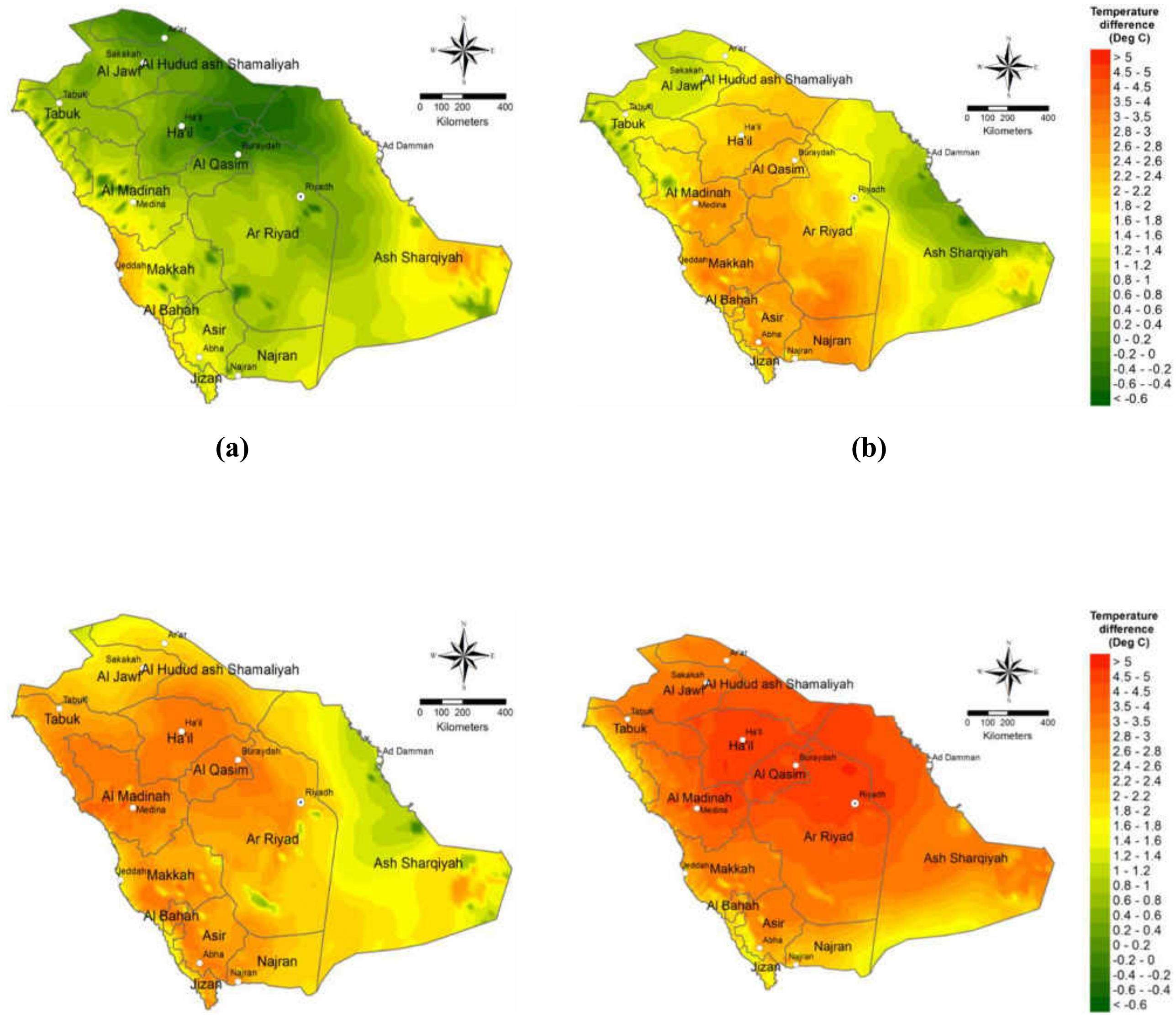


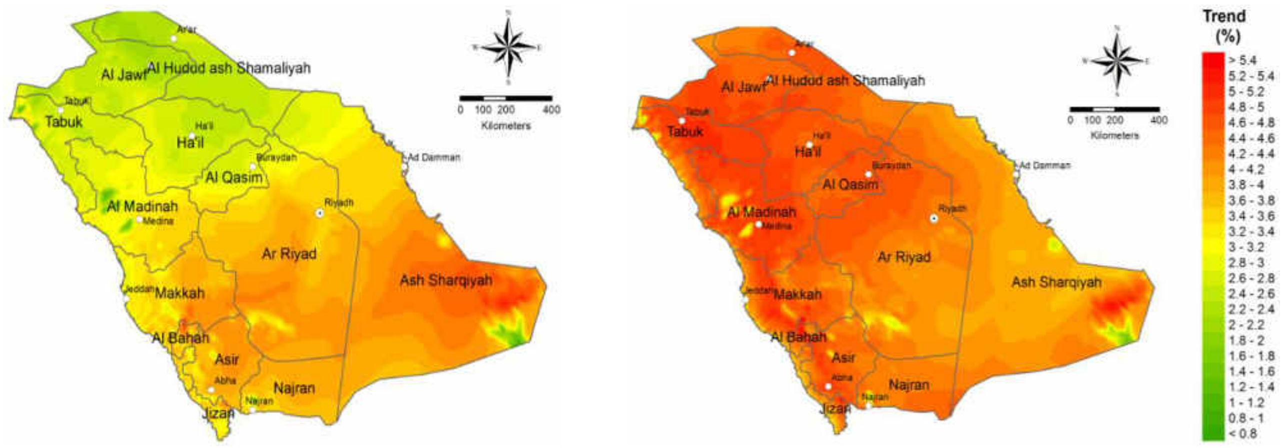
Figure 7A23: Difference of Temperature from 2030 – 2080 in (a) Winter, (b) Spring, (c) Summer and (d) Fall



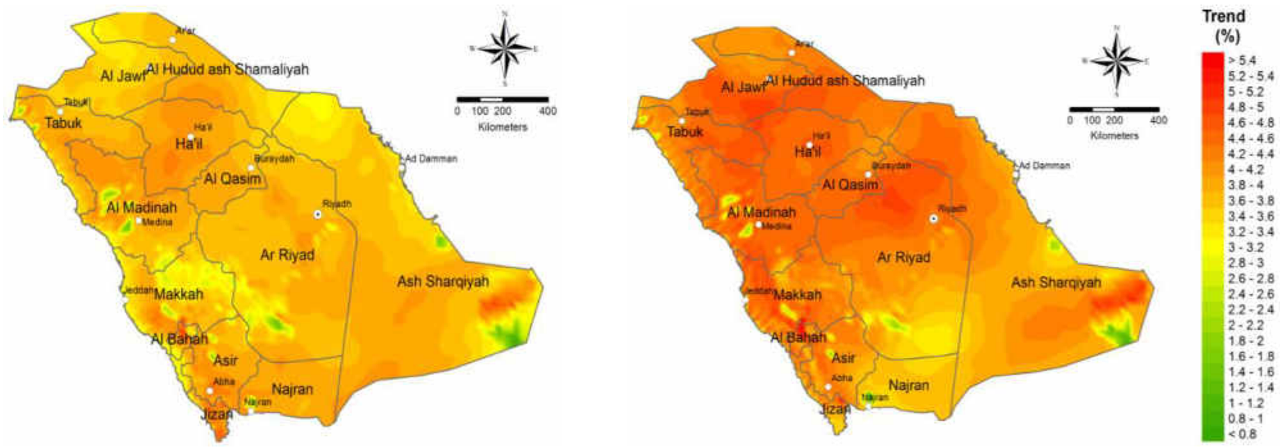
(a) (b)

(c) (d)

Figure 7A24: Trend of Temperature from 2030 – 2080 in (a) Winter, (b) Spring, (c) Summer and (d) Fall



(a) **(b)**



(c) **(d)**

Figure 7A25: Evapotranspiration in Winter 2030 (Left) and 2080 (Right)

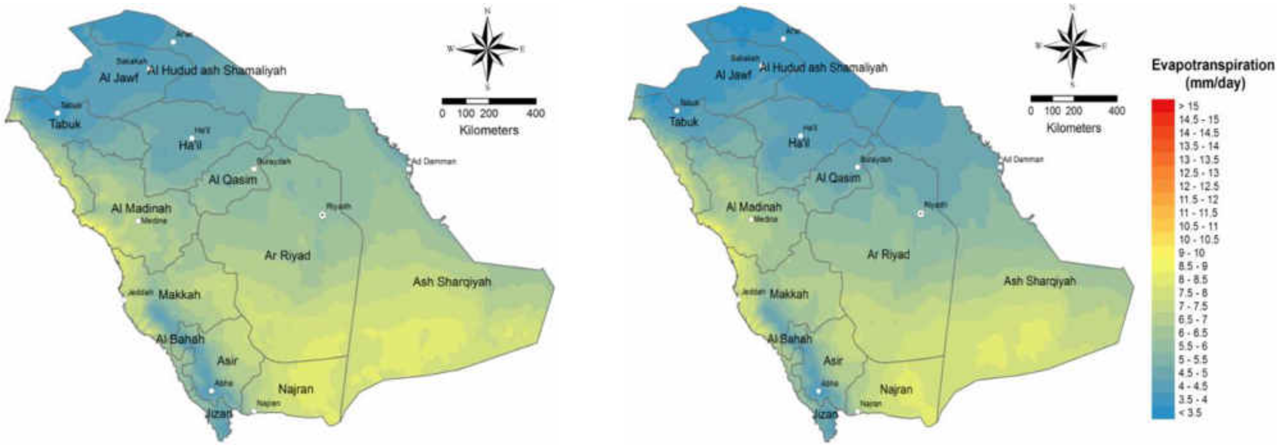


Figure 7A26: Evapotranspiration in Spring 2030 (Left) and 2080 (Right)

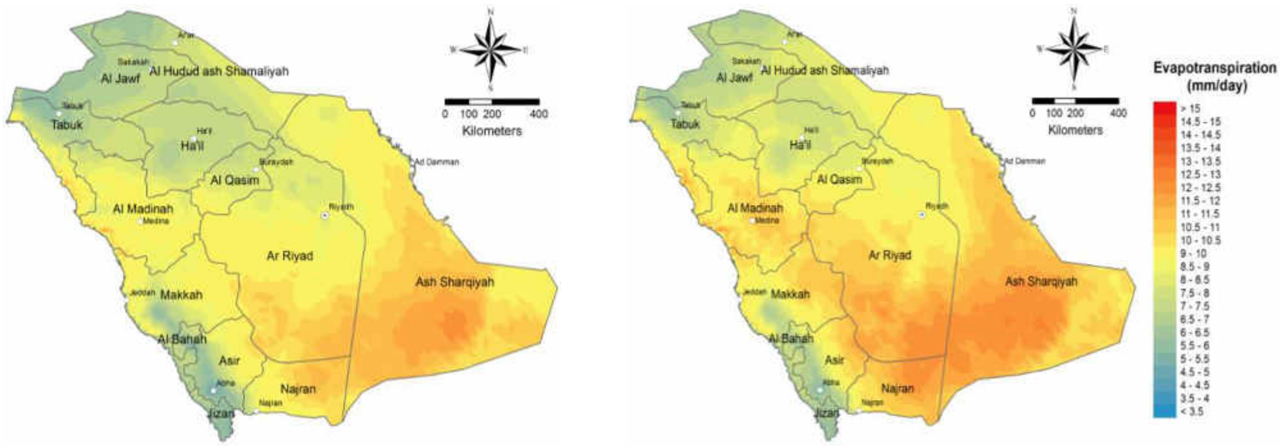


Figure 7A27: Evapotranspiration in Summer 2030 (Left) and 2080 (Right)

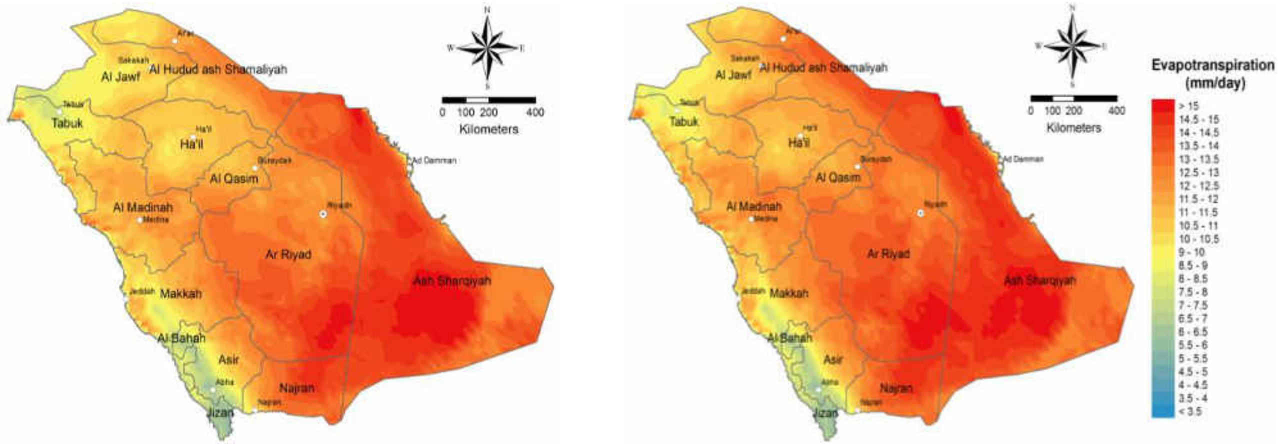


Figure 7A28: Evapotranspiration in Fall 2030 (Left) and 2080 (Right)

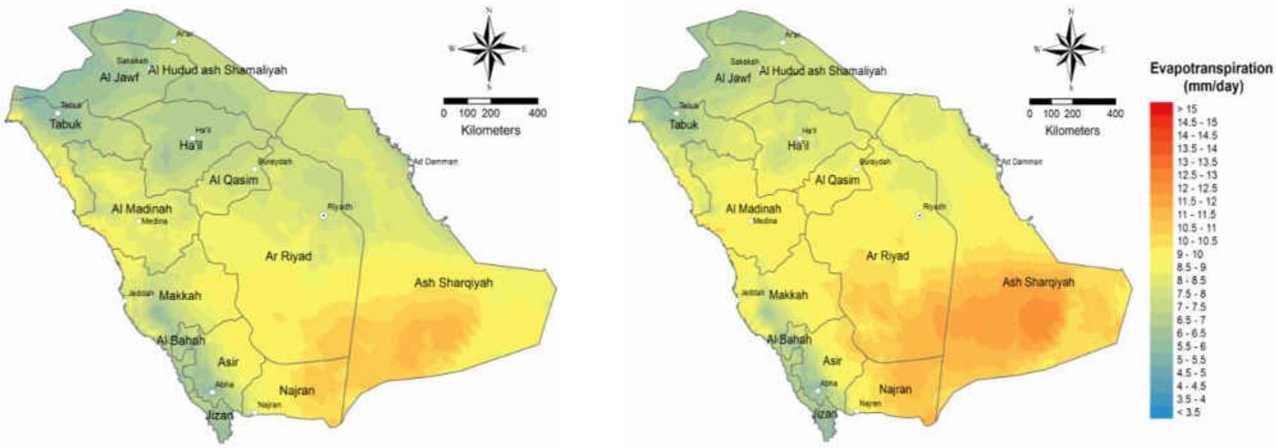
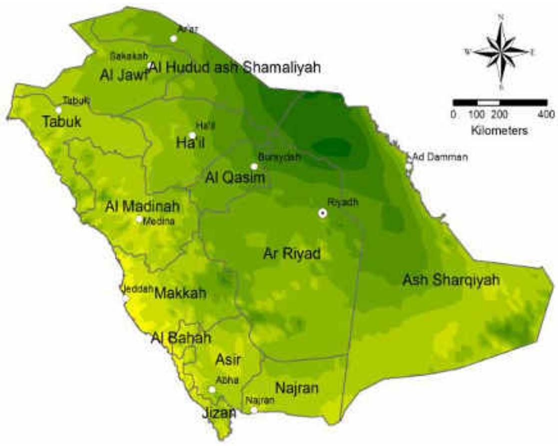
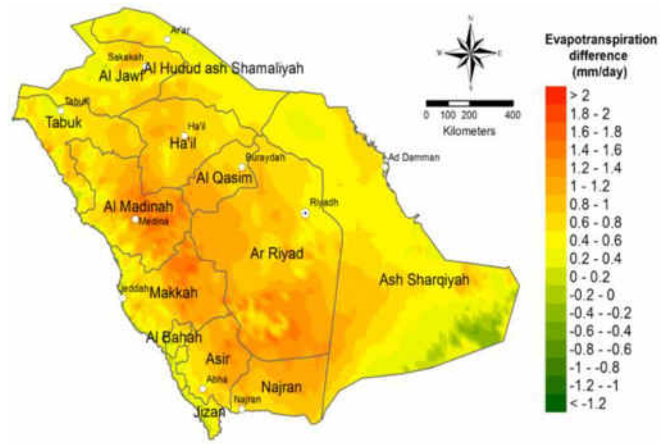


