Kingdom of Bahrain
Supreme Council for Environment

مملكة البحرين
المجلس الأعلى للبيئة

Bahrain's Third National Communication

Under the United Nations
Framework Convention
on Climate Change

Kingdom of Bahrain
Supreme Council for Environment

July 2020

His Royal Highness
Prince Khalifa bin Salman Al Khalifa
The Prime Minister

His Majesty
King Hamad bin Isa Al Khalifa
King of The Kingdom of Bahrain

His Royal Highness
Prince Salman bin Hamad Al Khalifa
The Crown Prince, Deputy Supreme Commander and First Deputy Prime Minister

Kingdom of Bahrain
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Bahrain's Third National Communication (TNC) was coordinated by the Supreme Council (SCE) for Environment and prepared in partnership with the United Nations Environment Programme, West Asia Office (UNEP), with funding from the Global Environment Facility (GEF).

An agreement with the Arabian Gulf University (AGU) and University of Bahrain (UOB) was established to execute the technical studies. Preparation of the TNC was a national effort with the participation of experts representing different national entities.

Abdullah Bin Hamad AL Khalifa
President, Supreme Council for Environment
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Foreword

I am pleased to present the Kingdom of Bahrain's Third National Communication as part of Kingdom›s commitments to the United Nations Framework Convention on Climate Change (UNFCCC) as well as the Paris Climate Agreement.

The Kingdom of Bahrain is keen to preserve the environment and its natural resources from depletion, as stated in its Economic Vision 2030, which encourages more sustainable sources of energy and investment in green technologies that contribute to mitigation of greenhouse gas emissions that cause climate change.

The Kingdom of Bahrain is a small island nation. One of the most serious threats to its development is sea level rise due to climate change. Therefore, Bahrain has embarked on implementing its international obligations, taking climate change into account in the formulation of policies, activities and development plans.

The Kingdom believes that the need to respond to climate change is incumbent on all countries under the principle of common but differentiated responsibilities. The Paris commitments require a common global effort at various levels and a significant flexibility on part of developed countries to provide funding for the Global Environment Facility (GEF) and the Green Climate Fund (GCF) and to facilitate technology transfer to enable greenhouse gas reductions and avoid the adverse impacts associated with climate change.

Finally, I would like to thank all ministries and national institutions that contributed to the preparation of this report; the technical assistance provided by the Western Asia Office of the United Nations Environment Program (UNEP); and the support of international experts.

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List of acronyms

°C	degree Celsius
AFOLU	agriculture, forestry and other land use
AGU	Arabian Gulf University
ALBA	Aluminum Bahrain
BAPCO	Bahrain Petroleum Company
BAU	Business-As-Usual
bcf	billion cubic feet
BCM	billion cubic meters
BDFH	Bahrain Defense Force Hospital
BTEA	Bahrain Tourism and Exhibitions Authority
CBD	Convention on Biological Diversity
CH_4	methane
cm	centimeter (hundredths of a meter)
CO_2	carbon dioxide
CO_2e	carbon dioxide equivalent
DEM	Digital Elevation Model
ESRI	Environmental Systems Research Institute
EWA	Electricity and Water Authority
FAO	Food and Agriculture Organization of the United Nations
FDI	Foreign Direct Investment
GAP	Government action plan
GCC	Gulf Cooperation Council
GCPMREW	General Commission for the Protection of Marine. Resources, Environment & Wildlife
GDP	gross domestic product
Gg	gigagram (billion grams)
GHG	greenhouse gas
gm	grams
GPIC	Gulf Petrochemicals Industries Company
GW	gigawatt (billion watts)
GWh	Gigawatt-hours (billion watt-hours)
GWP	global warming potential
HDR	Human Development Report
HFCs	hydrofluorocarbons
ICT	Information and Communication Technologies
IeGA	Information and e-Government Authority

IMF	International Monetary Fund
INDC	Intended Nationally Determined Contribution
IPCC	Intergovernmental Panel on Climate Change
IPPU	industrial processes and product use
IWRM	integrated water resource management
kg	kilogram
KHUH	King Hamad University Hospital
km	kilometer
km^2	square kilometers
kTOE	thousand tonnes of oil equivalent
kWh	kilowatt-hours (thousand watt-hours)
l	liter
LEAP	Long-range Energy Alternatives Planning
LED	light emitting diode
LNG	liquified natural gas
LULC	land use land cover
m^2	square meter
m^3	cubic meter
m^3/d	cubic meter per day
MED	Multi-Effect Distillation
MENA	Middle East and North Africa
MEPS	minimum energy performance standards
mg	milligram (thousandths of a gram)
mm	millimeter
Mm^3	million cubic meters
MoH	Ministry of Health
MoW	Ministry of Works
MSF	multi-stage flash
MSL	mean sea level
MSR	mangrove submerged roots
MW	megawatts (million watts)
N_2O	nitrous oxide
NBSAP	National Biodiversity Strategy and Action Plan
NEEAP	National Energy Efficiency Action Plan
NREAP	National Renewable Energy Action Plan
NSIDC	National Snow and Ice Data Center
OECD	Organisation for Economic Co-operation and Development

PCPMREW	Public Commission for the Protection of Marine Resources, Environment and Wildlife
PFCs	perfluorocarbons
PV	photovoltaic
QA	quality assurance
QC	quality control
R&D	research and development
RCP	Representative Concentration Pathway
RO	reverse osmosis
SCE	Supreme Council for the Environment
SDG	Sustainable Development Goals
SEU	Sustainable Energy Unit
SF_6	sulfur hexafluoride
SIDS	Small Island Developing State
SLRB	Survey & Land Registration Bureau-Bahrain
T&D	transmission & distribution
TDS	total dissolved solids
TIFF	Tagged Image File Format
TRIPS	Trade Related Aspects of Intellectual Property Rights
TWh	Terawatt-hours (billion watt-hours)
UAE	United Arab Emirates
UN	United Nations
UNDP	United Nations Development Programme
UNFCCC	United Nations Framework Convention on Climate Change
UoB	University of Bahrain
USEIA US	Energy Information Administration
UTM	Universal Transverse Mercator
WEAP	Water Evaluation and Planning model
WHO	World Health Organization
WPCC	Water Pollution Control Center

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Executive summary

Bahrain is a small island developing state (SIDS) situated in the west central part of the Arabian Gulf, about 25 km east of Saudi Arabia. Total land area is currently about 780 km^2, with a mostly flat, gently rolling topography and a total coastline of 946 km.

National circumstances

Bahrain's coastline and land area have evolved considerably over the last 30 years due to a series of land reclamation projects, which continue to the present day. Roughly, 111 km^2 of reclaimed land has been added since 1980, accounting for about 15% of its current total land area.

Bahrain is an arid country with mild, pleasant winters, and summers that are very hot and humid. Rainfall is negligible from April through the end of October, coinciding with high temperatures. Relative humidity is highest during the winter months of December through February, although other months of the year show only slightly lower levels.

Bahrain enjoys a rich social milieu, with diverse communities living side by side in primarily high-density urban contexts throughout the island. Several key aspects of the Bahrain social fabric are described in the subsections that follow. In 2019, total population is approximately 1.5 million with roughly half of the population comprised of visiting expatriates who come to pursue work opportunities. Most of the population is centered in the capital, Al Manamah and other major urban centers like Al Muharraq, Ar Rifa'and Hamad Town.

Agriculture accounts for only 0.3% of gross domestic product (GDP) and production consists mainly of fruits, vegetables, poultry, dairy products, shrimp, and fish, all of which is for domestic consumption. Low agricultural productivity is a function of both limited arable land - only 2.1% of the land is arable - and the hyper arid climate.

Bahrain produces around 42,000 barrels of oil a day. It also receives 50% of the revenues associated with the approximately 300,000 barrels per day produced in the Saudi operated Abu Sa'fa oil field which is situated on the maritime border between Saudi Arabia and Bahrain.

In 2017. Bahrain began construction of the Middle East's first liquified natural gas (LNG) receiving and regasification terminal off shore Hidd Industrial Area on Muharraq Island. When complete, the facility will help Bahrain meet increasing demand for natural gas for industrial and urban development.

Five power stations with a combined installed capacity of 3.9 GW account for Bahrain electric generation. Electricity consumption per capita is high, and is driven in large part by air conditioning demand.

Bahrain is a highly water stressed country from a freshwater resource availability perspective. There are only 3 cubic meters (m^3) of renewable groundwater per capita, compared to a world average of 6,000 m^3 per capita. Rising population combined with high consumption patterns have led to the gradual depletion of groundwater sources.

Water supply is provided by high-cost desalinated water produced using energy-intensive thermal and membrane-based technologies Water demand is very high on a per capita basis, about 500 liters per person per day. The municipal distribution network meets demand mostly for households, businesses, and government buildings and accounts for 60% of all water consumption. The balance is satisfied by groundwater extraction or on-site desalination.