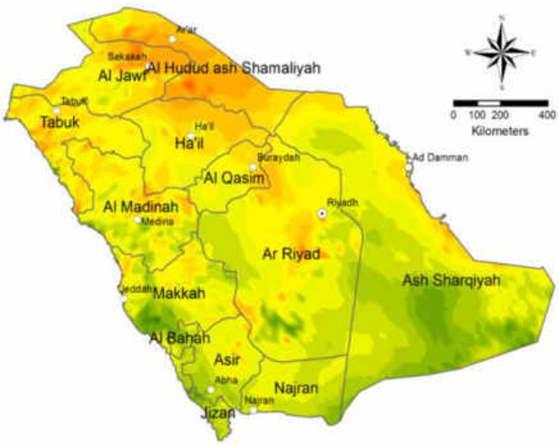
Figure 7A29: Difference of Evapotranspiration Between 2030 and 2080
(a) Winter, (b) Spring, (c) Summer and (d) Fall



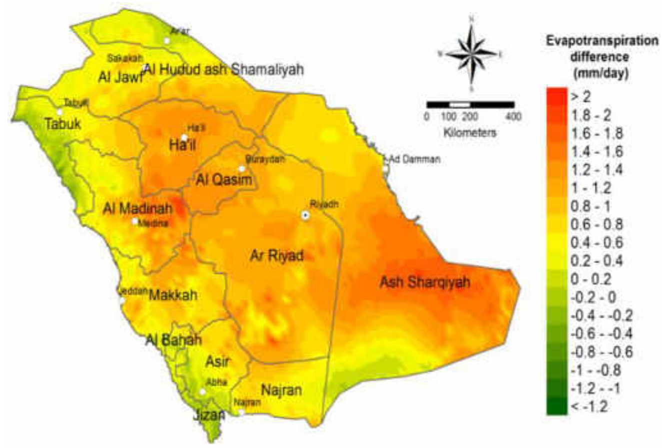
(a)



(b)

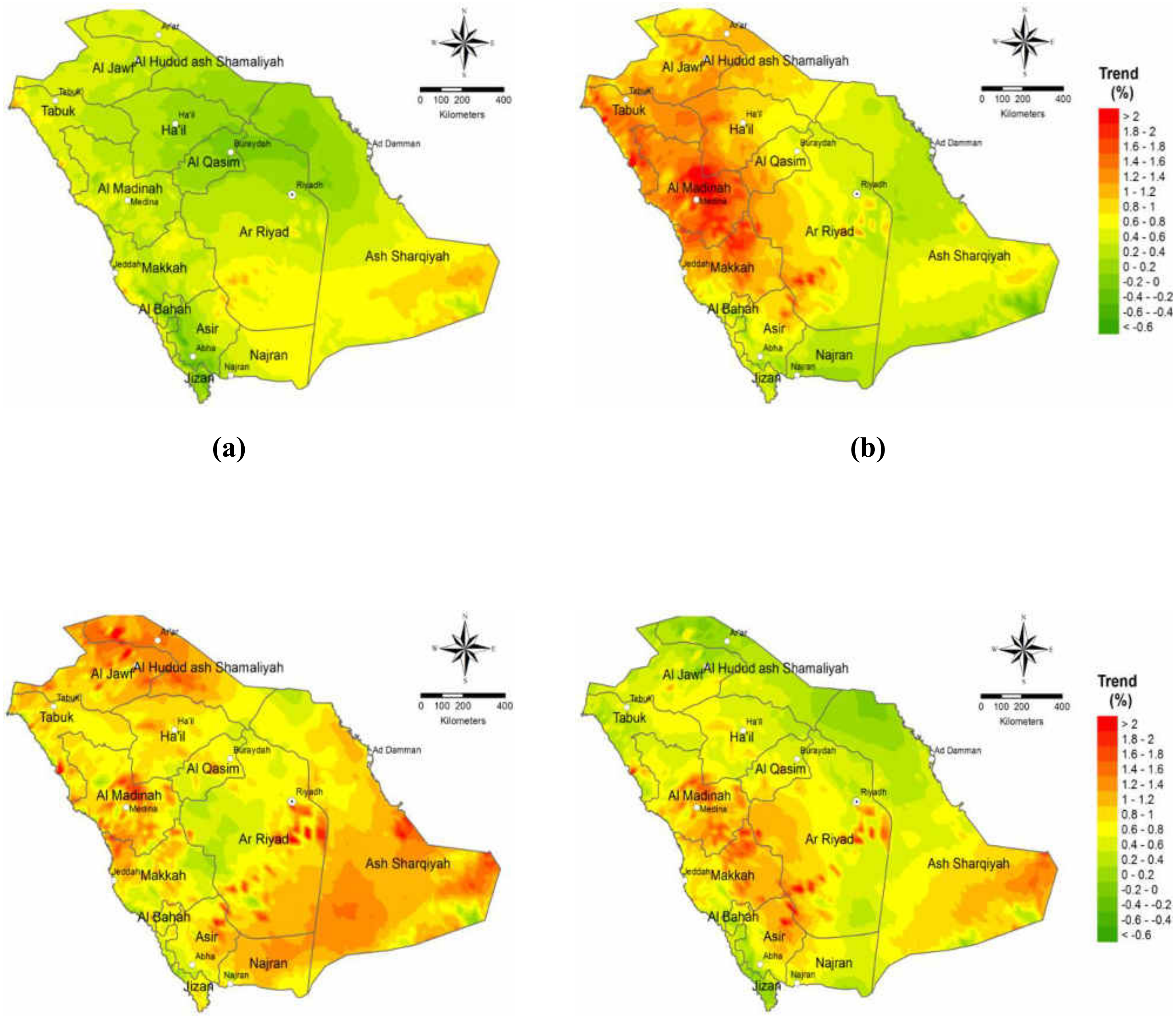


(c)



(d)

Figure 7A30: Trend of Evapotranspiration Between 2030 and 2080
(a) Winter, (b) Spring, (c) Summer and (d) Fall



(a) (b) (c) (d)

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SECTION – 8

Impacts of Climate Change on Desertification

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8.1 Introduction

The United Nations Convention to Combat Desertification (UNCCD) claims that in order to meet rising food demands by 2050, food production needs to be increased by 70%. However, due to desertification, productive land masses are rapidly decreasing. Due to climate-change-linked desertification, crop yield will be reduced by 50% in Africa, which may induce violence, riots and even wars (UNCCD, 2014). In the Kingdom of Saudi Arabia, over-grazing in the desert and urbanization have drastically speeded up land degradation and resulted in decreasingly productive landmasses. Water scarcity also causes desertification. Increases in temperature and evapotranspiration rate due to climate change will cause further deterioration.

8.2 Desertification in the Kingdom of Saudi Arabia

Saudi Arabia occupies approximately 2 million square kilometers of land and consists of five distinct landforms, including mountains, plateaus, deserts, coastal plains and lava flows, but desert covers approximately 30% of the total land area. A lack of oases and rivers makes the land more vulnerable to desertification.

Desertification is a change in soil properties and vegetation which results in a persistent loss of ecosystems that are fundamental to sustaining life (Ouda, 2013). Although the cause of desertification varies from region to region, climate change has been a major natural factor. Saudi Arabia has a high evaporation rate and low precipitation due to a typical climate ranging from semi-arid to hyper-arid conditions. In addition, an increase in temperature and decrease in precipitation due to climate change makes the soil more vulnerable to desertification.

The Saudi Arabian government has recently taken the following actions to control and mitigate desertification:

1. Policies have been drafted to encourage the development of rural areas to reduce the pressure on urban population and density.
2. In the agricultural sector, crops such as wheat, which needs excessive water, were abundant for export, but now the planting area of wheat has been reduced; instead, junipers and arid-weather-adapted crops have been introduced.
3. Efforts have been made to conserve natural resources such as protecting forests, by introducing arid-weather-adapted vegetation and building up national parks. In addition, remote sensing techniques are being utilized to monitor forest and range inventory.
4. Twenty-seven new dams are being constructed, with a capacity of 1,690 million cubic meters (MCM) of water storage, which will help in land conservation and reducing desertification.
5. On existing deforested and deteriorated sites, afforestation and sand dune fixation projects are being developed.
6. Priority is given to controlling sand movement and the development of green barriers and roadside tree plantation.

7. Environmental legislation is being introduced to help forest and rangeland management. Other measures, such as monitoring techniques, public education, awareness and research studies have also been undertaken.

8.3 Modelling of Climate Change – Aridity Index

The parameter used to measure desertification, known as an Aridity Index (AI), is a function of temperature, precipitation and evapotranspiration rate. AI is a numerical indicator of the degree of dryness of the climate at a given location. A number of aridity indices have been proposed in the literature. These indicators identify, locate or delimit regions that suffer from a deficit of available water, a condition that can severely affect the use of the land for agriculture or livestock support.

At the turn of the 20th century, Wladimir Köppen and Rudolf Geiger developed the concept of climate classification (Kottek et al., 2006), where arid regions were defined as those places where the annual rainfall accumulation (in centimetres) is less than R/2, where:

$R = 2 \times T$ if rainfall occurs mainly in the cold season,

$R = 2 \times T + 14$ if rainfall is evenly distributed throughout the year and

$R = 2 \times T + 28$ if rainfall occurs mainly in the hot season.

where:

T is the mean annual temperature in Celsius.

This was one of the first attempts to define an aridity index, one that reflects the effects of the thermal regime and the amount and distribution of precipitation in determining the native vegetation possible in an area. It recognizes the significance of temperature in allowing colder places such as northern Canada to be considered as humid with the same level of precipitation as some tropical deserts because of lower levels of potential evapotranspiration in colder places. In the subtropics, the allowance for the distribution of rainfall between warm and cold seasons recognizes that winter rainfall is more effective for the growth of plants that can flourish in the winter and go dormant in the summer than the same amount of summer rainfall during a warm-to-hot season. Thus, a place like Athens, Greece, that gets most of its rainfall in winter can be considered to have a humid climate with roughly the same amount of rainfall that imposes semi-desert conditions in Midland, Texas, where rainfall largely occurs in the summer (Kottek et al., 2006).

In 1948, C. W. Thornthwaite defined AI as follows:

$$AI_T = 100 \times \frac{d}{n} \quad (4.1)$$

where,

d is the water deficiency calculated as the sum of the monthly differences between precipitation and potential evapotranspiration for those months when the normal precipitation is less than the normal evapotranspiration; and n stands for the sum of monthly values of potential evapotranspiration for the deficient months (after Huschke, 1959).

This AI was later used by Meigs (1961) to delineate the arid zones of the world in the context of the UNESCO Arid Zone Research Programme.

In the preparations leading to the UN Conference on Desertification, the United Nations Environment Programme (UNEP) issued a dryness map based on a different aridity index (AI), proposed originally by Mikhail Ivanovich Budyko (1958) and defined as follows:

$$AI_B = 100 \times \frac{R}{LP} \qquad (4.2)$$

where:

R is the mean annual net radiation (also known as the net radiation balance), *P* is the mean annual precipitation and *L* is the latent heat of vaporization for water. Note that this index is dimensionless and that the variables R, L and P can be expressed in any system of units that is self-consistent.

More recently, UNEP has adopted yet another AI as defined by the following equation:

$$AI_U = \frac{P}{PET} \qquad (4.3)$$

where:

PET is the potential evapotranspiration and P is the average annual precipitation (UNEP, 1992). Here also, *PET* and *P* must be expressed in the same units, for example, in millimetres. In this latter case, the boundaries that define various degrees of aridity and the approximate areas involved are listed in Table 8.1.

Table 8.1: Classification of Aridity Index

Classification	Aridity Index	Global Land Area
Hyper-Arid	AI < 0.05	7.5%
Arid	0.05 < AI < 0.20	12.1%
Semi-Arid	0.20 < AI < 0.50	17.7%
Dry Sub-Humid	0.50 < AI < 0.65	9.9%

In this section, we will use the UNEP definition to estimate the AI.

8.4 Assessment of Vulnerability of Desertification

According to climate change information (wind speed, temperature, relative humidity and precipitation) from the PRECIS regional model (See sub section 7.3.2 in Water Resources section), was used to calculate evapotranspiration. According to the modelling result of precipitation and evapotranspiration, the corresponding AI for the 28,000 grids in the KSA was calculated based on Equation 4.3. The annual AI for the first (2030) and the last (2080) years of simulation runs are plotted in Figure 8.1. The difference between the annual values from these first and last years are plotted in Figure 8.2 and the corresponding trend values are presented in Figure 4.3. Seasonal plots covering Winter (December to February); Spring (March to May); Summer (June to August) and Fall season (September to November) for 2030 and 2080 are presented in Appendix 8A.

The aridity indices distributions are usually very low in most areas of Saudi Arabia, with slight seasonal changes. The aridity indices in most areas are lower than 0.05, which, according to the classification in Table 8.1, means that these areas are hyper-arid. The highest vulnerability to desertification usually occurs in winter and fall (Appendix 8A) in the southeast (Ash Sharqiyah region) and most of the central to north regions in the summer (Appendix 8A). In 2030, winter and summer are two seasons in which the whole Kingdom (except the southwest corner) is highly vulnerable to desertification. In spring and fall, vulnerability in some central and northeast areas is reduced. The vulnerability of the southeast mountain area is much lower than in other areas.

The overall desertification vulnerability trend is about 0–0.04%, which is very insignificant. The decreasing trend is more significant in the northwest. In addition to the southwest corner, the east also has a decreasing vulnerability. The trend in the southwest corner can be up to 2%, leading to a high resistance to desertification. Overall, vulnerability to desertification will increase in the northwest, remain constant in the central-east part and be significantly reduced in the southwest. The change in desertification vulnerability in other areas in 50 years will be insignificant due to the currently prevailing hyper-arid conditions. As a result, even a very insignificant change will have a devastating effect on ecosystems as it has already reached a very fragile condition.