A desert environment dominates Bahrain's terrestrial landscape, except for a narrow fertile strip that is found along the northern and northwestern coastlines. The desert is home to many types of insects, reptiles, birds and wild mammals. As a step in preserving terrestrial biodiversity, the AlAreen Wildlife Park and Reserve was established in 1976 to provide a refuge for the endangered species and their breeding habitats, as well as an educational center to learn about local wildlife.

The marine environment is characterized high rates of evaporation during most of the year and a shortage of freshwater input. The most vital marine habitats are mangrove and seagrass beds in the intertidal regions and coral reefs in the subtidal regions. Coastal development projects have significantly reduced the area of these natural resources, a situation that has led to efforts to restore habitats in the vicinity of reclaimed lands.

Bahrain enjoys a modern, high-quality healthcare system. Infant mortality in Bahrain is very low, as is mortality among children under 5 years of age. Life expectancy is marginally better than the Arab world, and marginally worse than the world average. There is also high literacy for males and females, due in large part to high enrollment rates across preschool and tertiary educational systems. Average literacy rates among adults exceed rates in SIDS, Arab states, and the World.

Bahrain has a relatively open economy. With a per capita income of over $22,000 in 2016, it is classified by the World Bank as a high-income economy. In 2016, Bahrain's real GDP was approximately US$ 31.4 billion at market exchange rates, up from US$ 23.8 billion in 2008, an average annual growth rate of about 3.6%. The largest share of GDP, about one fifth, comes from the mining and quarrying sector, of which oil and gas operations account for most of the contribution, about 97%.

In concert with other Gulf countries, Bahrain has been active in exploring economic diversification strategies to wean the economy away from oil dependency. In 2008, the Economic Vision 2030 initiative was launched with a goal of a diversified and dynamic economy, including diversified energy sources. The Vision has three guiding principles: sustainability, competitiveness, and fairness. The vision is distinct from previous diversification efforts across the Gulf due to its comprehensive and strategic nature.

Policymaking relevant to climate change takes place at multiple levels. At the multilateral/international level, Bahrain is party to many international conventions, including the UNFCCC, the Kyoto Protocol, the Paris Agreement, the Montreal Protocol on ozone depletion, and the 2013 Beijing Amendment to the Montreal Protocol. At the national level, Bahrain has been active in forming new institutions to take the lead in formulating policy relative to sustainability, the environment, energy, and climate change.

One notable example of a new institution is the Sustainable Energy Center (previously Sustainable Energy unit), launched in 2014. The Unit was a joint project with the United Nations Development Program (UNDP) and focuses on developing policies to promote energy efficiency and renewable energy, with associated benefits such as reducing carbon emissions and improving local air quality. Upscaled from unit to an organ of the government, the center has launched two major initiatives, namely the National Renewable Energy Action Plan (NREAP) and the National Energy Efficiency Action Plan (NEEAP).

Greenhouse gas inventory

Table ES-1 presents total greenhouse gases (GHG) emissions and sinks for the year 2006. Total GHG emissions in 2006 were 29,153 Gg CO_2-equivalent (CO_2e), which includes 20,149 Gg from energy; 8,704 Gg from industrial processes and product use (IPPU); and 268 Gg from waste. CO_2e emissions from Agriculture, forestry and other land use (AFOLU) were about 33 Gg, which after accounting for carbon sinks in managed green spaces and parks totaled 8 Gg. Net national emissions in 2006 were 29,129 Gg, after accounting for these carbon sinks.

Energy-related activities (Activities of oil sector and electricity sector and transportation sector) accounted for the dominant portion of GHG emissions in Bahrain in 2006. Approximately 69% of all GHG emissions are associated with the combustion of fossil fuels or the release of fugitive emissions. Industrial processes and product use accounted for about 30% of all GHG emissions, followed by the waste sector that accounted for about 1% of total emissions. Emissions from agricultural and land use activities are negligible, less than 0.2% of total national emissions.

Table ES–1: GHG emissions and sinks in Bahrain, 2006 (Gg)

		CO_2						
GHG Sources	**CO_2e**	**Emissions**	**Sinks**	**CH_4**	**N_2O**	**PFCs**	**HFCs**	**SF6**
1 Energy	20,149	19,686	0	16.7	0.2	0.00	0.00	0.00
2 Industrial processes and product use	8,704	2,004	0	0.9	0.0	0.81	0.03	0.00
3 Agriculture, forestry and other land	8	7	-25	1.0	0.0	0.00	0.00	0.00
4 Waste	268	0	0	9.9	0.1	0.00	0.00	0.00
Total National Emissions	**29,153**	**21,697**	**---**	**28.5**	**0.3**	**0.81**	**0.03**	**0.00**
Total Net Emissions	**29,129**	**21,697**	**-25**	**28.5**	**0.3**	**0.81**	**0.03**	**0.00**

GHG emission inventories were also prepared for the years 2007 to 2015, inclusive. Over this period, total emissions have increased by about 37%; from 29,153 Gg CO_2e in 2006 to about 39,902 Gg CO_2e in 2015, or roughly 3.5%/year. Emissions of CO_2 are increasing slightly above this rate, 4.0% per year. Notably, HFC emissions are experiencing the highest levels of annual growth in Bahrain, roughly 33% per year.

Vulnerability and adaptation - mangrove habitats

Dense grey mangrove forests are found in the Gulf of Tubli, a sheltered and shallow bay with extensive intertidal mudflats on the eastern side of the main island of Bahrain. Changing conditions in the Arabian Gulf pose incremental threats to these mangrove stands.

Three main anthropogenic factors have adversely impacted Bahrain's mangrove forests, leading to sharp reductions in their spatial extent and health. These include extensive land reclamation slurry discharge from nearby sand washing plants and treated wastewater. These impacts are further compounded by frequent illegal dumping of municipal solid wastes by tankers.

These factors have led to the loss of about a third of total mangrove area in Tubli Bay; from 150 hectares in 1980 to about 100 hectares in 1992. In response, Tubli Bay was declared nationally as a protected area in 1995 and Law 53/2006 designated Tubli Bay as a natural reserve. In 1997, it was designated internationally as a RAMSAR Site. Today, only 31 hectares remain.

The impact of climate change on mangroves in Tubli Bay was evaluated using a 3-part methodology. First, a preliminary qualitative assessment was undertaken to gain a better understanding of the factors that affect mangrove vulnerability to climate change. Second, biological characteristics of Tubli Bay mangroves were assembled from available studies to provide baseline information. Third, an economic valuation of the services and goods provided by Bahraini mangroves was undertaken to better understand the benefits provided by mangroves within an economic context.

The assessment found that the Bay has high exposure to climate change impacts, especially sea level rise. The *Avicennia marina* specie found in the Bay displays high sensitivity to prolonged seawater flooding that would be associated with future sea level rise. There is a potentially high impact from sea level rise due to the inability of landward migration, which also severely limits mangrove forest adaptive capacity. Combined, these factors suggest a high level of vulnerability of climate change in the absence of specific adaptation initiatives.

Various services are provided by Tubli mangroves, namely ecotourism, coastal protection, habitats for fisher and bird species. Of these, the ecotourism component has been quantified to date. Based on current pricing, visitor patterns, projected operating days, and other factors the annual monetary value of tourism services provided by Tubli Bay mangroves is around US$ 33,000/year. This estimate is likely to increase over time as plans to protect Bay waters are implemented and infrastructure to support ecotouristic activities is built.

Vulnerability and adaptation - coastal zones

Sea level rise is one of the primary and most certain consequences of climate change. As with all small island developing states, it represents an almost existential risk to the coastlines of the six major islands on which most of its population and infrastructure are located. These coastal areas, less than 5 meters above current sea levels, have very high population densities.

The objective of the coastal zone vulnerability assessment was to quantify the extent of seawater inundation by land type and location for a set of plausible sea level rise scenarios for the years 2050 and 2100. The study area consisted of all land area from the coastline to inland areas up to 5 meters above mean sea level (MSL) for seven distinct land segments, namely Northern Bahrain, Southern Bahrain, Muharraq, Sitra, Nabih Saleh, Umm Al Nassan, and the Hawar Islands. A 3-part methodology was applied that included data acquisition, data preprocessing, and seawater inundation modeling.

Figure ES-1 summarizes the extent of seawater inundation under the various scenarios for all of Bahrain. The results confirm that the country is highly sensitive to sea level rise. Significant inundation impacts are projected for certain land use categories, even at small levels of rising seas. Some key national implications of the assessment are outlined in the bullets that follow.

- Wetlands are projected to experience significant inundation. Approximately 27 km², or nearly half of all wetlands in Bahrain would be inundated if sea levels rise by up to 0.5 meters, with nearly three quarters lost if sea levels rise by up to 1.5 meters.

- Only modest areas of reclamation lands would be affected with small amounts of sea level rise. Of the total of 50 km² of reclaimed land, only about 2% (1 km²) would be inundated at 0.5 meters, but nearly 30% (14 km²) would be inundated at 2 meters of sea level rise.