Figure 8.1: Aridity Index in 2030 (Left) and 2080 (Right)

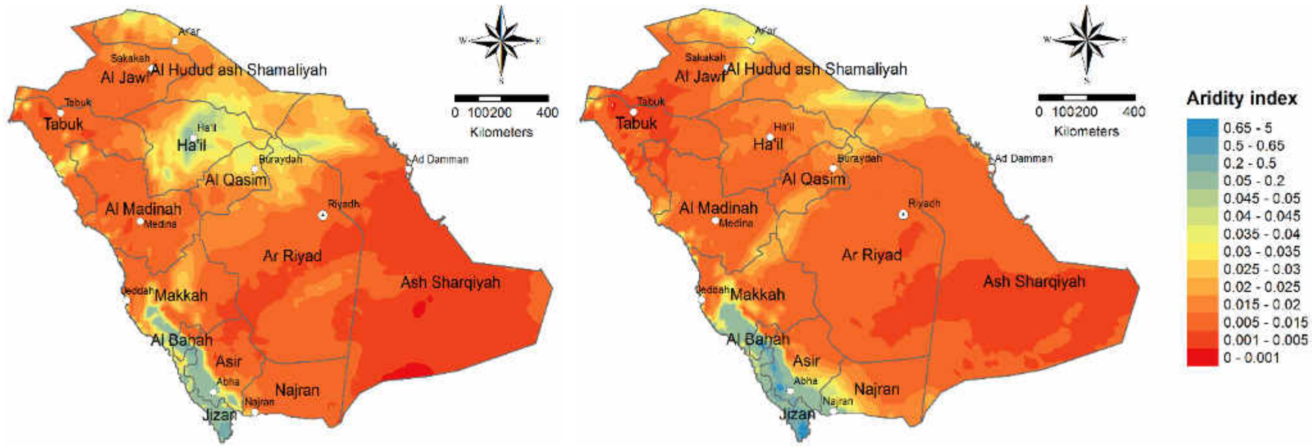


Figure 8.2: Difference of Aridity Index from 2030 to 2080

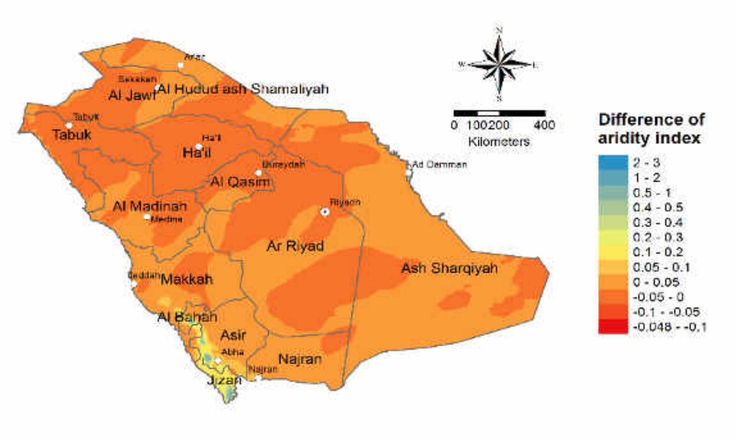
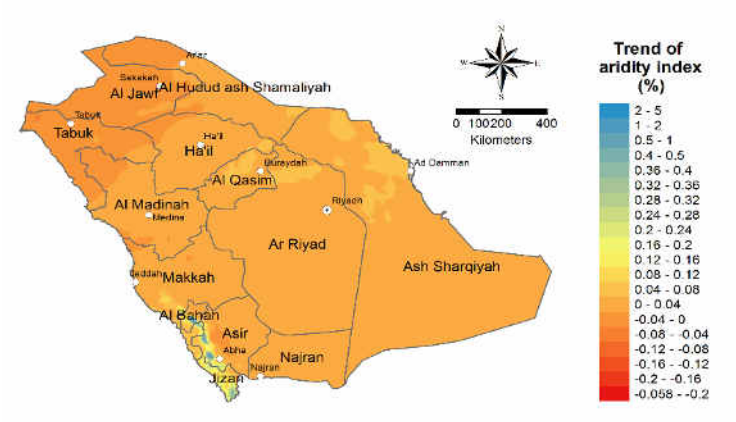


Figure 8.3: Trend of Aridity Index from 2030 to 2080



8.5 Desertification Management

8.5.1 Agricultural Sector

KSA is seeking to achieve food security by implementing its newly prepared water and environment friendly agricultural strategy and by developing social security network programmes for low income inhabitants (MOA, 2010). This strategy also includes promoting Saudi agricultural investments in collaboration with countries with a high agricultural potential. This policy primarily aims at producing food, but it also aims at saving 8.5 billion cubic meters (BCM) of irrigation water by 2030. The key targets are to:

- Reduce the hectares of producing wheat by 94% from 523,000 ha in 2004 to 33,700 ha in 2030.
- Stop alfalfa and other high water-consuming fodder crop production except where they utilize treated wastewater and promote the development of feed industries using agricultural waste products.
- Improve irrigation efficiency from 45% in 2010 to 65% in 2030 by improving agricultural and irrigation practices and using new irrigation water saving technologies and growing crops with low water requirements.
- Double fish production and improve the quality of fish farming to international standards.
- Increase fishing areas in international waters, promote investment in aquaculture and use genetic engineering to improve fish resources.
- Control coastal erosion by increasing protection of the coral reefs and mangrove areas.

This agricultural strategy also includes developing a national agricultural meteorology network and early warning system to improve water management with a more reliable prediction of droughts, pests and extreme events. It also aims to strengthen research and capacity building, technology transfer and information and marketing systems.

In Saudi Arabia, reference evapotranspiration (ET_0) is the key agro-climatic index that will determine future domestic crop production. Even though crops are predominantly grown on irrigated land (FAO, 2009), crop yield (metric ton/ha) may decline with an increase in ET0, since around half of Saudi Arabian irrigation systems depend on renewable groundwater resources which are being depleted due to low precipitation and high water demand (Alkolibi, 2002; Elnesr et al., 2010).

8.5.2 Strategy for Desertification Management

The prevailing economic development patterns, which persisted for a long time in the Gulf region, are based on conspicuous consumption patterns designed to drive society towards an excessive increase in production and consumption of goods and services (Taher and Hajjar, 2013). Saudi Arabia has planned to phase out the domestic production of wheat completely by 2016 and is now leasing agricultural land in African and Asian countries. The largest underlying uncertainty for crop production and crop yields in Saudi Arabia is due to a high demand for groundwater in agriculture, which cannot be sustained. Over 90% of crop production in Saudi Arabia is based on irrigation, which implies that moderate to high crop yield losses could be possible if a transition to rain-fed crop production were to occur (Climate: Observations, projections and impacts, 2011).

Technologies and control measures have been developed to control sand movement and sand drift. Factors affecting sand dune movement include surface roughness, the water-holding capacity of sand and temperature. Based on these factors, sand stabilization and vegetation have been introduced. Sand stabilization is achieved by covering a thin layer of a sand dune with a chemical stabilizer, resulting in the formation of a brittle crust on the surface that can easily be broken by man, animal, or vehicle movement. A very important requirement is that the stabilizer be a vegetation supportive and environmentally acceptable substance. Saudi Aramco used about 300,000 bbl/year of heavy crude oil and tar-oil for general purposes, including sand control and berm stabilization. Oil stabilization was found to be effective in large areas and was recognized as the most effective solution to control sand dune movement. However, the disadvantage is that it affects the appearance of the land and tends to degrade the soil on a long-term basis (Alghamdi, 2005).

Vegetation increases the surface roughness of the sand sheet or dune surface and thus stops sand migration. Although this measure is an environmentally sound solution, it is impractical and expensive when it comes to an open desert with very low precipitation. Vegetation might be considered a valuable solution where treated sewage water is available (Alghamdi, 2005).

Because of the disadvantages and difficulties in utilizing oil stabilization and vegetation, oil mulch was developed as a new stabilization material. Oil mulch, a hydrocarbon colloid, is a by-product of oil refining industries. Meanwhile, to help in sand stabilization, it can be sprayed when seeding plants, with the help of mulch. Even at a sand drifting area, vegetation can grab more water and maintain moisture in the soil (Amiraslani and Dragovich, 2010). With the help of mulch, reforesting on desertification lands will be cost-effective.

8.6 Conclusions and Recommendations

8.6.1 Conclusions

Estimates of climatic parameters show that KSA may suffer from increased droughts, more communicable diseases, less production of agricultural food and insufficient water in the future. According to the modelling results of precipitation and evapotranspiration, the corresponding aridity index for KSA's 28,000 grids were calculated based on the equation provided by UNEP. The results indicate that the aridity indices distributions are usually very low in most areas, with slight seasonal changes. These indices are lower than 0.05, which means that the areas are hyper-arid. Usually, the highest vulnerability to desertification occurs in winter or fall in the southeast (Ash Sharqiyah region) and in summer in most of the central to north areas. Vulnerability to desertification in over 90% of the areas is already so high that further deterioration is not aggravated significantly by the prediction model. The desertification situation in some regions of the southwest corner (central Al Baha, southwest Asir and Jazan) will be relieved from 2030 to 2080. Nevertheless, vulnerability to desertification in KSA is still very high. The overall trend of desertification vulnerability is about 0–0.04%, which is very insignificant. The decreasing trend is more significant in spring in the northwest, but not in summer (Appendix 8A). The situation of winter and fall is more or less the same (Appendix 8A). In addition to the southwest, the east also has a decreasing vulnerability. The trend in the southwest corner can be up to 2%, leading to a high resistance to desertification (Appendix 8A). Vulnerability to desertification will increase in the northwest, not change significantly in the central-east part and be significantly reduced in the southwest.

In the process of desertification, the soil organic and nutrients contents will be slowly degraded and the deterioration of soil structure and salinity buildup will lead to more evapotranspiration and less water supply to less productive lands to support rural communities. This will be pronounced in those rangelands which provide natural grazing for animals of rural communities especially the nomads who herd sheep and camels. The reduction in surface moisture or vegetative cover would increase temperatures and reduce rainfall. Desertification is likely to become irreversible if the environment becomes drier and the soil becomes further degraded through erosion and compaction. The most serious impacts on livestock production would be in the northern, southern and central parts of Saudi Arabia, where the rangelands are already under stress due to overgrazing and population growth. Substitution of natural grazing lands with cropped forage will be difficult due to an expected reduction in water supply sources. The importation and supply of forage crops to nomads and rural communities will be very difficult. The above impacts along with the expected deterioration of water supplies, rainfall, surface runoff and aquifer recharge will have a serious impact on rural communities as the welfare of these communities will be seriously threatened.

8.6.2 Recommendations

This study has limitations in terms of application, most of which can be attributed to the simplification of concept and predictions of climatic parameters by the Hadley model and the simplification of the evapotranspiration aridity index across KSA. Despite these limitations, the findings of this study shed light on the possible implications of climatic changes and future difficulties in addressing desertification with climate change. This study will also provide a guideline to identify an appropriate approach to future water resources and desertification management. Thus, a sustainable approach can be developed to protect human health, ecological balance and the environment. Although the current study gives an insight into the desertification trend in KSA using the PRECIS-RCM predicted data at 28,000 grid points covering Saudi Arabia, for a better understanding and more effective planning to combat desertification the following recommendations are made:

- Investigate the possible impacts of micro-climate changes, including frequent sandstorms, poor visibility and the suspension of fine particles in the environment, on desertification in the region.
- Relate the climate change impacts and desertification in KSA with regional and international impacts.
- Implement risk management applications to combat desertification with hazard mapping, agro-climatic zoning and the establishment of partnerships on land use for vegetation, terrestrial ecosystems and wildlife protection.
- Develop a multi-criteria decision support system for integrated water resource and desertification management.

Sustainable Water Resources Management (SWRM) has become crucial to combat desertification in those countries where renewable freshwater resources are highly constrained (Husain, 2008). There is a need to develop sustainable water resources management plan for Saudi Arabia and other neighboring countries by introducing multi-criteria decision-making (MCDM) methodology (Husain and Chowdhury, 2008) and incorporating opinions of different stakeholders such as regulatory agencies, industries and consumers in the decision-making process (Husain and Khalil, 2013, Husain and Danish, 2013). Treated wastewater effluent should be used for landscaping. This will help in protecting fragile condition in the Arabian desert and to protect desert plants and wildlife.

Appendix 8A: Plots for Seasonal Scenarios

Figure 8A1: Aridity Index in Winter 2030 (Left) and 2080 (Right)

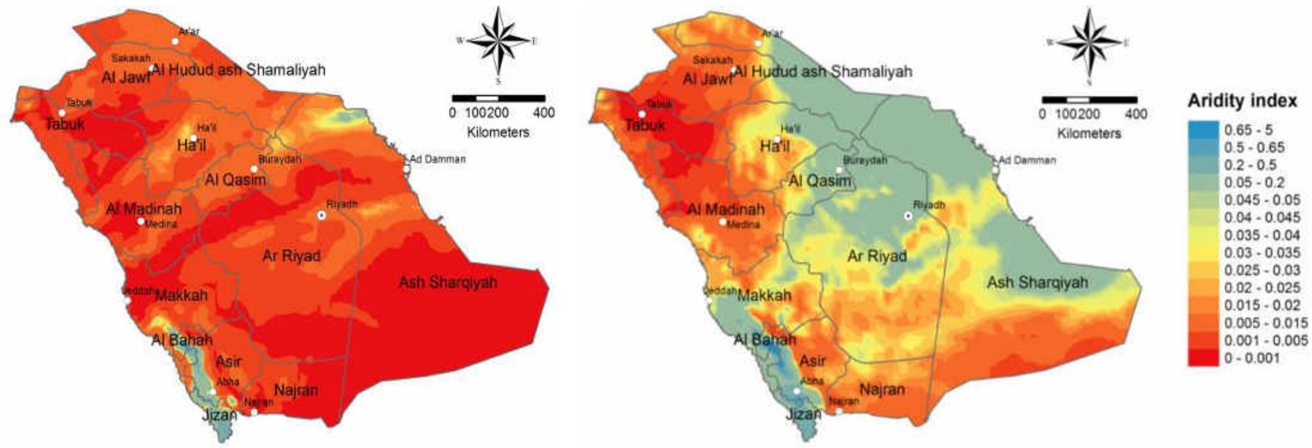


Figure 8A2: Aridity Index in Spring 2030 (Left) and 2080 (Right)

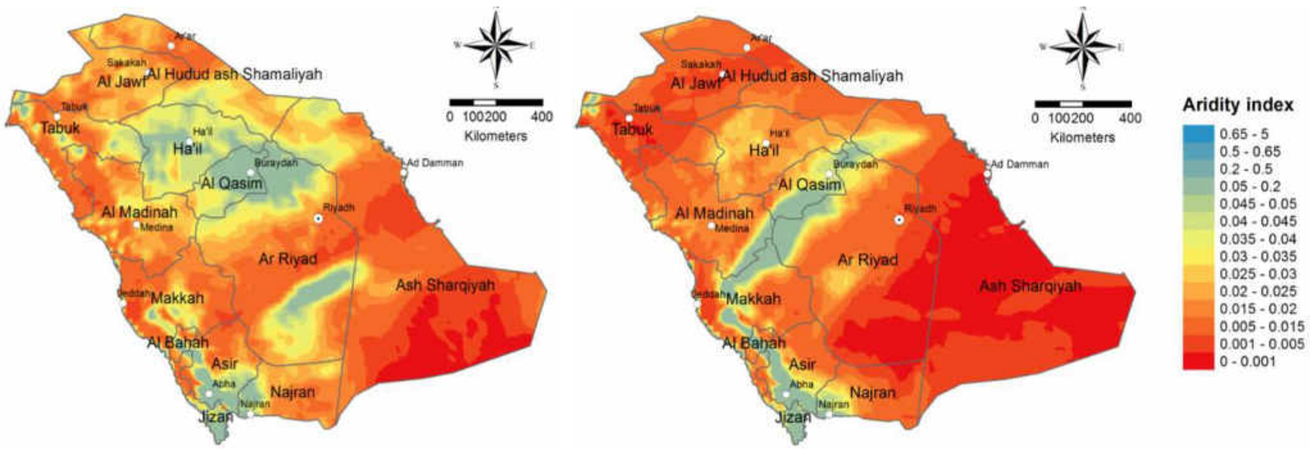


Figure 8A3: Aridity Index in Summer 2030 (Left) and 2080 (Right)

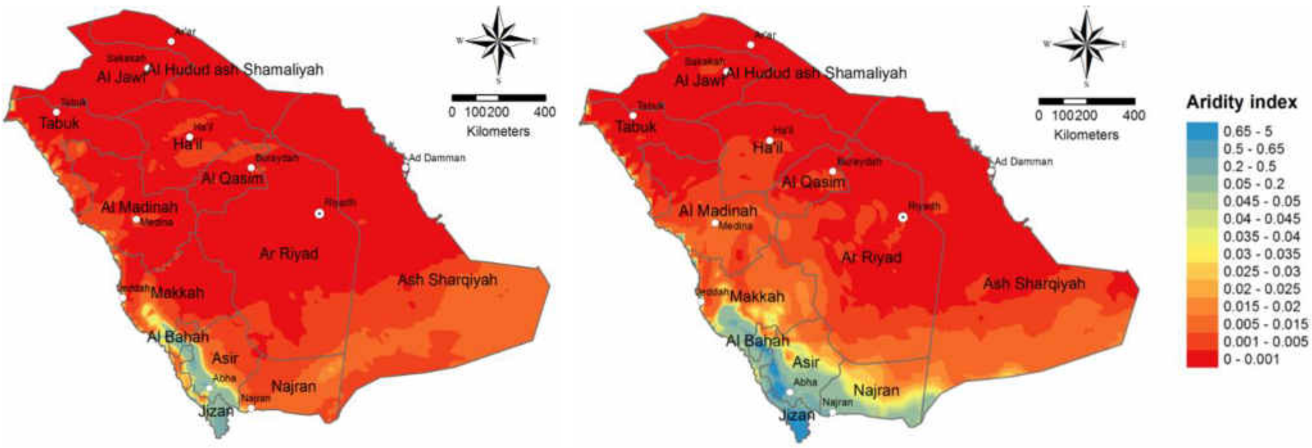


Figure 8A4: Aridity Index in Fall 2030 (Left) and 2080 (Right)