- Built-up areas in Bahrain are best situated to withstand sea level rise. Less than 2% (2 km²) would be inundated up to 1 meter of sea level rise and only 10% (13 km²) of these lands would be inundated up to 2 meters of sea level rise

- Industrial areas are somewhat more sensitive that built-up areas to withstand sea level rise. About 15% (4 km²) of these lands would be inundated with 2 meters of sea level rise, with under 3% (1 km²) inundated with 1 meter of sea level rise.

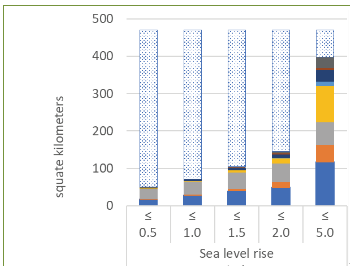
- All land use categories are severely affected under the high sea level rise scenario of 5 meters. The airport would be completely inundated while wetlands, reclaimed lands, and industrial areas would lose at least 94% of their total area. Built-up areas would experience a loss of 74% of its total area. Of the total sensitive land area of 470 km², only 72 km² (15%) would not be under water as these areas are above 5 meters above MSL.

Some adaptation measures have already taken place in certain sectors. Bahrain's building codes enacted in 2009 call for the height of the ground floor of a new building being 1.5 meters above the level of the pavement surface. However, much remains to be done in Bahrain to ensure climate resilience. In the near-term, the focus should be on increasing institutional capacity to incorporate sea level rise risks within development planning

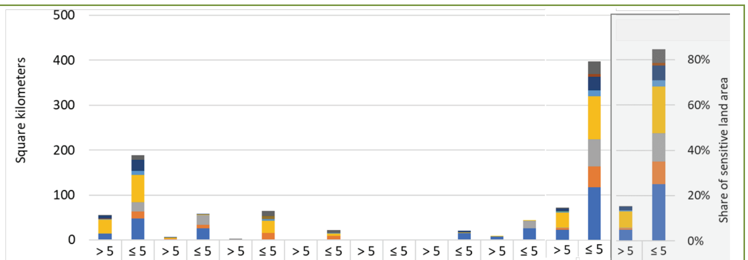
Vulnerability and adaptation - water resources

Climate change will exacerbate an already unsustainable water supply and demand situation. Sea level rise could lead to seawater intrusion into fresh groundwater lenses and adverse impacts on inlets/outlets of desalination plants. Lower precipitation could lead to lower groundwater recharge rates. Higher temperatures could deepen the already unsustainable levels of groundwater use by agriculture, households, and businesses. The main management challenge is how to balance decreasing water supply and increasing water use in the context of a changing climate.

The objective of the was vulnerability assessment was to quantify the impact of climate change on Bahrain's sensitive municipal water supply-demand equilibrium and to quantify the costs and benefits of specific adaptation initiatives (i.e., per capita use reduction, leakage reduction). A representation of the municipal water system was developed using Water Evaluation And Planning (WEAP) software for the 2015-2035 period. A scenario-based analytical framework was applied (Reference scenario, climate change scenario, adaptation scenario). The first initiative aims to achieve a 33% reduction in per capita municipal water



Sea level rise scenario (meters AMSL)	≤ 0.5	≤ 1.0	≤ 1.5	≤ 2.0	≤ 5.0
Not inundated	419	398	365	324	72
Industrial	1	1	2	4	28
Airport Zone	0	0	2	4	6
Agricultural	3	3	5	9	30
Archeological	0	0	0	0	0
Vacant	0	0	0	2	13
Built-up	1	2	5	13	96
Wetlands	27	35	44	50	60
Reclamation	1	2	7	14	46
Bare Land	18	28	40	50	118



	Northern Bahrain		Southern Bahrain		Muharraq		Sitra		Nabih Saleh		Umm Al Nassan		Hawar		Total		Share of total land area (%)	
	> 5	≤ 5	> 5	≤ 5	> 5	≤ 5	> 5	≤ 5	> 5	≤ 5	> 5	≤ 5	> 5	≤ 5	> 5	≤ 5	> 5	≤ 5
Industrial	2	10	0	0	0	12	0	6	0	0	0	0	0	0	2	28	0%	6%
Airport Zone	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0	6	0%	1%
Agricultural	7	25	0	1	0	1	0	0	0	0	0	3	0	0	7	30	1%	6%
Archeological Site	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0%	0%
Vacant	2	8	0	0	0	4	0	1	0	0	0	0	0	0	2	13	0%	3%
Built-up	30	62	2	1	1	27	0	5	0	1	0	1	0	1	34	96	7%	20%
Wetlands	0	20	1	23	0	0	0	0	0	0	0	0	0	17	1	60	0%	13%
Reclamation	1	16	1	7	1	15	0	8	0	0	0	0	0	0	3	46	1%	10%
Bare Land	14	48	1	26	0	0	0	1	0	0	0	16	8	26	23	118	5%	25%
Total	56	189	5	58	2	64	1	21	0	1	0	20	8	44	72	397	15%	85%
Share of total land area (%)	12%	40%	1%	12%	0%	14%	0%	5%	0%	0%	0%	4%	2%	9%	15%	85%		

Figure ES-1: Left: Overall area of sensitive land in Bahrain under range of sea level rise scenarios; Right: Area of sensitive land by land class, island, and elevation 5 meters above and below MSL

demand, from the current level of 183 to 122 m^3 per person per year by 2035. The second initiative aims to reduce leakage in the water distribution network to achieve reductions of 22% of annual water production by 2035 relative to water production in that year under business-as-usual conditions.

The results of the assessment make clear that significant water demand reductions are possible and therefore it is imperative for Bahrain to formulate a clear comprehensive national water policy and strategy based on integrated water resource management (IWRM) principles. Highlights are summarized in the bullets below.

- *Impact of climate change:* Under RCP8.5 assumptions, there would be a cumulative increase of 593 GWh of natural gas-fired electricity, which would lead to an additional 385 thousand tonnes of CO_2e. These impacts would also come at a significant present value cost to the economy, totaling about US$ 38.7 million. The impacts under RCP4.5 would be about one-fifth of these impacts.

- *Impact of per capita reductions:* Under RCP8.5 assumptions, reducing per capita water demand by 33% will lead to a cumulative reduction of 26 TWh of natural gas-fired electricity and avoid 17 million tonnes of CO_2e emissions. In addition, there would be a cumulative reduction of 5.1 BCM of brine discharge to surrounding Gulf waters. These benefits come at a significant present value cost savings to the economy, totaling about US$ 1.7 billion.

- *Impact of leakage reductions:* Under RCP8.5 assumptions, reducing pipeline network leakage by 22% will lead to a cumulative reduction of 18 TWh of natural gas-fired electricity, which would avoid 12 million tonnes of CO_2e. These benefits would come at a significant present value cost savings to the economy, totaling about US$ 1.2 billion.

- *Impact of both initiatives:* Figure ES-2 summarizes the impact of combining both initiatives. The top figure shows municipal water consumption in 2035 is about 4% less than 2015 levels, and about 47% lower than what it would otherwise be in 2035. The bottom figure shows cumulative levels for total water use, wastewater generation/treatment, brine discharge, and desalinated water production are about 27% lower than Reference scenario levels. Combining both initiatives will lead to a cumulative reduction of 40 TWh of natural gas-fired electricity requirements, which would avoid 26 million tonnes of CO_2e. These benefits would come at a significant present value cost savings to the economy, totaling about US$ 2.6 billion.

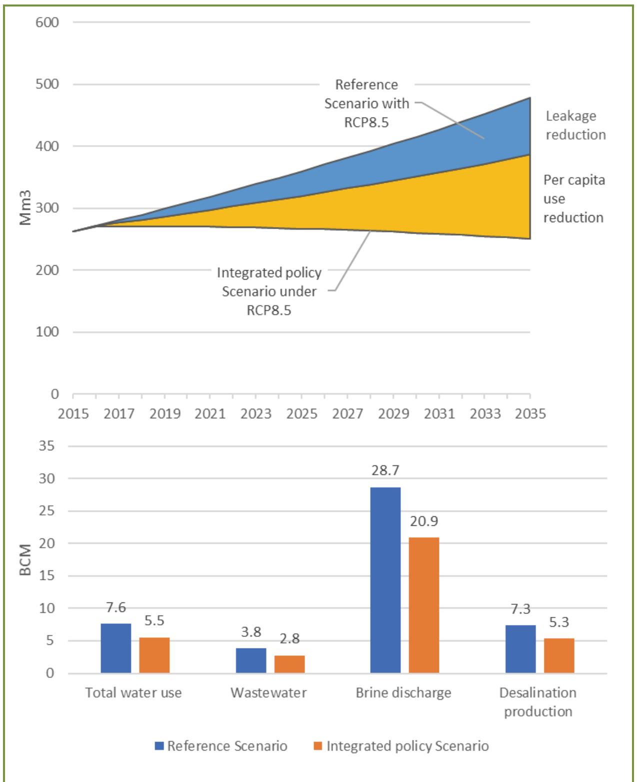


Figure ES-2: Top: Annual impacts of the integrated policies on municipal water demand; Bottom: Cumulative impacts of the integrated water policies

A clear, comprehensive, and integrated water resources policy will be required to achieve the above benefits. Institutional reforms that build upon the reactivation of the National Water Resources Council in 2016 are essential.