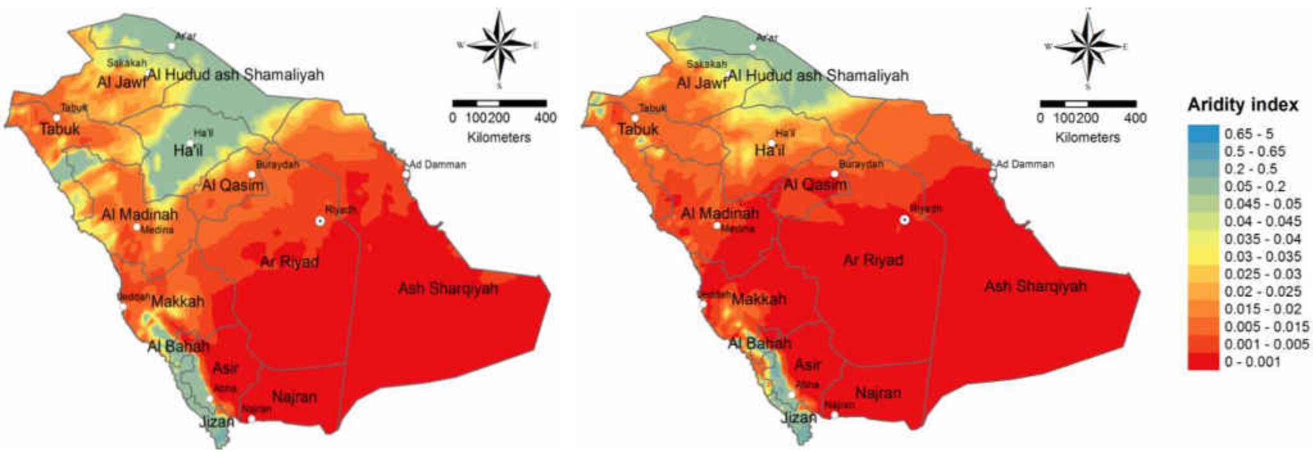
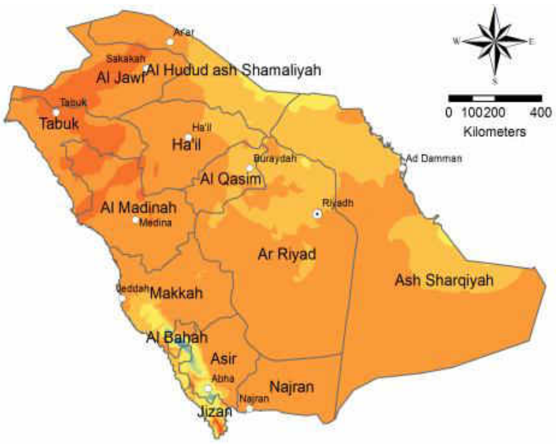
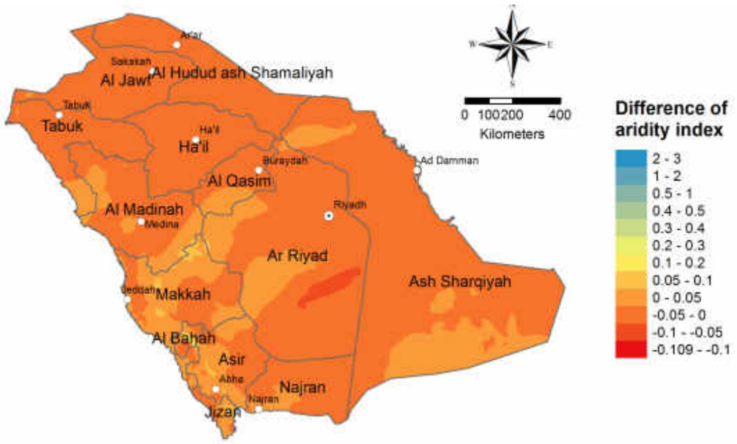


Figure 8A5: Difference of Aridity Index in (a) Winter, (b) Spring, (c) Summer and (d) Fall from 2030 – 2080

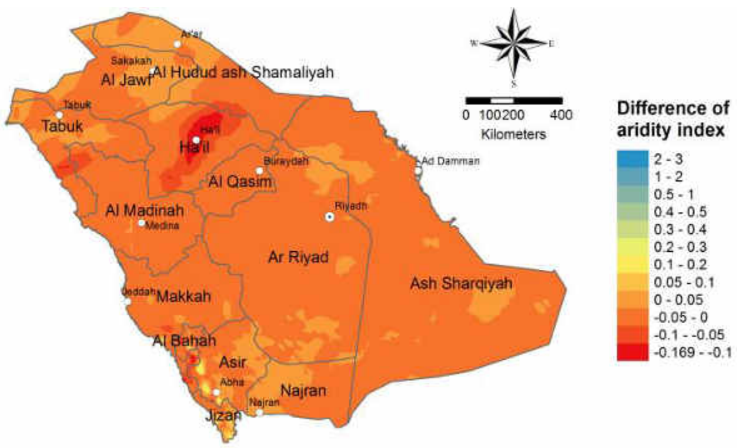


(a)



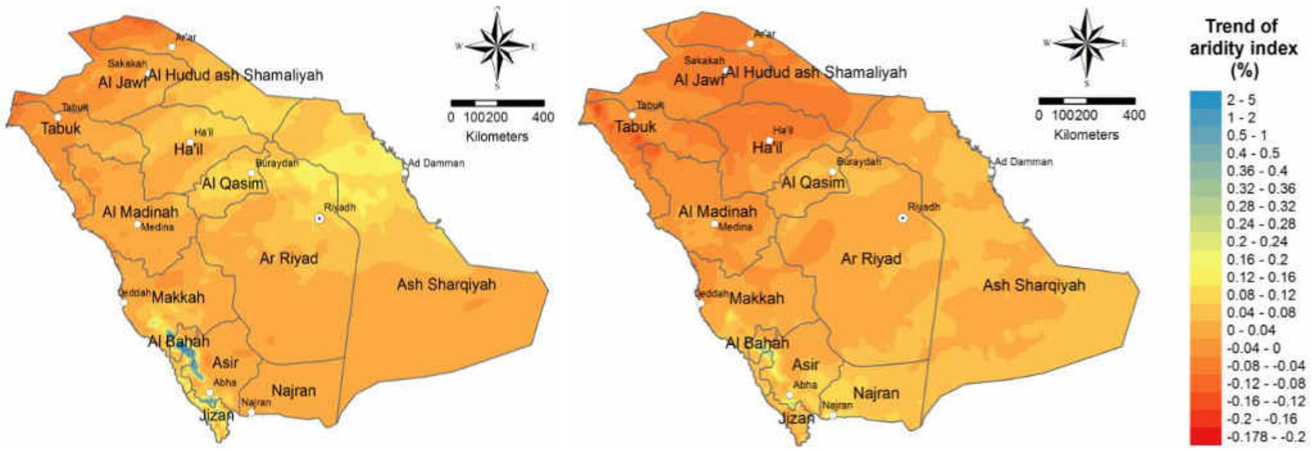
(b)

(c)

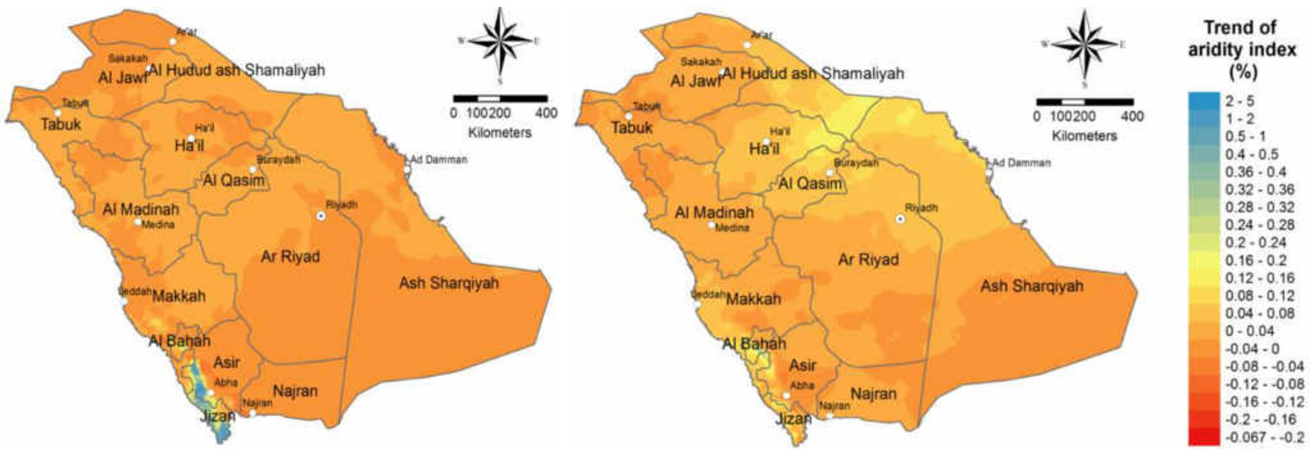


(d)

Figure 8A6: Trend of Aridity Index in (a) Winter, (b) Spring, (c) Summer and (d) Fall from 2030 – 2080



(a) (b)



(c) (d)

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SECTION – 9

Impacts of Climate Change on Health

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Section 9: Impacts of Climate Change on Health

9.1 Introduction:

The health sector is one of the most important sectors within the Kingdom of Saudi Arabia and the Government has over the years given it adequate attention and resources. The Government is committed to provide health services easily and conveniently at the highest levels and meeting international standards for residents. The entities providing various forms of health delivery services are as follows:

- The Ministry of Health (MOH): It is the major government agency entrusted with the provision of preventive, curative and rehabilitative health care for the Kingdom's population. The Ministry is responsible for the management, planning, financing and regulating the health care sector and also undertakes the overall supervision and follow-up of health care related activities carried out by the private sector.
- Three other entities also finance and deliver primary, secondary and tertiary health care to specific enrolled security and armed forces populations namely, the Ministry of Defence (MOD), the Ministry of Interior (MOI) and the Ministry of National Guard (MONG).
- Several other autonomous government agencies are also responsible for the delivery and financing of health care services. These are the Ministry of Education providing immediate primary health care to students. The universities also provide, through their medical colleges or hospitals, specialist curative services and medical education and training programs, while conducting health research in collaboration with other research centers.
- The Ministry of Labour and Social Affairs operates institutions for the mentally retarded and custodial homes for orphans, providing their guests with required medical care.
- The General Organization for Social Insurance (GOSI).
- General Presidency of Youth Welfare provides health services for certain categories of the population in connection with its management of sport facilities.
- The Royal Commission for Jubail and Yanbu provides health facilities for employees and residents in the two industrial cities of Jubail and Yanbu.
- The Saudi Arabian Airlines operates its own health care facilities and provides health care services to its employees.
- Private sector also provides health services through its health facilities including hospitals, dispensaries, laboratories, pharmacies and physiotherapy centers throughout the Kingdom.

9.2 Saudi Health Council (SHC):

The vision, mission and functions of the Saudi Health Council (SHC, 2016) are as follows:

Vision

A coordinated and integrated health delivery parties in the Kingdom of Saudi Arabia to ensure reaching outstanding health level through enhancing health and reducing rates of illness, disability and death.

Mission

To set the structures in place that include the coordination and cooperation among different healthcare delivery parties in the Kingdom to provide a high quality easily accessible health service which eliminates duplication and wasting resources and ensures health services distribution, also working with relevant health parties and sectors which ensure the execution of national programs.

Functions

The council performs several functions, important among them are the following: preparation of the strategy for effective health delivery system in the Kingdom of Saudi Arabia. Setting of appropriate organization for hospitals managed by the MOH and other government agencies to ensure proper economic management on the basis of set performance standards and quality as well as putting in place cooperation and integration policy among all the parties providing health care services. It also undertakes necessary studies, hold seminars and workshops related to the decisions made by the council, establish an information system that links the council to the relevant agencies and provides the council with what it needs of information, data and reports. The council also puts in place the appropriate method to ensure the execution of its decisions and ensuring the cooperation and integration between the agencies specialized in providing health services.

9.2.1 Health Care Delivery Strategy in the Kingdom:

The approval of the formation of High Commission on the Health care strategy in the Kingdom was announced by the Royal Decree number (39175) dated 21/9/1430H (11/09/2009) which indicated by the cabinets' decision number (320) dated 17/9/1430H (11/09/2009). The Vision and Mission of the strategy are aimed at achieving the general health objective and reach the best possible health standard for the population through improving health and reducing disease, disability and death rates. In order to achieve its strategic objectives, the health care delivery strategy has adopted financial, service and health indicators.

9.2.2 Ministry of Health (MOH):

MOH is one of the largest ministries in the Kingdom of Saudi Arabia holds the full supervision of the Health Affairs in the Kingdom and provide free health services to the population and aims to accomplish a promising future vision with the delivery of best-quality integrated and comprehensive healthcare services. All health services in the Kingdom of Saudi Arabia are provided free of charge to citizens, contractors with the ministries and various state institutions and members of their families. The services are also provided without charge to pilgrims who come to the Kingdom to visit the Islamic holy sites, as well as the home labour force among citizens. In respect of contractors with the private sector institutions and companies, they are obliged to take regular health insurance for their workers and dependents.

The Ministry of Health has a 10-year strategy for the period (1431-1440H) corresponding to (2010-2019) which is coherent and consistent with the healthcare strategy of the Kingdom, ratified by the Council of Ministers' resolution No. 320, dated 17/9/1430H, corresponding to 7/9/2009. Since the beginning of the preparation of the 5-year national development plans of the Kingdom of Saudi Arabia about 40 years ago, there has been a steady improvement of healthcare services provided to the Saudi citizens. The huge interest in developing a better healthcare service is embodied and manifested in Article 31 of The Basic Law of Saudi Arabia, which states that "the State shall protect public health and provide healthcare to every citizen".

The strategy also effectively responses to a series of major challenges facing the healthcare sector in Saudi Arabia. There is an ever increasing level of awareness among service recipients as well as their high level of expectation for the delivery of health services of high quality standards that is readily accessible. The health sector is also witnessing many challenges such as the high costs of health services resulting from the accelerating development of medical technologies in hardware, equipment tools and advanced and expensive medical technologies, as well as the unremitting discoveries of new expensive drugs. This is however a global challenge not limited to the Kingdom alone.

Through the current strategic plan, the Ministry of Health has employed modern methodologies in providing health care services that makes the health system completely devoted to patients, thus ensuring a patient-centered health care system aimed at meeting patients' health needs in the right place at the right time. This covers everything starting from primary health care till specialized therapeutic services in a professional manner, preserving all patients' rights, such as the right to know about their condition, the right to know the different treatment options, the right to choose their physician and the right to be always treated with care and respect.

This strategy proceeds from a set of basic values and principles governing the work in all MOH facilities and these include: Patient first, Justice, Professionalism, Quality, Honesty and Transparency, Teamwork, Initiative, Productivity and Societal involvement

9.3 Direct and Indirect Impacts of Climate and Weather on Human Health:

Although global warming may bring some localized benefits, such as fewer winter deaths in temperate climates and increased food production in certain areas, the overall health effects of a changing climate are likely to be overwhelmingly negative. Climate change affects social and environmental determinants of health namely; clean air, safe drinking water, sufficient food and secure shelter.

9.3.1 Heat-Related Impacts

According the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC), climate change will have widespread and diverse health impacts (IPCC, 2014). More frequent and intense heat waves will increase mortality and morbidity in vulnerable groups in the urban areas. Changes in the geographical distribution of vector-borne diseases, as vector species that carry and transmit diseases migrate to more hospitable environments, will occur. (Smith, K.R, et al, 2014). These effects will be most noted close to the edges of the current habitats of these species. At present the worldwide burden of human ill-health from climate change is relatively small compared with effects of other stressors and is not well quantified. However, there has been increased heat-related mortality and decreased cold-related mortality in some regions as a result of warming. Local changes in temperature and rainfall have altered the distribution of some waterborne illnesses and disease vectors (WHO, 2003).

Impacts from recent climate-related extremes, such as heat waves, droughts, floods, cyclones and wildfires reveal significant vulnerability and exposure of some ecosystems and many human systems to current climate variability. Impacts of such climate-related extremes include alteration of ecosystems, disruption of food production and water supply, damage to infrastructure and settlements, morbidity and mortality and consequences for mental health and human well-being. For countries at all levels of development, these impacts are consistent with a significant lack of preparedness for current climate variability in some sectors (Campbell-Lendrum, D. and R. Woodruff, 2007).

Until mid-century, projected climate change will impact human health mainly by exacerbating health problems that already exist. Throughout the 21st century, climate change is expected to lead to increases in ill-health in many regions and especially in developing countries as compared to a baseline without climate change.

Examples include greater likelihood of injury, disease and death due to more intense heat waves and fires increased likelihood of under-nutrition resulting from diminished food production in poor regions, risks from lost work capacity and reduced labour productivity in vulnerable populations and increased risks from food- and water-borne diseases and vector-borne diseases. Positive effects are expected to include modest reductions in cold-related mortality and morbidity in some areas due to fewer cold extremes, geographical shifts in food production and reduced capacity of vectors to transmit some diseases.

But globally over the 21st century, the magnitude and severity of negative impacts are projected to increasingly outweigh positive impacts. The most effective vulnerability reduction measures for health in the near term are programs that implement and improve basic public health measures such as provision of clean water and sanitation, secured essential health care including vaccination and child health services, increased capacity for disaster preparedness and response and poverty alleviate.

Heat waves can cause death either directly through causing heat illnesses or by aggravating pre-existing heat-sensitive medical conditions. Additional risk factors for heat-related mortality are mediated through the additional pressure on water and electrical systems, risk-associated behavioral responses and worsening environmental conditions, especially air quality.

Increased heat-related morbidity can occur, like mortality, through direct heat illness or through aggravation of pre-existing diseases. Either of these outcomes may require primary care or hospitalization and a proportion of this morbidity may eventually result in mortality.

9.3.2 Floods

In 2009, heavy rains in Saudi Arabia left 77 people dead and substantially damaged infrastructure and residential areas in Jeddah (Assaf, 2010). In 2011 there were also 10 deaths and damage to infrastructure and properties also in Jeddah (Flood list, 2013). In recent years Saudi Arabia has been experiencing almost yearly flood disasters and in several cities across the Kingdom, people get stranded for several days with some fatalities and damage to property.

9.3.3 Ecosystem-Mediated Impacts

Climate change and vector-borne and other infectious diseases (Malaria and Dengue fever)

In Saudi Arabia, epidemics of malaria occurred in western province in 1950, 1957, 1982 after heavy rains and floods (Sebai, 1988). From this period, after heavy rains, the malaria epidemics frequently occur and continued to be a major health problem in many parts of the Kingdom. During the period of 1997 – 1998, MOH Annual Report (1998) report stated flare up of malaria epidemic where more than 35 thousand cases were reported. This was attributed to heavy rains that occurred worldwide, during which heavy breeding of malaria vectors were encountered leading to increased malaria outbreaks. Also during 2007, due to heavy rains, increased number of malaria cases were reported as a result of increased malaria vector population. These fluctuations in the occurrence of malaria cases can be related directly to rainfall situations, where heavy rains and other climatic conditions (temperature and relative humidity RH %), secure many favourable breeding conditions to mosquito vectors of malaria.

The Ministry of Health (MOH) established a malaria control programme in all regions of the Kingdom since 1963 and has continued as one of the major preventive health activities in the country (Snow, et.al., 2003). The programme was instituted with the objective of reducing the incidence of malaria and subsequently eradicating the infection in the Kingdom. Since then the burden of malaria has been successfully reduced through an integrated program of:

- Early case detection and proper malaria case management
- Integrated vector control according to WHO guidelines
- Inter sectorial co ordination
- Health education
- Continuous man power training
- Community participation
- Partnership with all concern agencies
- Monitoring & Evaluation (M&E)

Malaria transmission was interrupted in the Eastern and Northern Provinces since early 1970s, as well as the pilgrimage areas of Western Provinces and the main valleys of Asir Plateau by the year 1980. However, residual foci of malaria were still found and continued to be a major health problem in the south-western parts in Tihama areas along the Red Sea. Surveyed villages in these foothills presented a spleen rate of about 80% to 100% among the young school children.

Since 2004, the MOH has initiated a new strategy of malaria elimination program from the Kingdom (Global Health Sciences, 2015). The government has adopted a national malaria elimination policy with the objective of interrupting local malaria transmission from all parts of the Kingdom. Hence, adequate facilities, efforts and manpower have been secured to achieve this objective within a specific period of time. Two major precipitations in August of 2005 and 2007 did not, however, lead to significant epidemics as witnessed during the El Nino years of 1997/1998. It is notable that the period 2007–2014 was drier than the period 2000–2006, corresponding with lower case-incidence in the second interval (El Hassan et al., 2015).

Dengue fever was reported in Jeddah in 1993 with consequent epidemic in 1994. Due to this outbreak, active surveillance was established by MOH. All the hospitals in the Kingdom were advised to report suspect cases of dengue hemorrhagic fever (Fakeeh and Zaki, 2001). Alshehri (2013) showed that there is a strong correlation between mosquito density and climate factors as temperature and relative humidity. The climate factors help the replication and the movement of the disease agent and vector. In addition, climate change may also be important factor in expanded geographical ranges for dengue fever cases. Many studies indicate that as the temperature of a region increases, the geographical range of mosquitoes increases to higher altitudes.

Reports of the MOH over the past 20 years have clearly showed the effect of climate change on the health of its people. The reports compared the data on incidence and prevalence of dengue fever, mosquito density and climate parameters such as rain fall, temperature and humidity to help explain in part disease occurrence during any particular year as they relate to outbreaks and fluctuations.

The following disease pattern was observed (Fakeeh, M and Zaki A.M., 2003 and MOH, 2010):

- Cases usually begin to increase during the months of February and March, peaking in Makkah and Jazan areas in April and May. In Jeddah the peak is during May and June and occasionally in July. The cases decrease at the end of July or sometimes in August.
- A rapid decrease in the number of reported cases was noted for almost one decade (reported cases from 1995 to 2003 ranged between 0-36 cases per year).

The disease resurged in 2004 in Makkah and in 2006, another outbreak was reported in Jeddah and the number of cases reported continues to date. There were also cases detected in Jazan region in the south.

To combat this situation, a Royal Decree Number (36) was issued on 13/3/2006, whereby each concerned Ministries namely; Ministry of Health, Ministry of Municipal and Rural Affairs, Ministry of Agriculture and Ministry of Finance have been assigned a role in the process of Dengue Control and Prevention. A comprehensive plan to control dengue fever was established by the concerned parties and they consisted of (i) disease surveillance and case management (ii) vector inspection and control and (iii) health education.

All sectors of the community were engaged in an intensively coordinated work to control and remove all possible breeding sites for vector mosquitoes. As a result of these measures, the cases of dengue fever declined in 2007; but started to increase in number in the succeeding years, in Jeddah, Makkah and Jazan due to ineffective mosquito control effort (MOH, 2010).

9.3.4 Climate Change, Air Quality and Respiratory Diseases

Al-Frayh et.al. (1988) analyzed house dust samples in Riyadh and reported the presence of different types of fungal spores, among which many species are known to be allergenic. Hasnain et al. (1989) identified 32 generic categories of allergenic fungal spores in the atmosphere of Riyadh. Of these, Cladosporium was found to be highest in concentration. The concentrations of these spores are also seasonal with an increase in warmer months and a decline in winter. Some indoor air pollutants identified in this study were also linked to asthma. Later, Kwaasi et al. (1998), found that sandstorm dust is a ‘prolific source of potential triggers of allergic and non-allergic respiratory ailments’ in Riyadh. Griffin (2007) reported an increase of 100% in the number of colony-forming units (CFU) over background levels during dust storms in Saudi Arabia. Dust storms and humidity were among several environmental risk factors associated with the prevalence of asthma.

Bronchial asthma is one of the most common diseases in the Kingdom of Saudi Arabia, among children and adults. The estimated prevalence of asthma ranges from 15% to 25% with local variations between the regions, since there are very limited number of local studies about the prevalence of asthma. Some local studies have indicated the increase in the prevalence of asthma from 8% in 1986 to 23% in 1995 among school children in Riyadh, Jeddah, Hail and Jazan. Studies thereafter have shown that the burden of asthma might be significantly higher than previously estimated (Rabe et al. 2004 and Abudahish A and Bella H, 2006). These led to increased morbidity and mortality, as well as visits to primary care physicians, asthma specialists, emergency departments and hospital admissions. The result was increased sick leaves and school leaves with the loss of school and work days due to asthmatic attacks.

9.3.5 Occupational Health

Saudi Arabia, with the exception of the province of Asir, has a desert climate characterized by extreme heat during the day, an abrupt drop in temperature at night and very low annual rainfall. Because of the influence of a subtropical high-pressure system, there is considerable variation in temperature and humidity. The two main differences in the climate of Saudi Arabia can be felt between the coastal areas and the interior. The average summer temperature is about 45°C, but readings of up to 54°C are not unusual. The heat becomes intense shortly after sunrise and lasts until sunset. Medical disorders (skin disorder, heat syncope, heat cramps, heat exhaustion and heatstroke) and exacerbating pre-existing chronic conditions (various respiratory, cerebral and cardiovascular diseases), resulting from excessive exposure to hot environments occur among many types of workers include, but not limited to, petroleum drilling operators, fishermen, steel workers, oven and furnace operators, farmers, ranchers, construction and road workers. Not to be forgotten the pilgrims and visitors to the holy cities as well as employees and staff in the field in the Hajj who organize, help and serve pilgrims.

Consequently, the above-mentioned effects lead to increased morbidity and mortality, increased visits to primary care physicians, visits to emergency departments, hospital admission, admission in Intensive Care Units and increased sick leave and school leave with the loss of work and study days. To protect the workforce from the impact of heat wave, the Ministry of Labour implements the Ministerial Resolution 1559, based on the guidance of Council of Ministers, no. 25 686/b, dated 2/6/1431H (16/5/2010), which provides:

- Prohibition of work under the sun from noon until three in the evening during the period from the first of July to the end of August every year.
- Punish violators with a fine or close the facility and it may be a combination of a fine and closure.

9.3.6 Effect of Climate Change on Mental Health

Mental health takes a high position in the health worry list of climate change. That is because all environmental and physical illness affect mental well-being, especially among the vulnerable. Climate changes obviously worsen the conditions of those already suffering from mental illnesses. Before going into the details, we must stress on the psycho-social adverse effects of the media. The media through which we, the humans, are informed have reached a peak in its development and is till swiftly developing every day. TVs, PCs and mobile phones plus the internet are attainable to the vast majority of Human beings worldwide. People are informed minute by minute about floods, effects of global warming etc. raising their conscious and subconscious level of anxiety and probably pushing the vulnerable to franks categorized mental illness and the mentally ill to a possible relapse.

Mental health disease could result from organic reasons or without it. The physiology of the Human body is designed to function at optimum environmental conditions. So any changes, however minor, will have some effect on the physiology of the human being and as explained above and on the psychological wellbeing. Organic reasons related to climate changes are known to all, while the mental health results of disaster are not known to the majority of people. Anxiety, depression and post-traumatic stress disorders are on the top of the list for the general population round the globe that will certainly increase by many folds among the vulnerable and will show even worse on the mentally ill.

9.4 Adaptation Measures to Protect Health from the Adverse Effects of Climate Change

A number of strategies and actions are being put in place to improve the basic public health and health care delivery services in the Kingdom of Saudi Arabia in order to reduce the negative consequences of climate change on the health of its people. These include (WHO, 2007):

(i) Regular updates on the current evidence regarding climate change and human health impacts and adopting WHO recommendations related to raising resilience and adaptation strategies.

(ii) Strengthening of surveillance systems for diseases that are climate sensitive, such as malaria, dengue fever, leishmaniosis and schistosomiasis. There are national programs to control these diseases and existing indicators of such programs can be used to predict the extent of the impact of climate change on vector borne diseases.

(iii) Disease mapping is also carried out to pinpoint areas where people have the highest risk of contracting such kind of diseases. For example, there is observed increase of 22 percent in the number of reported cases of malaria in the Saudi Arabia in 2014 compared to the number in 2012 (MOH, 2013). According to the Saudi Ministry of Health and the World Health Organization, statistics for the year 2012 revealed that there has been a very successful control of schistosomiasis over the past twenty years. However, in the case of leishmaniosis, there has been fluctuations in the number of reported cases year after year, the disease appears to spreading to areas that had no previous reported cases (WHO, 2015).

(iv) Institute measures to building the capacity of officials of the government and private sector to understand the causes and impacts of field of climate change.

(v) Develop an awareness program about the potential health effects of climate change.

(vi) Improve epidemiological surveillance program of food borne diseases as diseases transmitted through food pose a threat to public health, especially in light of climate change and this occupies the problem of global concern; with the resulting human and economic losses.

(vii) Strengthening of emergency health systems and early warning systems to cope with emergency health threats which may be caused by climate change such as floods and other crises that may worsen due to climate change through the General Administration of health emergencies.

(viii) Protection of workers, any type of injuries resulting from working in high temperatures through the enactment of legislation to prohibit labour under the sun during the period from 12 noon until 3 pm during the months of July and August.

Early Warning Systems:

Extreme weather events such as floods, heat wave, aridness and hurricanes in the Kingdom will induce significant health effects. The strategy to develop an Early Warning systems and adaptation measures to reduce human health consequences of climatic change depends on:

(i) Improving Strategic Planning for Preparedness and Response and enhancing Coordination of Emergency Health Services.
(ii) Controlling and Preventing Disease Outbreaks during Emergencies.
(iii) Ensuring Effective Delivery of Emergency Health Services.
(iv) Improving Information Management and Analysis for Emergency Health Services

Role of other sectors in Health Adaptation that play an important part in determining the risks of disease and injury resulting from climate change (water supply and sanitation, infrastructure, energy and transportation sectors, etc.).

9.4.1 Data and Information Gaps and Other Constraints:

The public and health care professionals are not fully aware about the issue of climate change and its adverse health impacts. There is also a lack of comprehensive research programme on climate change and health impacts across the Kingdom. As a result, there is a scarce statistics on climate related health problems and other environment related health events with climate change.

9.5 Recommendations

It is recommended to initiate/strengthen the following actions:

- Awareness raising of the health impacts of climate change in Saudi Arabia.
- A strategic partnership with universities and research centers to conduct researches in the field of climate change and health at undergraduate and graduate levels.
- A national awareness programme on climate change and health should be conducted.

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Section - 10

Impacts of Climate Change on Agriculture and Food Security

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Section 10: Impacts of Climate Change on Agriculture and Food Security

10.1 Introduction

Currently, Saudi Arabia spends about 4 percent of its foreign currency on food imports. It can import its food requirements from international sources. Even in times of high food prices, such as in 2008, Saudi Arabia did not have any difficulty in securing food imports. This secure position is expected to continue as long as the country maintains strong exports and food is available in the international market. At the household level, Saudi Arabia is also generally food-secure due to a relatively higher per capita income of about $2,000 a month (Chatham House, 2013). However, specific pockets of poverty may exist where incomes and household food security are considerably low.

Serious environmental constraints, in particular water scarcity, undermine Saudi Arabia's ability to produce food domestically. To address these challenges, the Saudi government has phased out subsidies on domestically produced wheat and barley. Although these policy changes have led to a reduction in wheat acreage, farmers have replaced this crop with alfalfa, a more water-intensive crop. The government policy to promote access to water, low pricing tariffs and the prioritization of fresh water for agriculture rather than household use has resulted in inefficient water use. Agriculture water demand amounted to approximately 90% of the total water demand. As a result, a significant amount of its non-renewable groundwater resources may have been depleted in order to meet agricultural demands.