Further deterioration of groundwater resources should be addressed by establishing a cooperation mechanism between Bahrain and Saudi Arabia in the development and management of transboundary groundwater resources, including groundwater artificial recharge/storage enhancement using surplus tertiary treated wastewater.

Going forward, it will be important to expand water sector coverage beyond the municipal sector, in order to capture opportunities for efficiency and conservation in the agricultural and industrial sectors.

Modeling Bahrain's water system would benefit from using stochastic methods to better understand uncertainty and integrating previous groundwater modeling into the WEAP model.

Greenhouse gas mitigation

Launched in 2017, the National Energy Efficiency Action Plan lays out 22 a comprehensive set of initiatives to increase energy efficiency potential in Bahrain. The Plan identifies 22 new initiatives across all sectors to achieve a reduction in energy use of 6% by 2025 relative to average energy use over the period 2009-2013.

Launched in the same year, the National Renewable Energy Action Plan identified feasible solar, wind and biogas renewable energy options for Bahrain, establishing a national renewable energy target of 5% of peak capacity by 2025 and 10% by 2035, relative to the projected peak capacities in those years. On an electric generation basis, this amounts to 478 GWh and 1,456 GWh of renewable electricity by 2025 and 2035, respectively.

Considered individually or together, the initiatives established under the energy efficiency and renewable Plans will lead to significant levels of annual avoided CO_2e emissions. Given the prominence of energy in the GHG emission profile, the scope of the GHG mitigation assessment focused on these plans exclusively.

Three scenarios were considered: a Business-As-Usual (BAU) scenario assuming pre-Plans conditions; an energy efficiency scenario; a renewable energy scenario; and a combined scenario considering both energy efficiency initiatives and renewable energy. The Long-range Energy Alternatives Planning (LEAP) modeling tool was used to estimate future annual energy savings, incremental costs, and CO_2e emission reductions.

Table ES-2 provides an overall summary of the costs and benefits associated with the energy efficiency and renewable energy initiatives of the Plans. The following bullets highlight key findings:

CO_2e reductions: The 22 energy efficiency initiatives provide most of the cumulative emission reductions, about 77%, over 3 times the cumulative emission reductions from renewable energy initiatives.

- *Investment costs:* Both the energy efficiency and renewable energy initiatives can be implemented at substantial cost savings to society. The net present value of cost savings from energy efficiency investments is nearly US$ 1 billion, roughly 8 times that of renewable energy.

Table ES–2: Costs and benefits associated with energy efficiency and renewable energy generation targets

Scenario	CO_2e reductions (million tonnes) In 2025	In 2030	2015-2030	Costs (million PV 2015 US$)	Cost of Saved Carbon (2015 US$/t$CO_2$e saved)
Energy efficiency	1.2	1.2	12.8	-926	-72
Renewable energy	0.3	0.7	3.9	-123	-32
Combined efficiency & renewable	1.5	1.9	16.7	-1,050	-63

- *Costs of avoiding carbon:* While both energy efficiency and renewable energy investments reduce carbon emissions while also reducing costs, energy efficiency is roughly 2.3 times more cost-effective per unit of carbon avoided.

Other information

Public awareness of climate was assessed through a survey. Findings showed that 88% of the study sample believed that the climate had actually changed and 85% considered the climate change phenomenon to be severe and deserved to be addressed. Most believed that climate change is due to human causes due to the increased concentration of greenhouse gases in the atmosphere.

Other major findings include the need to make better use of social media to build awareness, as well as print and televised media, including the use of slogans. Based on these findings, a climate change awareness plan was developed that specified activities, target groups, input requirements, and institutional roles.

The degree to which climate change is part of early grade education was evaluated through a series of studies. The core finding is that climate change concepts have thus far not been largely incorporated into science and social science curricula at the elementary school level. To remedy this situation, several recommendations have been proposed focusing on curriculum reform, teacher awareness raising, and introducing climate-based activities as teaching aides.

Technology transfer issues were evaluated relative to key barriers and needs. To promote strategic technology transfer, advancement on the following measures will be necessary:

- Provision of an enabling environment for technology transfer in renewable energy technologies in light of the findings of a previously conducted technology needs assessment;

- Enforcing intellectual property rights to provide confidence to prospective private sector investors;

- Improving knowledge management processes and platforms for knowledge sharing;

- Enhancing funding for research and development (R&D) in green technology and climate technologies for small- and medium-sized enterprises;

- Developing technology transfer policies and integrating them within technology actions plans; and

- Enhancing human capacity to support science-policy dialogues, build public awareness, and manage technology information.

1. National Circumstances

1. National Circumstances

Bahrain is a small island developing state (SIDS) in the Arabian Gulf that faces unique circumstances regarding the threat of climate change. On the one hand, it enjoys a high standard of living, a modern infrastructure, good health facilities, high literacy rates, and deep economic integration with other Gulf countries. Each of these circumstances position it well for developing suitable responses.

On the other hand, fresh water resources are negligible requiring energy-intensive desalination. The climate is hot nearly year-round leading to intensive electricity use for space cooling. Its economy is primarily driven by oil revenues with limited economic diversification. Layered onto these circumstances is a rapidly growing population and development activities over the past 20 years, putting increased strain on natural resources while generating mounting pressure on the environment. Together, these factors pose a serious challenge to Bahrain's efforts to transition toward climate resilient green growth.

This chapter outlines Bahrain's physical, social, economic, and development policy circumstances. Data were obtained primarily from Bahrain's Information and eGovernment Authority (IeGA), the UN Human Development Report (HDR), and other governmental organizations in Bahrain, as well as from global organizations such as the World Bank and the International Monetary Fund. This chapter also reflects important changes that have taken place in Bahrain relevant to climatic change since its Second National Communication.

1.1. Physical setting

Situated in the west central part of the Arabian Gulf, the Kingdom of Bahrain is located approximately 25 km east of Saudi Arabia and is bounded by latitude 25°32'N and 26°20'N and longitude 50°20'E and 50o50'E. It is an archipelago of more than 36 islands, shoals, and small islets that vary considerably in size and structure.

1.1.1. Geography

Figure 1-1 shows a map of Bahrain. Total land area is currently about 780 km^2, making it one of the smallest countries in the world. The topography is mostly flat, gently rolling land with low relief. Its highest point is Jabal Dukhkhan at 135 meters, which is also the site of its only oil field.

Bahrain has a total coastline of 946 km. Its coastline and land area have both evolved considerably over the last 30 years due to a series of land reclamation projects, which continue to the present day. Roughly, 111 km^2 of reclaimed land has been added since 1980, accounting for about 15% of its current total land area. The extensive dredging needed for these reclamation efforts has led to irreparable damage to coastal areas, with many corals being killed and sea-grass beds destroyed. It has also adversely affected the areas dredged causing excessive siltation and turbidity of seawater and increased groundwater salinity (Madany et al, 1987; Zainal et al., 2012).

1.1.2. Climate

Bahrain is an arid country with mild, pleasant winters, and summers that are very hot and humid. Table 1-1 summarizes monthly averages of key climatic indicators for the period 1960-2017. Rainfall is negligible from April through the end of October, coinciding with high temperatures. Relative humidity is highest during the winter months of December through February, although other months of the year show only slightly lower levels. Onshore wind speeds are typically throughout the year, ranging from 3.8 to 5.5 meters per second.

1.1.3. Agriculture and land use

Agriculture in negligible in Bahrain, accounting for only 0.3% of GDP (World Bank, 2019) and covers only a small fraction of the country's needs in food. Agricultural products are mainly fruits, vegetables, poultry, dairy products, shrimp, and fish, all of which is for domestic consumption. The main crop is the date palm and is of great historical and cultural value to the Bahrainis.

Production trends over the 2000-2017 period are summarized in Figure 1-2. While vegetable production levels have increased by about 2.3% per year since 2000, vegetable production has declined by about

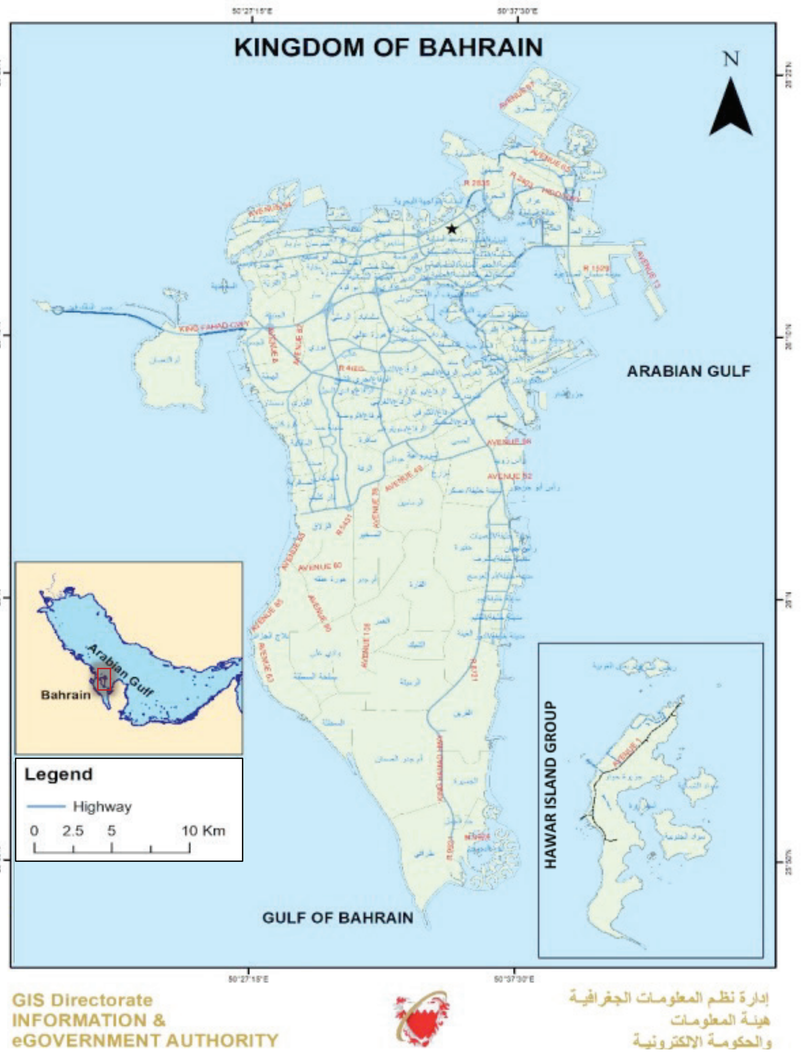


Figure 1-1: Map of Bahrain

0.7%/year while production of other items such as pulses, roots/tubers, tree nuts have declined by about 4.8%/year.

Low agricultural productivity is a function of both limited arable land and a hyper arid climate. Figure 1-3 illustrates the fact that Bahrain is poorly endowed in terms of arable and forest land, compared to both the Middle East and North Africa (MENA) and world averages. That is, only 2.1% of the land is considered arable, roughly one fifth of the world average.

In contrast, permanent crop land in Bahrain takes up a disproportionate share of land area, about three times the world average. This illustrates the acute difficulty that desert countries such as Bahrain face in forging a modern economy. Prior to the discovery of oil in 1929, Bahrain's population, as well as other countries in the Gulf region, relied on nomadic lifestyles due to the challenge of eking out a living in the virtual absence of forest and arable land.

1.1.4. Energy

Bahrain produces around 50,000 barrels of oil a day. It also receives 50% of the revenues associated with the approximately 300,000 barrels per day produced in the Saudi operated Abu Sa'fa oil field which is situated on the maritime border between Saudi Arabia and Bahrain. As of 2015, Bahrain's proven crude reserves come to 130 million barrels (Energy Information Administration (USEIA), 2019).

Bahrain's natural gas production totaled 520 billion cubic feet (bcf) in 2015, plus an additional 230 bcf of associated gas (Al-Doseri, 2018). As of 2015, Bahrain's proven natural gas reserves come to 3,250 bcf (USEIA, 2019). In 2017. Bahrain began construction of the Middle East's first liquified natural gas (LNG) receiving and regasification terminal offshore Hidd Industrial Area on Muharraq Island. When complete, the facility will help Bahrain meet increasing demand for natural gas for industrial and urban development.

There have also been some recent discoveries of additional fossil fuel resources. In April 2018, the Bahrain government announced a large discovery of up to 80 billion barrels of shale oil, and 20 trillion cubic feet of gas (Naumann et al., 2018). The potential economic impact of these discoveries is currently being assessed.

Electricity consumption per capita is high in Bahrain, even by Gulf country standards. As illustrated in Figure 1-4, per capita consumption levels are over double the weighted average of the other Gulf countries (i.e., Kuwait, Saudi Arabia, Qatar, United Arab Emirates, and Oman) and seven times the world average. While Bahrain's high electricity consumption levels are driven in large part by air conditioning demand, it also reflects generous electricity subsidies to households and businesses which disincentivize efficiency and conservation investments (Naumann et al., 2018).

1.1.5. Water and sanitation

Bahrain is a highly water stressed country from a freshwater resource availability perspective. There are only 3 cubic meters (m^3) of renewable groundwater per capita, compared to an average of 1,400 m^3

across the MENA and a world average of 6,000 m^3 per capita (World Bank, 2019). While there are non-renewable water springs, rising population combined with inefficient consumption have led to the gradual depletion of these fossil groundwater sources.

Today, groundwater accounts for only around 9% of water production (Albuflasa, 2018). The balance of water supply is provided by high-cost desalinated water produced using energy-intensive thermal (multi-stage flash, MSF; multi-effect distillation, MED) and membrane-based technologies (reverse osmosis, RO). The combined desalinated water production capacity is about 846 thousand cubic meters per day. An inventory of desalination units is shown in Table 1-2.

Water demand is satisfied by the municipal distribution network and on-site groundwater extraction or desalination. The municipal distribution network meets demand mostly from households, businesses, and government buildings and currently accounts for 60% of all water consumption. The remaining 40% of water use is from farms and industrial facilities.

Municipal water consumption is very high in Bahrain. On a per capita basis, water is currently consumed at an average rate of 500 liters per day per person, one of the highest levels in the world.

Bahrain has also made substantial progress in providing basic sanitation services for about 92% of its population. The Ministry of Works (MoW) operates 11 treatment facilities with a total capacity of about 352,770 m^3/d (see Table 1-3). The largest wastewater treatment facilities are the Tubli and North Sitra plants.

1.1.6. Terrestrial environment

A desert environment dominates Bahrain's terrestrial landscape, except for a narrow fertile strip that is found along the northern and northwestern coastlines. The desert is home to many types of insects, reptiles, birds and wild mammals. It is also an important source of palm dates and medicinal desert plants that are used in folk medicine.

For centuries biodiversity has played a large role in defining the identity and heritage of the Kingdom, most vividly illustrated by the 1976 establishment of the AlAreen Wildlife Park and Reserve to promote conservation and protect rare animals and birds found in the kingdom and region. While primarily established to provide a refuge for the endangered species and their breeding habitats, it also serves as an educational center to learn about local wildlife (http://www.alareen.org/HomePage.aspx).Mammal species in the reserve include the Arabian Oryx, Nubian ibex and the Bahraini Alrheem Gazelle, in addition to some bird species such as the Houbara Bustard and some common desert plants (see Figure 1-5).

Table 1–1: Climatic indicators for Bahrain, 1960-2017 (Source: Bahrain Ministry of Transportation and Telecommunications)

Month	Average temperature (°C)	Annual rainfall (mm)	Mean daily relative humidity (%)	Average wind speed (meters/second)
January	17.1	19.5	72	5.1
February	18.2	19.0	70	5.3
March	21.1	16.4	65	5.1
April	25.6	9.5	59	4.7
May	30.5	1.4	54	4.8
June	33.1	0.0	53	5.5
July	34.5	0.0	56	4.6
August	34.6	0.0	61	4.1
September	32.8	0.0	63	3.8
October	29.5	0.4	65	3.9
November	24.5	13.1	67	4.6
December	19.4	18.4	72	4.9
Minimum	*17.1*	*0.0*	*53*	*3.8*
Maximum	*34.6*	*19.5*	*72*	*5.5*
Average	*26.7*	*8.1*	*63*	*4.7*

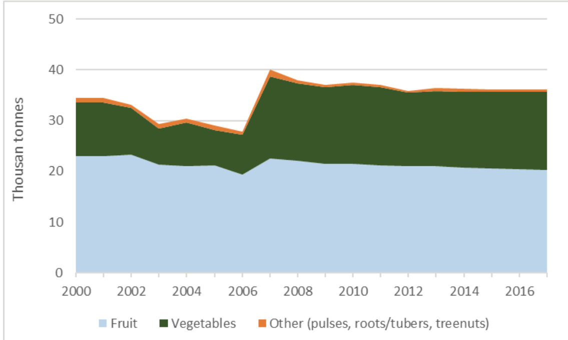


Figure 1-2: Agricultural productivity in Bahrain, 2000-2017 (Source: FAO, 2019)