Over-exploitation of fisheries provides a further environmental challenge. Due to their relatively small size and limited oceanographic circulation, both the Red Sea and the Arabian Gulf are particularly vulnerable to toxic pollution, eutrophication, habitat degradation and loss of species, all of which undermine the particularly useful role that local fish stocks could play in achieving food security in the Gulf region.

The main objective of this chapter of the report is to assess the impact of climate change on Saudi Arabia's agriculture and food security and to recommend measures to address the adverse impacts of climate change on the sector.

10.2 Impact Of Climate Change On Agriculture and Food Security

10.2.1 Food Supply and Challenges

Due to aridity and low precipitation, Saudi Arabia faces a challenge to become self-sufficient in food (World Bank and FAO, 2012). A rising population will limit and cause a decline in resources, including arable land and fresh water. In addition, the increasing impacts from climate change will lead to more challenges to food security.

Over the past decade, Saudi Arabia's agriculture has drastically improved. The government has converted large areas of desert into agricultural fields. Implementing major irrigation projects and adopting large-scale mechanization has resulted in developing agriculture, adding previously barren areas to the stock of cultivatable land.

Today agriculture in Saudi Arabia focuses on wheat, dates, dairy products, eggs, fish, poultry, fruits, vegetables and flowers. Table 10.1 shows the trend of total agriculture area in use, total cereal production area in use and production, total wheat production area in use and production, total date palm area in use, number of date palm trees and dates production, estimated number of camels, sheep, goats, cows, number of livestock projects, milk production, number of chicken, eggs, fish, shrimp catch and production and honey production respectively.

Figures 10.1 to 10.10 show these agriculture areas in use and production of that crop trend, foods in the KSA from 2009 to 2013 based on data from the Ministry of Agriculture Statistical Yearbook (2014).

These figures show that the agriculture area and the production of cereals and wheat have dropped but these figures indicate that crop yields have mainly increased during 2009-2013, which may be due to the use of modern technologies. However, significantly decreased yields of cereals and wheat were observed since 2010, due to a change in government policy to restrict the use of non-renewable groundwater resources for agriculture and other purposes. Furthermore, even though crop yields continue to increase, the gaps between yields and productions have become larger in the period under discussion. However, area of date palm remains constant with increased production. Honey, eggs and milk production increased considerably, while chicken production showed a minor decreasing trend. Cattles showed a mixed trend with camels and cows remaining constant while sheep showed decreasing and goats an increasing trend.

Table 10.1: Various Agricultural Parameters and Production Figures for the Period 2009-2013

Year	2009	2010	2011	2012	2013
Agriculture Area (Hectare)	834,989	806,682	787,739	745,637	694,549
Area for Cereal Production (Hectare)	328,725	286,932	260,312	212,156	166,005
Production of Cereal Crops (tons)	1,592,405	1,570,944	1,418,160	1,088,349	885,012
Area for Wheat Production (Hectare)	195,884	219,505	192,818	144,169	102,613
Production of Wheat Crops (tons)	1,152,447	1,349,389	1,184,454	854,256	660,145
Area for Dates Production (Hectare)	161,975	155,118	156,023	156,848	156,901
Estimated Number of Date Palm Trees	23,634,310	23,437,090	21,617,367	25,096,578	25,104,161
Production of Dates (tons)	991,660	991,546	1,008,105	1,031,082	1,095,158
Estimated Number of Camels	233,085	223,441	219,931	213,320	229,871
Estimated Number of Sheep	5,987,668	6,249,904	6,562,871	5,921,726	5,885,532
Estimated Number of Goats	1,036,341	1,075,394	1,068,883	1,057,928	1,333,990
Estimated Number of Cows	456,371	486,503	426,204	393,324	424,489
Milk Production (Thousand Liters)	-	1,603,949	1,678,244	1,712,422	1,783,286
Number of Chicken	602,250,596	585,909,646	527,717,142	444,680,021	493,201,951
Number of Eggs (in 1000)	-	-	3,995,925	4,003,237	4,380,143
Fish Shrimps Catch and Production of Fish Farms (tons)	100,471	91,511	90,752	89,999	90,053
Honey Produced (kg)	107,736	113,406	119,375	125,658	130,045

**Agriculture Statistical Year Book 2014*

Figure 10.1: Agriculture Area Progression with time (2009-2013)

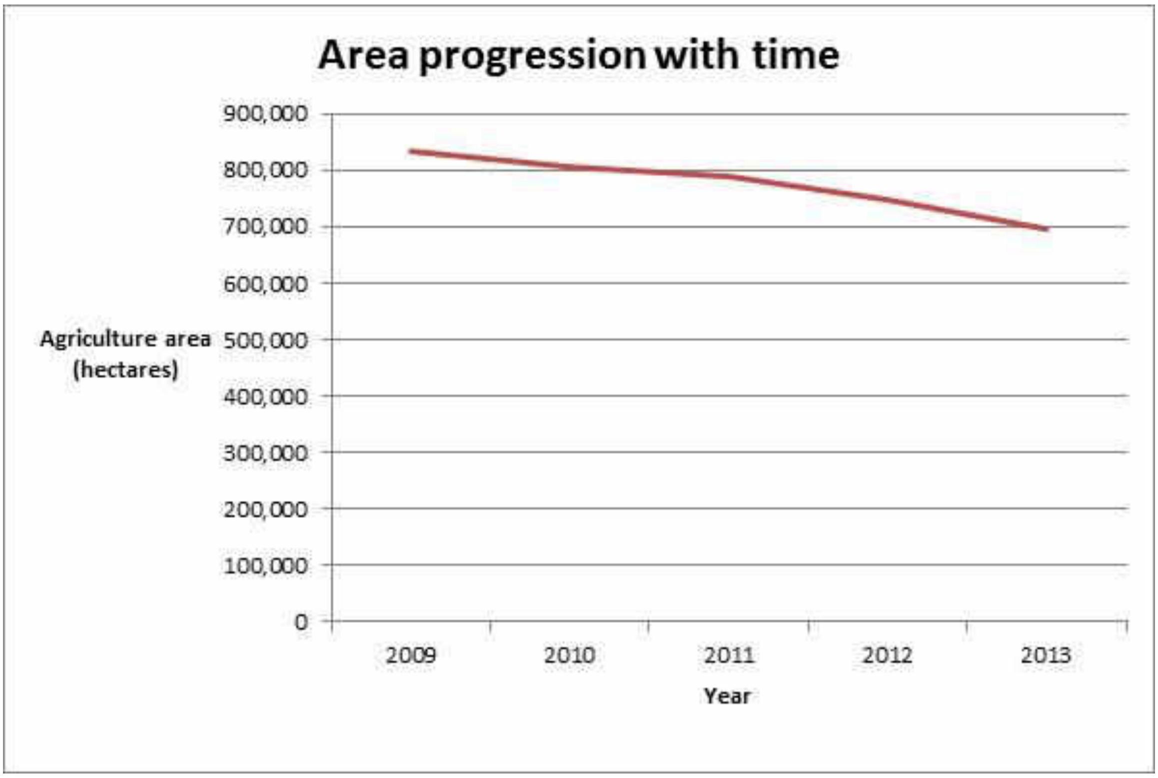


Figure 10.2: Cereal Crop Area and Production Progression with time (2009-2013)

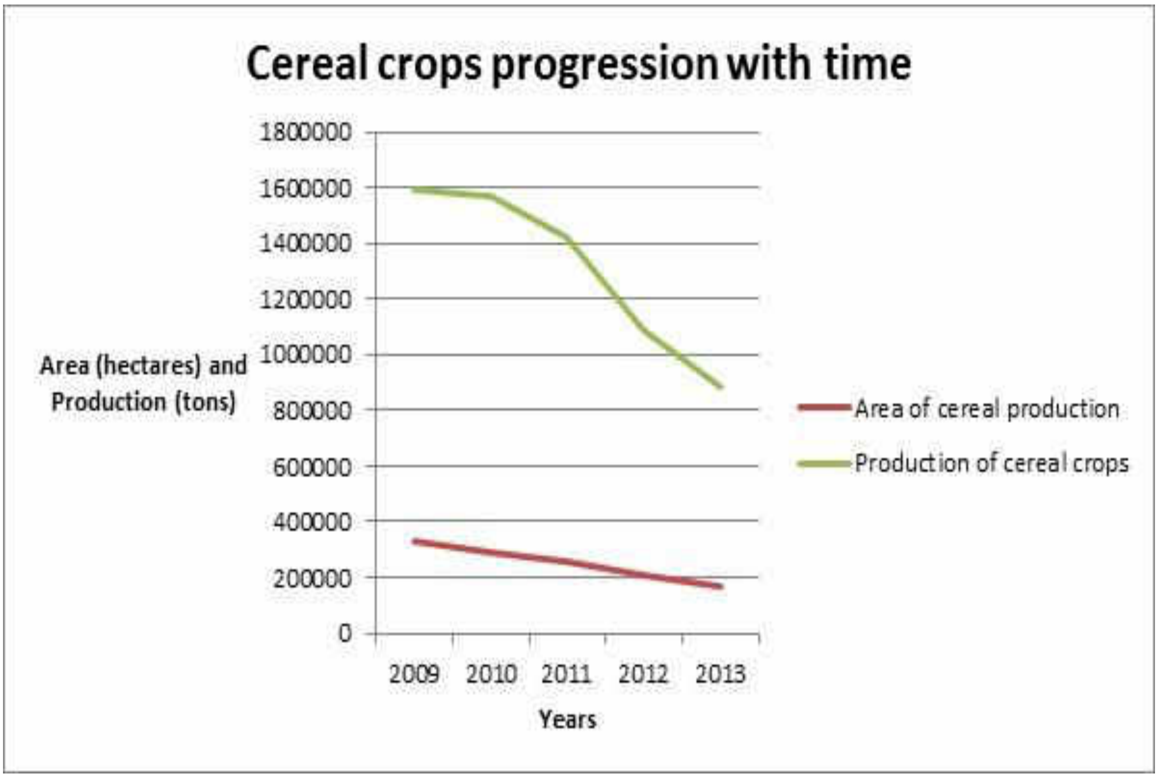


Figure 10.3: Wheat Crop Progression with time (2009-2013)

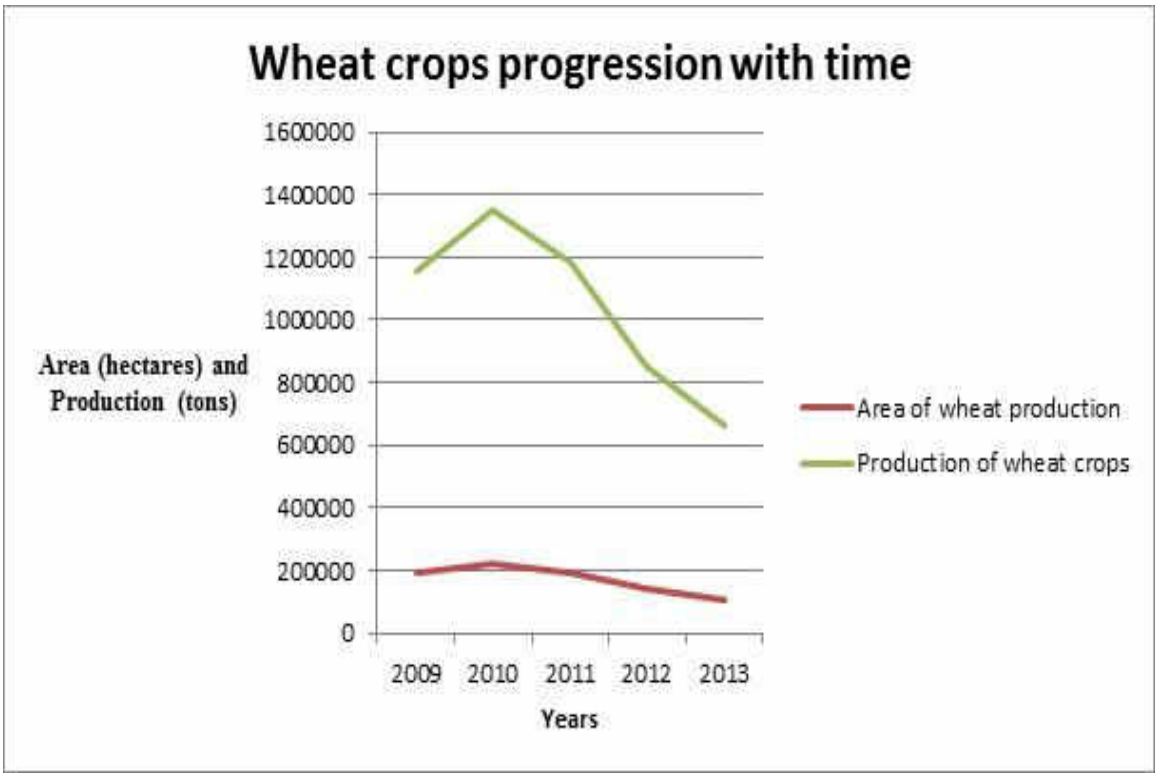


Figure 10.4: Date palm Trees with time (2009-2013)

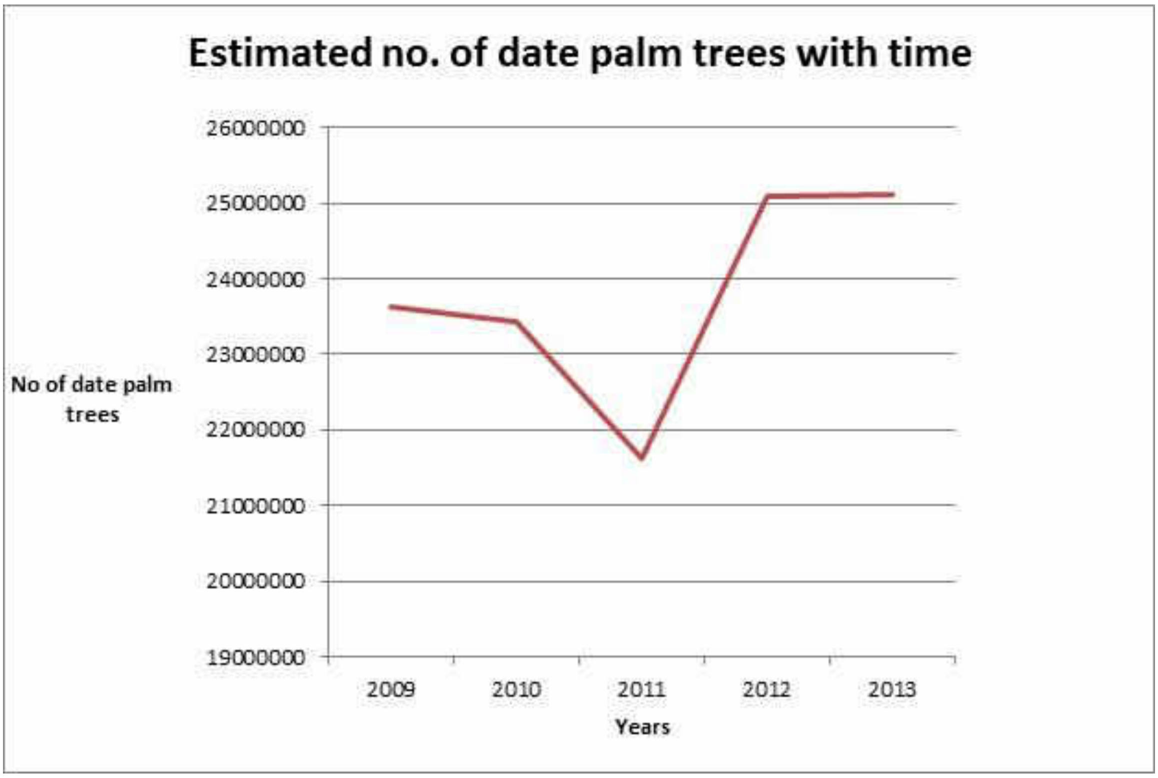


Figure 10.5: Date Production with time (2009-2013)