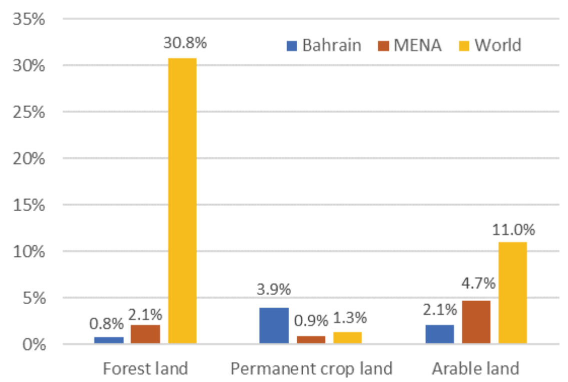


Figure 1-3:: Land use patterns in Bahrain in 2015, compared with other regions (Source: World Bank, 2019)

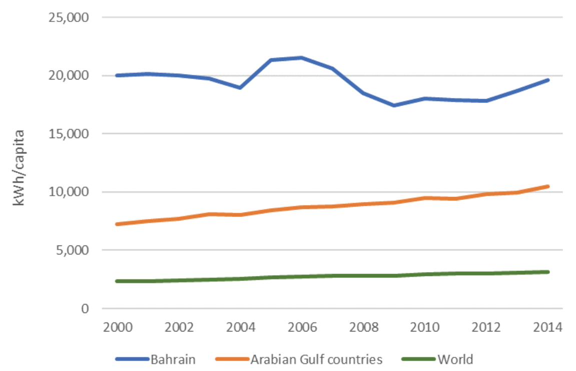


Figure 1-4: Electricity consumption levels in Bahrain, compared with other regions, 2000-2014 (Source: UNDP, 2016)

Table 1–2: Inventory of desalination plants (source: Zubari, *et al.*, 2018)

Plant	Online year	Technology	Capacity 1000 m³/d	Raw Water
Sitra	1975	MSF	113.6	Seawater
Ras Abu Jarjur	1984	RO	73.4	groundwater
Al Dur	1990	RO	45.5	Seawater
Al-Hidd	1999	MSF & MED	409.1	Seawater
Alba	2002	MED	31.8	Seawater
Al-Dur	2012	RO	218.2	Seawater
Total			846.1	

Bahrain has environmental protection policies, legislation and regulations in place to protect and conserve its terrestrial biodiversity. The Kingdom has also been a signatory to the Convention on Biological Diversity (CBD) since 1996. Furthermore, in efforts to preserve its natural assets. the country embarked on a two-year process (2013-2015) to revise and update its first National Biodiversity Strategy and Action Plan (NBSAP) that had been developed in 2007.

Today, the 2016-2021 NBSAP is recognized as the principal element for CBD implementation in Bahrain, aiming to reverse "… the loss of biodiversity within Bahraini terrestrial, marine and freshwater ecosystems." Various activities such as restoration, reforestation and public awareness raising programs are ongoing in support of this central aim. Emerging evidence of increasing number of species and habitat restoration provide confirmation of the unfolding effectiveness of Bahrain's 2016-2021 NBSAP.

Figure 1-5: Mammal and plant species found in the AlAreen Wildlife Park and Reserve (source: Bahrain's 2016-2021 NBSAP)

1.1.7. Marine environment

The marine environment is characterized high rates of evaporation during most of the year and a shortage of freshwater input. Average seawater temperatures range from 8°C in winter to 3 °C in summer, with daily variations that can reach 4°C between day and night. Sensitive habitats of coral reefs and seagrass are largely affected by such wide seasonal and daily variations.

The most vital marine habitats in Bahrain are represented by mangrove and seagrass beds in the intertidal regions and coral reefs in the subtidal regions. There is only one species of mangrove, Avicennia marina, which is distributed around Tubli bay. Mangroves are under high stress due to land reclamation activities, with a reduction in area from 24 km² in 1956 to about 12 km² in 2008.

Seagrass beds in Bahrain are represented by three species; Halophila ovalis, Halophila stipulacea and Halodule uninervis. The latter two species are the most common and are widely distributed in the southeast coast extending to Hawar Island. Seagrass beds support marine biodiversity and provide nursery and feeding grounds for endangered species such as green turtle and dugong, as well as other benthos. Coastal development projects have significantly reduced the area of seagrass beds, a situation that has led to efforts to restore seagrass habitats in the vicinity of reclaimed lands.

Table 1–3: Inventory of wastewater treatment plants (source: Zubari, *et al.*, 2018)

Plant	Online year	Influent	Treatment	Technology	People served	Design Flow, m³/day
Tubli WPCC	1982	Domestic	Tertiary	Ozone, Chlorine, Filtration	700,000	200,000
North Sitra	2008	Domestic & Industrial	Tertiary	Deep gravity sand filters	72,500	16,500
Askar	1997	Domestic	Secondary	Activated sludge	1,250	288
Hidd Industrial	2005	Domestic & Industrial	Tertiary	Sand Filters	N/A	2,325
Jasrah	2006	Domestic	Tertiary	Sand filters	1,500	340
Bahrain University	1985	Domestic	Tertiary	Sand filters	1,679	504
Jaow	1992	Domestic	Secondary	Activated sludge	1,500	408
South Alba	1994	Domestic & Industrial	Tertiary	Chlorine	14,800	900
Al Dur	2003	Domestic	Tertiary	Sand Filters	250	70
Hamalah	2015	Domestic	MBR	MBR	1,500	1,100
Ma'ameer	2010	Domestic and Industrial	MBR	MBR	N/A	2,250

Coral reefs are found mostly in the east and north due to the comparatively higher salinity and temperatures associated the south and west areas. The main coral habitats include the 200 km^2 Fasht Al-Adhm in the east of Bahrain, Khawr Fasht and Fasht Al-Jarim in the north, and Bulthama, about 70 km northeast (Vousden, 1988). In the past, dense Acropora dominated coral cover (50–80%) was typically found (see Figure 1-6, left). Today, less than 10% remain due to large scale coastal development and bleaching episodes of the 1990s (Burt et al., 2013). More than 50 finfish species are associated with the remaining coral reefs (see Figure 1-6, middle, right).

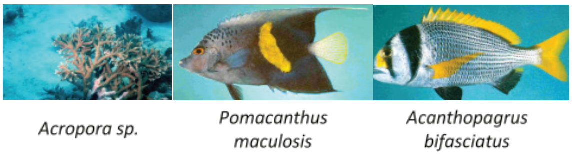


Figure 1-6: Left: Common coral species; Right: Common finfish species associated with coral reefs in Bahrain' waters (source: Al-Dawood, 2018)

1.2. Social setting

Bahrain enjoys a rich social milieu, with diverse communities living side by side in primarily high-density urban contexts throughout the island. Several key aspects of the Bahrain social fabric are described in the subsections that follow.

1.2.1. Population

In 2016, Bahrain's total population was just over 1.4 million. (In 2019, Bahrain's total population reach approximately 1.5 million). Roughly, half of the population is comprised of expatriates who come to country to pursue work opportunities (see Figure 1-7; left). The average annual rate of population growth has decreased significantly from 5.3%/year during the 2005-2010 period, to about 1.8%/year during the 2010-2015 period (see Figure 1-7; right). Bahrain's high growth rate during 2005-2010 was over double the growth rate in the rest of the Arab world are is attributed to high levels of migrant workers (i.e., non-citizens) that obtained work visa during that period. In contrast, Bahrain's growth rate during 2010-2015 was lower than that of the Arab world, indicating the relative volatility of demographics in Bahrain. Women account for approximately 37% of the total population; a low figure due primarily to the large numbers of migrant workers are primarily male.

Figure 1-8 shows the age-based composition of Bahrain's population. Again, due primarily to the abundance of migrant workers, Bahrain's population is skewed toward people in the age group 15-64, away from the two extremes (under 5, over 65): people in this group represent about 76% of the population, compared to between 63% and 66% across the three comparison groups (i.e., small islands developing states (SIDS), Arab states, world). As a result, Bahrain's old age dependency ratio is only about 3%, compared to 7% for Arab states, 11% for SIDSs, and 13% for the world.

1.2.2. Health

Bahrain's enjoys a modern, high-quality healthcare system evidenced by favorable public health indicators. For example, infant mortality in Bahrain is very low: 5.3 per 1,000 live births. As shown in Figure 1-9 (left bars), this is roughly 80% to 85% lower than the three comparison groups (i.e., Arab states, small island developing states (SIDS), world). Mortality among children under 5 years of age is also very low, about 6.2 per 1,000 live births, as shown in Figure 1-9 (middle bars) or roughly, 85% to 90% lower than the comparison groups.

Moreover, people in Bahrain enjoy long life expectancy. By the measure of life expectancy at age 60, the population across males and females averages

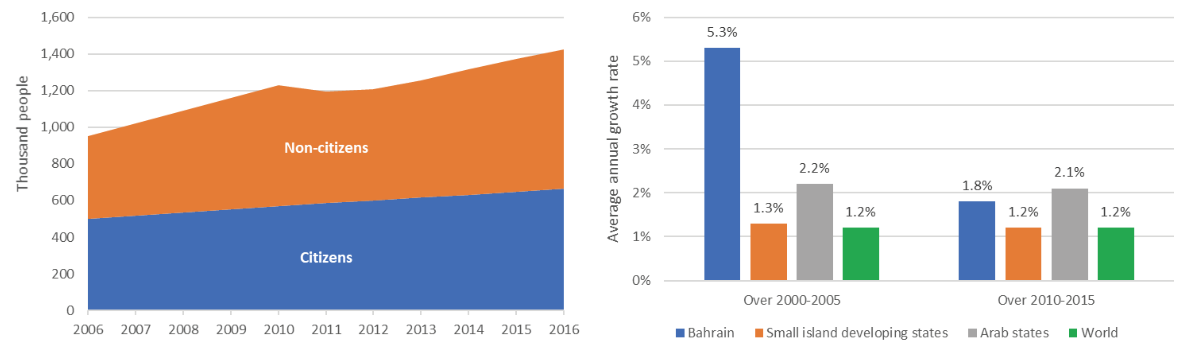


Figure 1-7: Left: Bahrain population composition, 2006-2016 (Source: IeGA, 2019); Right: Average annual population growth in Bahrain compared to other regions (Source: UNDP, 2016)

about 19.4 years of life beyond age 60, as shown in Figure 1-9 (right bars). This is barely distinguishable from the comparison groups, performing marginally better than the Arab world, and marginally worse than the world average.

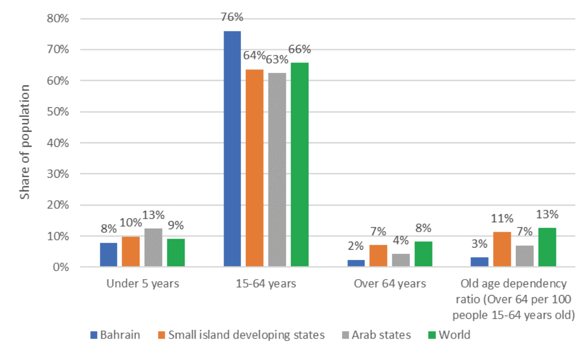


Figure 1-8: Share of population by age group in Bahrain in 2015, compared with other regions (Source: UNDP, 2016)

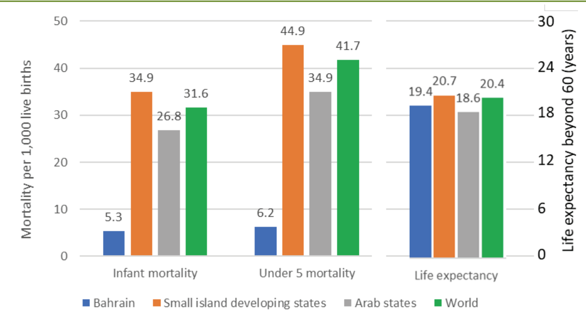


Figure 1-9: Mortality indicators in Bahrain, compared with other regions, 2015 (Source: UNDP, 2016)

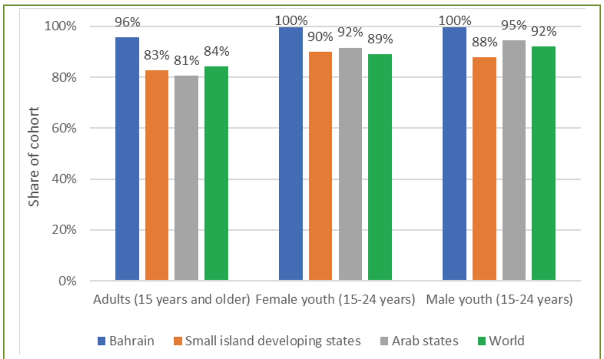


Figure 1-10: Average literacy levels in Bahrain, compared with other regions, 2005-2015 (Source: UNDP, 2016)

In an effort to explore possible links between climatic conditions and human health indicators in Bahrain, an extensive data collection and analysis effort was undertaken (Hamadeh, et al., 2018). Publicly available annual mortality data were obtained for the years 2003-2015 from the Ministry of Health's (MOH) website with earlier years obtained from hard copies of health statistics.

All Morbidity data were obtained from the MOH and Bahrain Defense Force Hospital (BDFH) and King Hamad University Hospital (KHUH). A total of 135 preliminary correlation relationships were developed, mostly over the period 2006 – 2012, between mortality and morbidity indicators (e.g., with a set of climatic indicators (i.e., temperature, humidity) and air quality indicators (i.e., concentrations of nitrogen dioxide, sulfur dioxide, carbon monoxide, ozone, coarse particulate matter (PM_{10}) and fine particulate matter ($PM_{2.5}$). The results indicated a potentially rich area investigation to be further pursued in coming years.

1.2.3. Education

Bahrain's population, both citizen and non-citizen, male and female, enjoy high literacy rates when compared to other regions. This is due in large part to high enrollment rates across preschool and tertiary educational systems. Figure 1-10 shows that average literacy rates in Bahrain among adults exceed the literacy rates in SIDS, Arab states, and the World by 12% to 15%. This characteristic holds true for both female and male youth where national literacy rates exceed those in the comparison regions by 5% to 12%.

1.2.4. Urbanization

Bahrain is a highly urbanized country, with nearly 89% of the country's population living in urban areas as of 2017. Most of the population is centered in the capital, Al Manamah and other major urban centers like Al Muharraq, Ar Rifa' and Hamad Town. Urban growth and associated activities (e.g., camping) have adversely affected natural desert areas in some parts of the country, especially those near the populated areas in the north.

Urbanization levels in Bahrain have remained fairly constant over the past several decades, increasing by only 0.1% per year since 1960. In contrast, urbanization in Arab states, SIDS, and the world showed much lower levels in 2017; 58%, 55%, and 55%, respectively although the rate of growth of the share of urbanized population in these regions grew between 5 and 11 times the rate in Bahrain (see Figure 1-11).

1.3. Economic setting

Bahrain has a relatively open economy and is ranked as 5th among MENA countries in the 2019 Index of Economic Freedom (Heritage Foundation, 2019). With a real per capita income of over $22,000 in 2016 (2010$), it is classified by the World Bank as a high-income economy. In 2016, Bahrain's real GDP was approximately US$31.4 billion (2010 US$) at market exchange rates, up from 23.8 billion in 2008, an average annual growth rate of about 3.6%.

1.3.1. Key sectors

Figure 1-12 shows the sectoral breakdown of Bahrain's GDP for the years 2008 and 2016. The largest share of GDP, about one fifth, comes from the mining and quarrying sector, of which oil and gas operations account for most of the contribution, about 97%.

The oil & gas subsector remains the cornerstone of Bahrain's economy in the postwar period, accounting for over 80% of public revenues. This has been the case since the demise of the pearl diving industry during the 1930s.

At about 16% of GDP, financial services account for the second largest sector, reflecting the significant contribution that Islamic finance makes to Bahrain's economy. Lebanon used to be the global capital of Islamic finance, but after the Lebanese civil war during the 1990s, Bahrain emerged as a new financial services hub and has maintained a strong presence in Islamic finance ever since.

The third largest sector is manufacturing, which primarily reflects the production and export of aluminum and downstream products, such as metal cables. In contrast to the mining and quarrying and financial services sectors which have experienced declining shares of GDP, the manufacturing sector as a share of GDP has been expanding slightly over the 2008 to 2016 period, from 14% to 15%.

1.3.2. Key economic indicators

Figure 1-13 shows several macroeconomic indicators for Bahrain for 2015. Bahrain had a budget deficit equal to 16% of GDP, which was the result of oil prices declining sharply during 2014, which adversely impacted government revenues. Falling oil prices and a rising budget deficit contributed to a rising public debt, which reached 66% of GDP in 2015.

At 1.8%, consumer price inflation was very low in 2015, similar to previous years. This is due in large part to a fixed exchange rate of the Bahraini dinar with the US dollar. This has been in effect since the early 1980s and has helped keep consumer prices highly stable despite oil-price volatility.