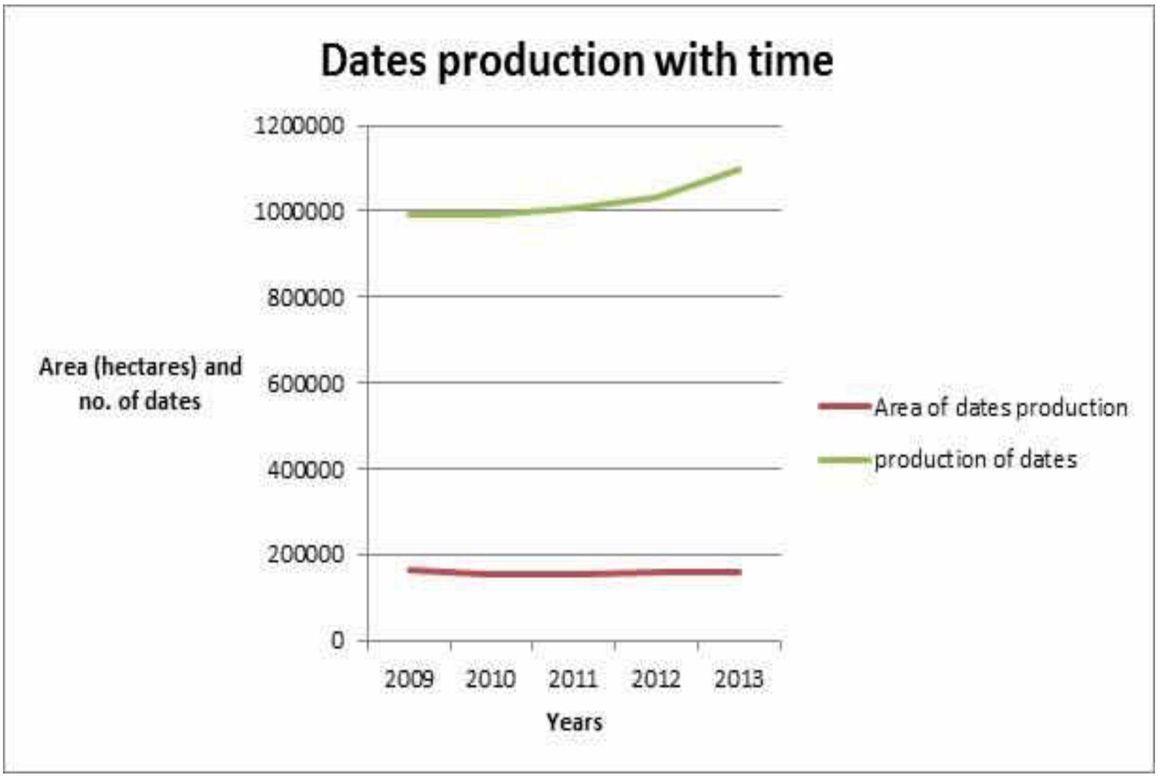


Figure 10.6: Ruminants with time (2009-2013)

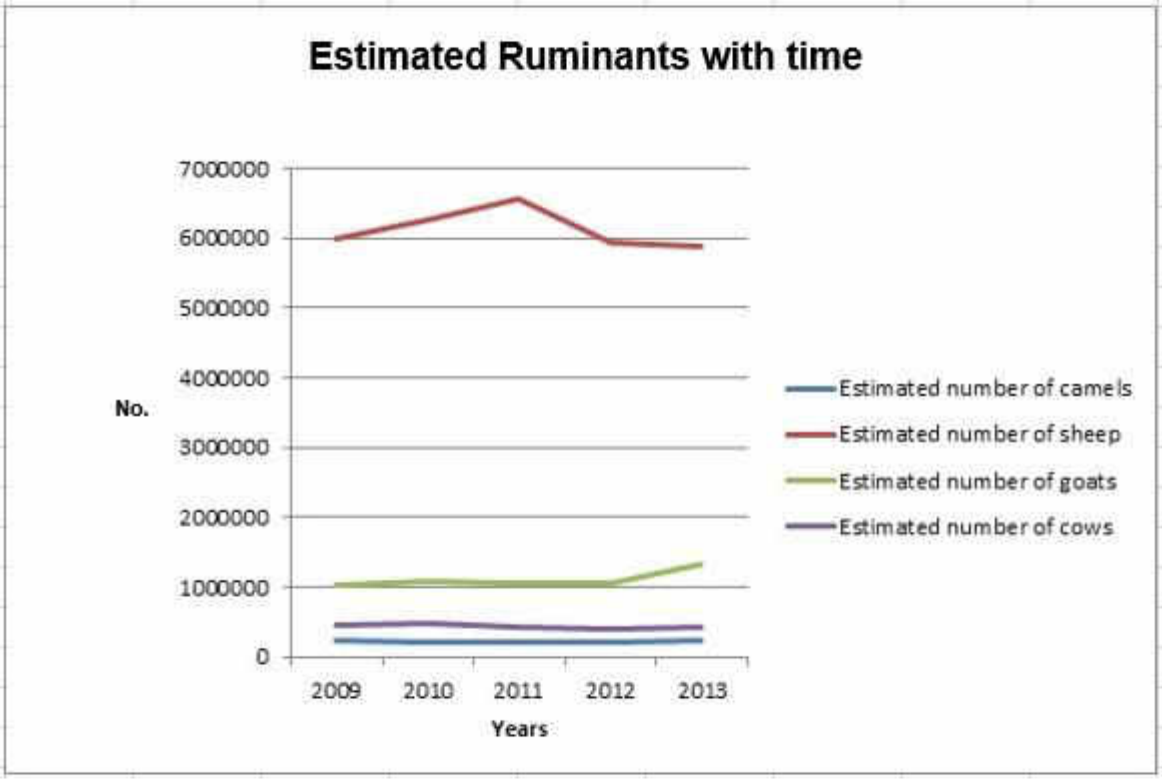


Figure 10.7: Fish & Shrimp Catch and Production of Fish Farms with time (2009-2013)

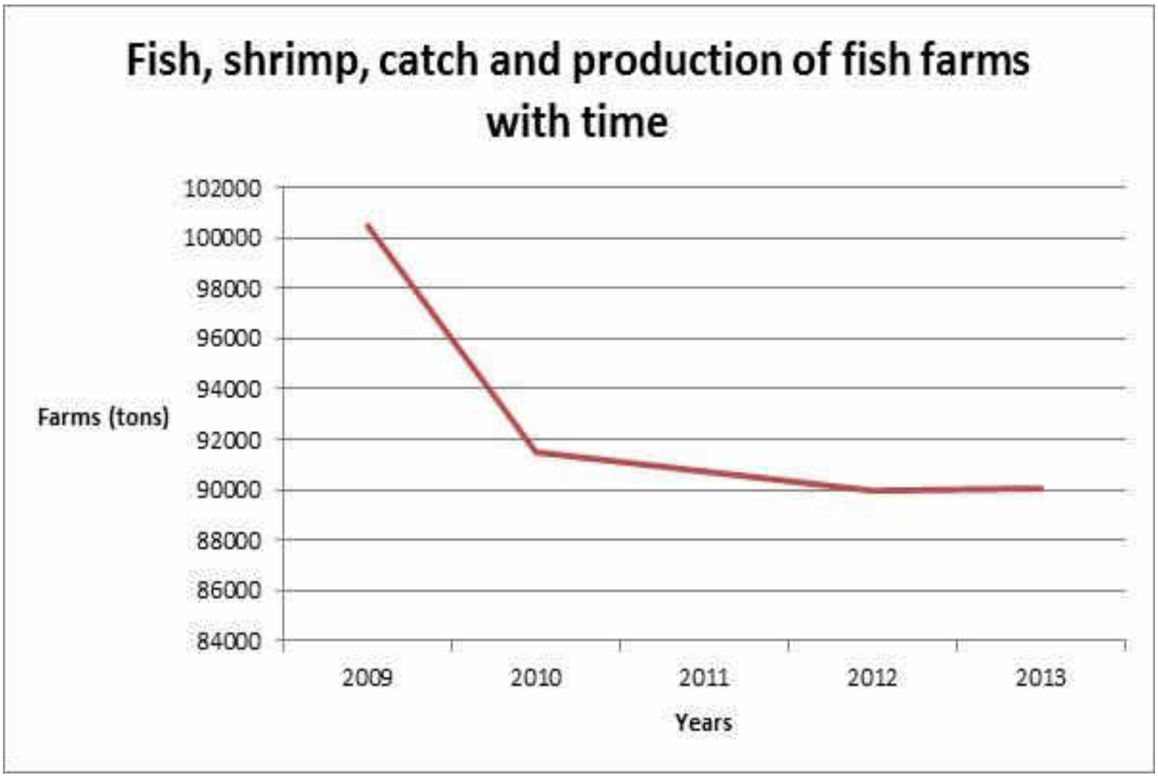


Figure 10.8: Milk Production with time (2009-2013)

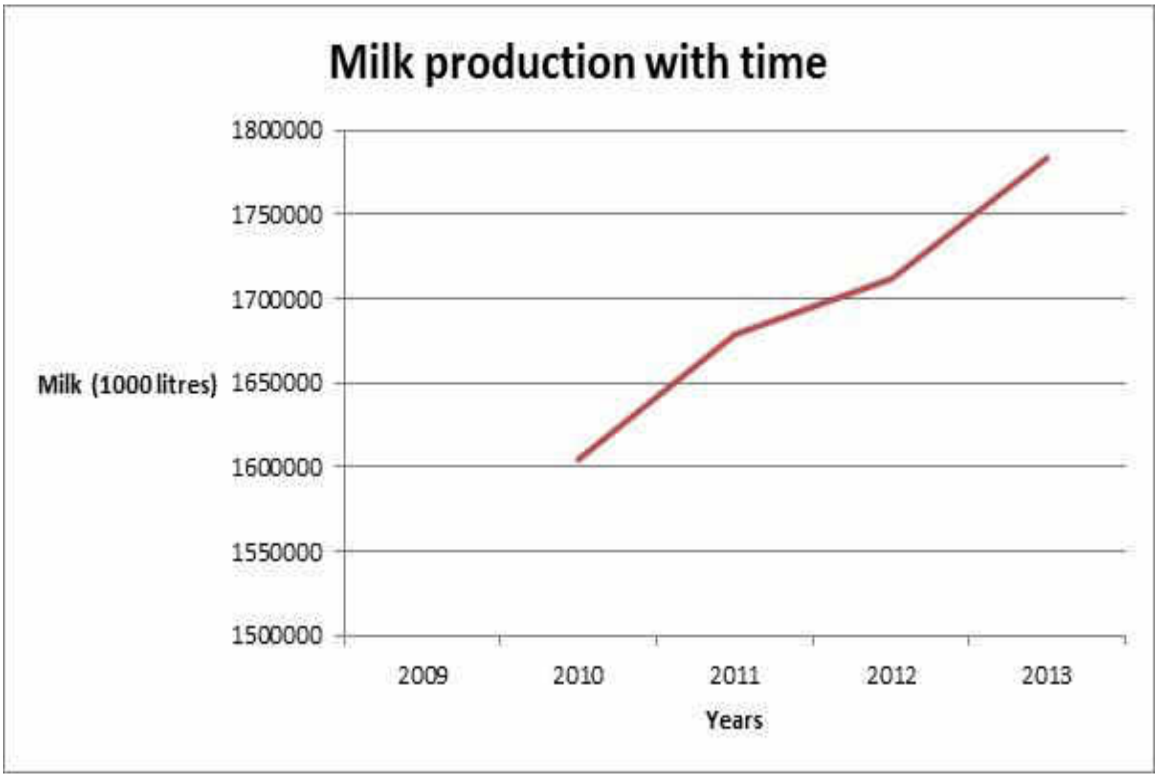


Figure 10.9: Chicken and Egg Production with time (2009-2013)

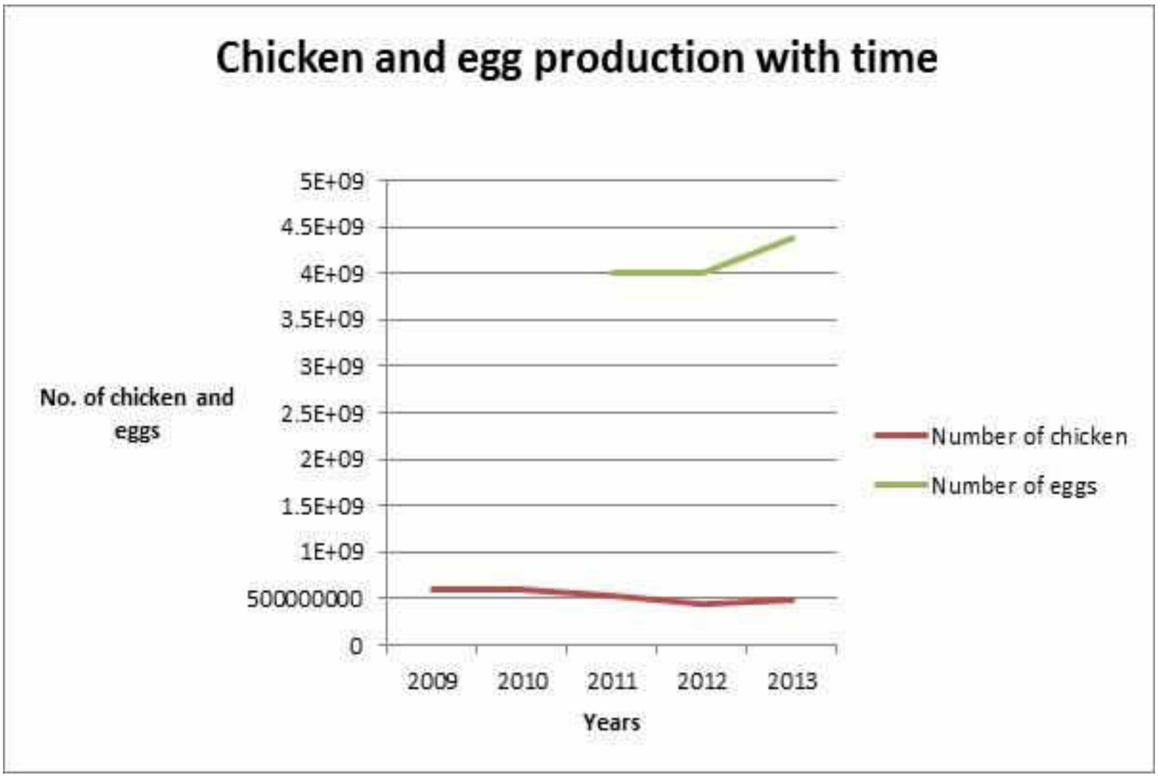
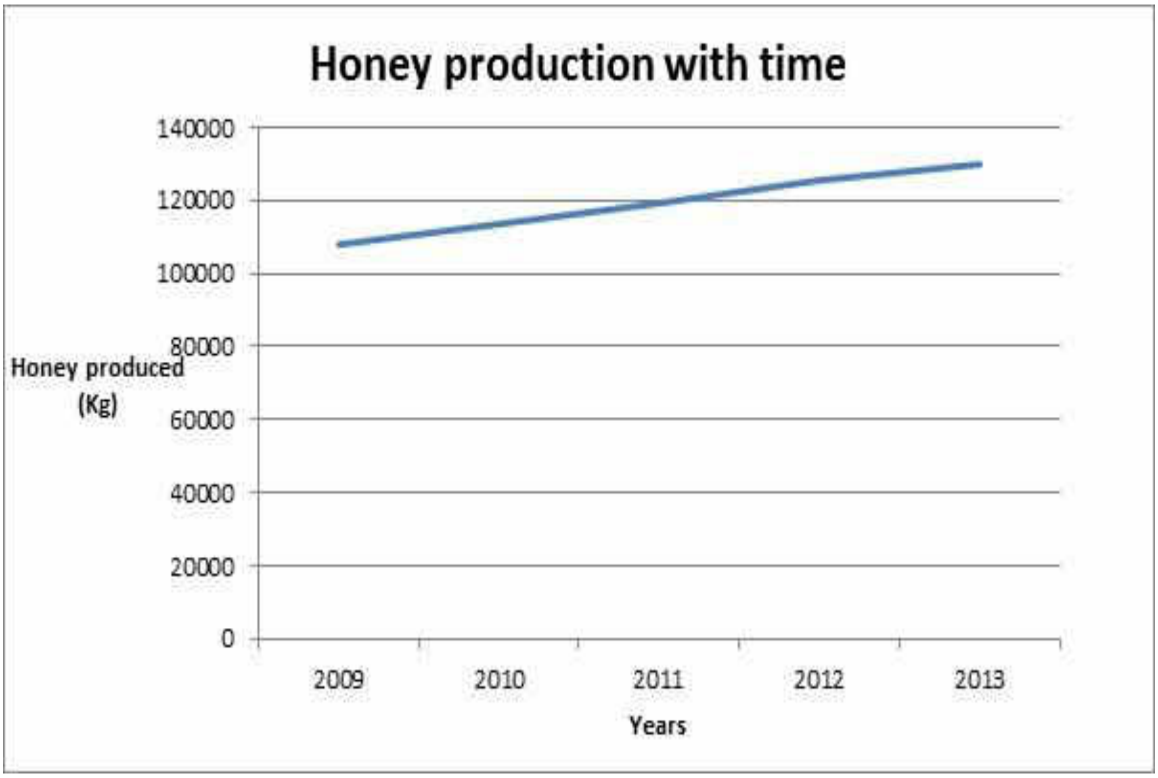


Figure 10.10: Honey Production with time (2009-2013)



In order to improve crop yield, the government is heavily involved in the agriculture industry and the Ministry of Agriculture is primarily responsible for Saudi Arabia's agricultural policies. The private sector also plays a role, as the government offers long-term interest-free loans, along with low-cost water, fuel, electricity and duty-free imports of raw materials and machinery. However, Saudi Arabia is still dependent on imports to meet 70 percent of its food requirements. The top four imported agriculture products are barley, wheat, maize and rice, which account for about 67 percent in quantity and 31 percent in value of agricultural imports.

10.2.2 Impact of Climate Change on Agriculture and Food Security

In arid regions such as Saudi Arabia, limited water resources (groundwater and surface water) and a sensitive desert environment are major ecosystem features. Any increase in air temperature and other meteorological parameters will affect the reference crop evapotranspiration, crop water requirements and water recharge to aquifers. Groundwater resources are the major water supply source for agriculture in Saudi Arabia. About 90 percent of the national agriculture water use is satisfied from groundwater which is pumped from local aquifers. Surface water is very limited because of low annual precipitation. The annual recharge of aquifers relatively closer to the land surface from the low average rainfall has been very significant in partial compensation for water withdrawal from these shallow aquifers. Furthermore, irrigation demands are more than 90 percent of the total water demands. These are satisfied mostly by groundwater resources. Any increase in air temperature and other meteorological parameters will affect the availability of groundwater and surface water by increased evaporation from open water bodies, soil and plants and by a reduction in water recharge to aquifers. This recharge reduction will result in the deterioration of water quality and aquifer yield. Consequently, urban, industrial and agricultural water supplies from groundwater will be affected and the survival of cultivated and desert plants will be at risk and lead to desertification. Thus, any increase in reference evapotranspiration (ET_0) will result in an increase in evaporation rates and a decrease in the available water supply. Similarly, an increase in ET_0 results in increasing water demands for urban, industrial and agricultural uses. Normally domestic and industrial sectors show an increase of about 20 to 30 percent from winter to summer; Irrigation water demands will also be elevated by an increase in ET_0 and crop water requirements in agricultural sectors. Consequently, the available water resources for satisfying increasing demands will be under additional stress because of a decrease in water recharge and surface runoff and an increase in domestic, industrial and agricultural demands.

The impact of climate change on agriculture will be negative in most regions of the globe (Hartig et al., 1997). However, those areas which are most vulnerable to climatic change are tropical and subtropical deserts. Past projections by Global Climatic Models (GCMs) also suggest that the negative impact of climate changes on agriculture and water resources might extend to wetland areas including Bulgaria, the Czech Republic and Russia (Hartig et al., 1997). An increase in temperature, a decrease in relative humidity and/or a reduction in precipitation along with their variability, will intensify the negative impact of climate change in arid regions, including Saudi Arabia (Alkolibi, 2002).

In Saudi Arabia, cultivated land accounts for less than 1 percent of the total area. The most important agricultural crops are winter wheat, dates, vegetables and citrus fruits (El-Shaer et al., 1997) and the main production areas are the central and northern regions. Saudi Arabia is one of the world's largest producers of dates: its total date production in 2009 was 991 kilo tonnes while increased to 109 kilo tonnes in 2013 mostly from the central and eastern regions (Ministry of Agriculture, 2014). Vegetables are grown in most parts of Saudi Arabia, about 30 percent are produced in greenhouses but remaining 70% depend on irrigation water. Any negative effect on water resources due to climate change will also negatively affect agricultural products (Parry and Swaminathan, 1993).

As discussed in detail in the Water Resources section, this study projects reduced and variable patterns of precipitation and changes in annual temperature (-0.6°C to 5°C) and evapotranspiration by -1.2 mm/day to 3.5 mm/day, between 2030 and 2080 across Saudi Arabia. Lower precipitation and higher evapotranspiration will force many shallow water aquifers and valley basins to dry up (Alkolibi, 2002). Since many agricultural crops depend on these water sources, the effects of climate change on food production will be unavoidable. In addition, an increase in temperature may threaten the production of winter wheat, as it is very sensitive to temperature change; consequently, its temperature tolerance limit may be exceeded (Parry and Swaminathan, 1993).

An increased frequency in droughts and floods negatively affects crop yields and livestock. Additional water storage due to the construction of dams and reservoirs and aquifer recharge from treated wastewater effluents can alleviate water shortages but they are not always feasible. Farmers may be able to partially adjust by changing crop patterns and planting dates and adopting other strategies. The potential for increased water needs should be considered in the design of new irrigation supply systems and in the rehabilitation of old systems. Measures to combat water scarcity, such as the use of wastewater in agriculture, need to be carefully managed in order to avoid negative impacts on agriculture, occupational health and food safety. Unilateral measures to address water shortages due to climate change can lead to competition for water resources. International and regional approaches are required in order to develop a sustainable solution.

10.2.3 Policy Options for Climate Change and Food Security

The impact of climate change on freshwater resources may affect sustainable development. It is likely that the negative impact from the increased frequency and severity of floods and droughts cannot be avoided and the significance of climate change lies in its interaction with other sources of change and stress. Its impact should therefore be considered in a multivariable context considering potential synergies among water management strategies, farming practices and conservation measures.

Of particular interest for projections of water resources, with or without climate change, are possible changes in strategy for dam construction and decommissioning, water supply infrastructure and wastewater treatment and reuse. With increased temporal runoff variability due to climate change, increased water storage behind dams may be beneficial.

Among the most important drivers of water uses are population growth and economic development, but they also include changing societal views on the value of water. The latter refers to the prioritization of water for domestic and industrial uses rather than for irrigation and the efficient use of water, including the extended application of water-saving technologies and water pricing.

Adaptation strategies should be designed in the context of economic development, environmental protection and health policies. Many of the options that can be used to reduce future vulnerability are of value in adapting to the current climate and can be used to achieve other environmental and social objectives.

10.2.4 Agricultural Production

Based on the past experience in wheat production, the investment in domestic agricultural production was found to be economically and environmentally infeasible in Saudi Arabia, except for limited production in non-strategic high-value foods and meat and dairy production.

10.2.5 Investment in Agricultural Production Overseas

Although data on its investments in farmland overseas is not readily available, it is known that Saudi Arabia is investing in farm operations in Sudan, Pakistan, Argentina and the Philippines. King Abdullah's initiative on agricultural investments overseas partly encourages such investment with a subsidy to Saudi companies for agricultural operations in foreign countries. The sovereign investment in land to secure a supply of food is a high-risk situation when host governments may withdraw their commitments in times of high crop prices, internal disturbances, water scarcity and associated regulatory issues.

10.2.6 Strategic Reserves and Storage

In 2010, Saudi Arabia announced plans to increase its strategic reserves of wheat from six months to 12 months of consumption by 2016 (around 3 million metric tons) with Saudi logistics and stockpiling wheat operated by the Grain Silos and Flour Mills Organization. Although the storage policy represents a sensible option to improve food security in the event of a supply disruption, several issues need to be addressed in order to increase the reserve:

- The high costs of stockholding,
- Crowding out of private sector stockholding,
- A tendency to capitulate to political demands to release and buy at inappropriate times,
- A woeful record of price management and
- The difficulty of rotating large stock levels and the risk of spoilage.

Given these drawbacks, a 12-month strategic reserve may be larger than is needed to ensure against the risk of supply disruptions. The location of Saudi Arabia's stocks also results in system inefficiency. Of its 2.5 million metric tons of current silo capacity, 90 percent is located in the hinterland (near previous production centers in the north). Even with plans to expand silos near the ports of Jeddah and Jazan, 80 percent of silo capacity remains in the interior. The location of these stocks results in significant transportation costs as trucks travel hundreds of miles from port to fill the silos.

10.3 Conclusions and Recommendations

10.3.1 Conclusions

Effects from changes in climate parameters will have a direct effect on agricultural production. In addition, an increase in temperature may threaten the production of winter wheat due to its sensitivity to temperature change. Among other crops and vegetables which are produced across Saudi Arabia, approximately 30 percent comes from greenhouse cultivation. The remaining 70 percent are cultivated in open field and could be adversely affected by increased temperatures, reduced precipitation, higher evapotranspiration and lower water reserves. In addition, an increased frequency of droughts and floods negatively affect crop yields and livestock.

10.3.2 Recommendations

To enhance the resilience of agriculture sectors and food security in the Kingdom of Saudi Arabia, the following measures are recommended:

1. New water storage facilities, both surface and underground, can alleviate water shortages.
2. Farmers should be able to partially adapt to climate change by changing cropping patterns and/or planting dates for annual crops and by adopting other strategies.
3. The potential for higher water needs should be considered in designing new irrigation supply systems and in rehabilitating old systems. In general, measures to combat water scarcity such as the use of treated wastewater for agriculture, needs to be carefully managed to avoid negative impacts on occupational health and food safety (Husain and Danish, 2005).

To effectively implement measures aimed at combating the adverse impacts of climate change on agriculture and food security, the following are recommended:

- Assessment of water-use stress on agriculture with a more detailed approach.
- Database for food security at national, regional and international levels.
- Investment in agricultural research to develop new varieties of crops in high salinity environment.
- Coordination between agricultural research and extension and advisory services to help farmers become aware of any technological solutions developed.
- Support for developing rural enterprises in an affected area to engage farmers in new approaches to income-generating activities.
- Assistance to farmers moving to a more suitable location and in some cases, investment in irrigation.
- Implementing management applications for agriculture development with food security mapping, suitable agro-climatic zoning and the establishment of partnerships.
- A multi-criteria decision support system for integrated water resource and agricultural management.

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ACRONYMS

BHE	Borehole Heat Exchangers
BIPV	Building integrated photovoltaic
CCAC	Climate and Clean Air Coalition to Reduce Short-Lived Climate Pollutants
CCRC	Clean Combustion Research Centre
CCS	Carbon Capture and Storage
CDM	Clean Development Mechanism
CECCR	Centre for Excellence for Climate Change Research
CM	Carbon Management
CPV	Concentration Photovoltaics
CSLF	Carbon Sequestration Leadership Forum
CSP	Concentrator Photovoltaics
ECIF	Extension Centre for Integrated Farms
ECRA	Electricity and Cogeneration Regulatory Authority
EER	Energy Efficiency Ratio
EIA	US Energy Information Administration
EOP	Economic Offset Program in the Kingdom of Saudi Arabia
EPA	US Environmental Protection Agency
ERI	Energy Research Institute
ESCO	Energy Service Companies
ETCS	European Train Control System
GACA	General Authority of Civil Aviation
GAMEP	General Authority of Meteorology and Environmental Protection
GCC	Gulf Cooperation Council
GCM	Global Circulation Models
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GMI	Global Methane Initiative
HDV	Heavy Duty Vehicle
HYSOLAR	Hydrogen Solar Power
ICC	International Computer Company
IEA	International Energy Agency
INDC	Intended Nationally Determined Contribution of the Kingdom under the UNFCCC
JNLF	Jeddah New Landfill
JOLF	Jeddah Old Landfill
KACARE	King Abdullah City for Atomic and Renewable Energy
KACST	King Abdulaziz City for Science and Technology

KAPSARC	King Abdullah Petroleum Studies and Research Centre
KAU	King Abdulaziz University
KAUST	King Abdullah University of Science and Technology
KFUPM	King Fahd University of Petroleum and Minerals
KSU	King Saud University
LDAR	Lead Detection and Repair
LED	Light-emitting diode
LEED	Leadership in Energy and Environmental Design
LFG	Landfill Gas
Maarifah	National Plan for Science, Technology and Innovation in the Kingdom of Saudi Arabia
MD	Membrane Distillation
MEWA	Ministry of Agriculture Currently Ministry of Environment, Water and Agriculture (MEWA)
MIT	Massachusetts Institute of Technology
MOEP	Ministry of Economy and Planning
MOF	Metal-Organic Framework
MOUN	Madinah Urban Observatory Network
MOWE	Ministry of Water and Electricity Currently Ministry of Energy, Industry and Mineral Resources (MEIMR)
NEEP	National Energy Efficiency Plan
NIS	National Industrial Strategy
NREL	National Renewable Energy Laboratory
NSS	National Spatial Strategy
NSTIP	National Science, Technology and Innovation Plan
ODS	Ozone Depleting Substances
OPEC	Organization of Petroleum Exporting Countries
PAFC	Phosphoric Acid Fuel Cells
PEM	Proton Exchange Membrane
PEMFC	Polymer Electrolyte Membrane Fuel Cells
PERGSA	Regional Organization for the Conservation of the Environment of the Red Sea and Gulf of Aden
PME	Presidency of Meteorology and Environment
PRECIS	Regional Climate Model
PTA	Public Transport Authority
PV	Photovoltaic
RCJY	Royal Commission for Jubail and Yanbu
RegCM3	Regional Climate Model
RES	Renewable Energy Sources
ROPME	Regional Organization for Protection of the Marine Environment

ROU	Reverse Osmosis Unit
ROWA	Regional Office for West Africa
RUE	Rational Use of Energy
SABIC	Saudi Arabia Basic Industries Corporation
SASIA	Saudi Arabian Solar Industry Association
SASO	Saudi Arabian Standard Organization
SAT	Surface Air Temperature
SEC	Saudi Electricity Company
SEEC	Saudi Energy Efficiency Centre
SEI	Solar Energy International
SGBC	Saudi Green Building Council
SOLERAS	Solar Energy Research American-Saudi
SPADC	SABIC Plastic Applications Development Centre
SWCC	Saline Water Conversion Corporation
SWDRI	Saline Water Desalination Research Institute
SWHS	Solar Water Heating Systems
TAQNIA	Saudi Technology Development and Investment Company
TES	Thermal Energy Storage
The Kingdom	Kingdom of Saudi Arabia
The Policy	National Policy for Science and Technology in Kingdom of Saudi Arabia
TIC	Technology Innovation Centre
TTDE	Technology Transfer and Development Ecosystem
TTO	Technology Transfer Offices
UHCPVS	Ultra-High Concentrator Photovoltaic
UNDP	United Nations Development Program
UNEP	United Nation Environment Program
UNESCO	United Nation Education, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
USF	University of South Florida
WDRC	Water Desalination Reuse Centre
WHR	Waste Heat Recovery
YCC	Yanbu Cement Company


3rd NC
N
W
E
S
0 100 200 400
Kilometers
Ar'ar
Sakakah
Al Jawf
Al Hudud ash Shamaliyah
Tabuk
Tabuk
Ha'il
Ha'il
Buraydah
Al Qasim
Ad Dammam
Riyadh
Al Madinah
Medina
Ar Riyad
Ash Sharqiyah
Jeddah
Makkah
Al Bahah
Asir
Abha
Najran
Najran
Jizan
Precipitation
(mm/year)
0-40
40-60
60-80
80-100
100-120
120-140
140-160
160-180
180-200
200-220
220-240
240-260
260-280
280-300
300-400
400-500
500-1000
1000-1500
1500-2000
2000-3000