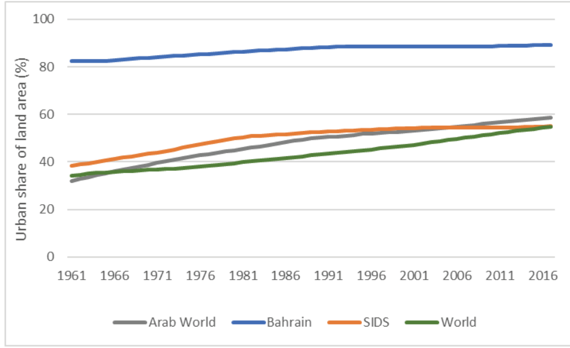


Figure 1-11: Urbanization levels in Bahrain, compared with other regions, 2015 (Source: World Bank, 2019)

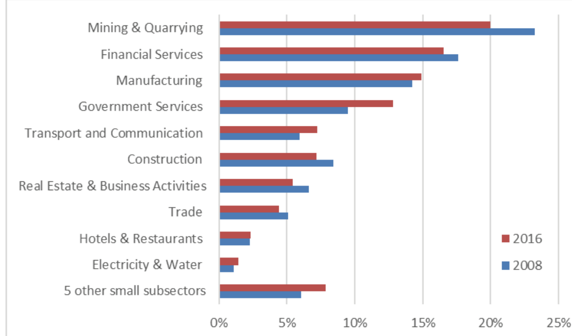


Figure 1-12: Sectoral composition of Bahrain GDP, 2008 & 2016 (Source: IeGA, 2019)

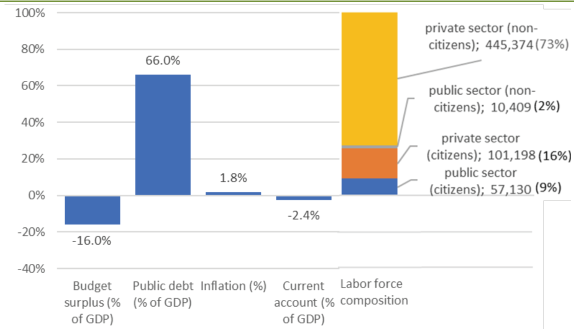


Figure 1-13: Selected macroeconomic indicators for Bahrain, 2015 (Source: IMF, 2019; Labor Market Regulatory Authority, 2019)

The high contribution of oil to exports meant that falling oil prices led to a current account deficit equal to 2.4% of GDP. This represents a sharp departure from previous years of large current account surpluses due to a sustained period of elevated oil prices.

Falling oil prices have placed the economy on a path that requires a long-term adjustment, as the budget deficit, the public debt, and the current account deficit are all at unsustainable levels.

Finally, the labor force reflects the large number of expatriates that contribute to private and public sector activities. About 75% of the entire labor force consists of non-citizens, most of whom are involved in the private sector. The remaining 25% of the labor force consists of citizens, most of who are also associated with private sector activities. Women are active in the labor force yet participate at a rate that is below the world average.

1.3.3. Economic Vision 2030

In concert with other Gulf countries, Bahrain has been active in exploring economic diversification strategies to wean the economy away from oil dependency. Prior to the new millennium, these efforts had been largely unsuccessful, partially due to the absence of suitable alternatives, but also due to the lack of adequate pressure to make tough policy decisions, as state finances were not significantly strained.

In recognition of the necessity of economic reform, in 2008 the government launched its Economic Vision 2030 initiative, with a goal of a diversified and dynamic economy, including diversified energy sources. The vision has three guiding principles: sustainability, competitiveness, and fairness. These principles were then translated into three sets of aspirations, as outlined in the bullets below:

- *Economic:* The emphasis is on growth in productivity (rather than rising oil production and oil prices) becoming the primary source of economic growth;

- *Governmental:* This focuses on government transitioning away from a generator of economic activity toward that of a regulator, while improving its efficiency, and removing barriers to private sector innovation; and

- *Societal:* The emphasis is on providing citizens with high quality education and healthcare, ensuring a secure and safe environment, and providing a safety net for those less fortunate.

The vision is distinct from previous diversification efforts across the Gulf due to its comprehensive and strategic nature, as it was conceived based on the assumption that its implementation would require high levels of coordination between relevant governmental organizations. Moreover, several new governmental organizations were founded under the vision's umbrella including the following key units.

- *Economic Development Board:* tasked with attracting foreign direct investment (FDI);

- *Tamkeen:* tasked with transforming the private sector into the main source of economic growth;

- *Telecommunications Regulatory Authority:* tasked with ensuring a high quality of information and communications infrastructure;

- *Labor Market Regulatory Authority:* tasked with managing the large pool of migrant workers in a manner that ensures the growth of job opportunities for Bahraini citizens; and

- *Information and eGovernment Authority:* tasked with digitizing government services.

As a result of Vision 2030, Bahrain's economy today differs significantly the turn of the millennium. Foreign Direct Investment (FDI) has now become an important source of jobs and growth; private enterprises receive targeted support, as do citizens seeking to gain professional qualifications that contribute to modern human capital. In addition, Information and Communication Technologies (ICT) infrastructure is comparable to that found in Organisation for Economic Co-operation and Development (OECD) economies. Moreover, the number of Bahrainis working in the private sector has risen considerably while many government services have become electronic, leading to vast improvements in quality and delivery time (Naumann et al., 2018).

Government agencies are continuing in the implementation of Economic Vision 2030, as the economy remains highly dependent upon oil, albeit less dependent than it was in the past. The fiscal problems caused by a mixture of the global financial crisis and falling oil prices have forced the government to launch a fiscal balancing program in 2018, with the assistance of Kuwait, Saudi Arabia, and the UAE. As part of the program, Bahrain introduced a value added tax in 2019.

1.3.4. Key economic challenges

Despite high levels of per capita mineral deposits, Bahrain is poorly endowed in virtually every other resource that is associated with a modern, successful economy. This makes the process of diversifying the economy very challenging, and distinct from the challenge that other, oil-dependent economies have faced in the past, such as Indonesia, Malaysia, and Mexico; or that face today, such as Algeria, Iraq, and Libya.

Bahrain's small size and population means that it has a very small domestic market, undermining the country's ability to exploit economies of scale in production, which is normally a critical precursor to sustainable technological development. As part of the GCC, Bahrain has had access to its single market since its inception in 2008. However, this has been a very recent development, and the benefits of access to this economic zone have yet to be fully realized.

Being a SIDS presents an additional set of challenges. Bahrain is missing many of the key ingredients conventionally required to build a modern economy, most notably the means to create an agricultural surplus. This makes Bahrain fundamentally dependent upon foreign trade, amplifying the challenges of food and water security. In addition, Bahrain has added exposure to natural disasters such as recurring sand and dust storms and rising temperatures.

Finally, Bahrain's presence in the Middle East introduces a series of geopolitical challenges stemming from its proximity to several combat theaters, which bring with them the threat of spillover violence, including terrorism. Among other things, this adversely affect global investment possibilities in the region. For a small country like Bahrain, where foreign direct investment is a central component of the country's economy strategy, any inhibitor to investment represents a difficult challenge.

1.4. Policy setting

Policymaking relevant to climate change takes place at multiple levels. At the multilateral/international level, Bahrain is party to many international conventions, including the 2015 Paris Agreement, the 1999 Montreal Protocol on ozone depletion, and the 2013 Beijing Amendment to the Montreal Protocol. At the national level, Bahrain has been active in formulating policy relative to sustainability, the environment, energy, and climate change itself, each of which is summarized in the subsections below.

1.4.1. Sustainability

Government action plans (GAPs) are the main policymaking mechanism to operationalize Economic Vision 2030. The most recent GAPs cover the period 2015-2018 and contain explicit steps and performance indicators for the near-term realization of the sustainability objectives in the economic vision.

By coincidence, the most recent GAP was launched around the same time as the UN Sustainable Development Goals (SDG) framework. Given the significant overlap between the SDGs and Bahrain's Economic Vision 2030, the Bahrain government set about integrating the GAP with the SDGs. The Bahrain government is now committed to the SDG program, and delivered its first voluntary national report during July 2018, and takes steps to ensure that policy plans are articulated in terms of the language of the SDGs

1.4.2. Environment

In 1995, environmental and wildlife laws were passed, with the goals of protecting the environment, preserving species, and rehabilitating suitable habitats for wildlife. In 1996, the Supreme Council for the Environment (SCE) was established to formulate environmental policy associated with the implementation of these laws. The SCE has significant executive authority, including the ability to issue environmental regulations, to monitor adherence to those regulations, and to fine those who fail to comply. The SCE also coordinates the actions of other governmental organizations, including ministries, as it seeks to realize its mission of protecting the environment.

In 2006, the Bahrain government launched a formal environmental strategy, which features a series of strategic goals in a variety of domains, including air, water, agriculture, the marine and coastal environment, tourism, transport, and waste management. The plan was subsequently approved by the Cabinet and the core pillars of environmental policy have been integrated into Economic Vision 2030.

In 2019, Bahrain finds itself in a very different situation compared to the one of 2006. This is due to changes to the economy, and changes in global attitudes and regulations relating to climate change, as well as the recent launch of the SDG framework. As such, the SCE is currently working on a new set of environmental policies.

1.4.3. Energy

In 2014, the Sustainable Energy Center (SEC) -previously Sustainable Energy Unit- was launched. The SEU is a joint project with the United Nations Development Program (UNDP) and focuses on developing policies that promote energy efficiency and renewable energy, with associated benefits to reducing carbon emissions and improving local air quality.

To date, the SEU has launched two major initiatives, namely the National Renewable Energy Action Plan (NREAP) and the National Energy Efficiency Action Plan (NEEAP), each of which is outlined in the paragraphs below.

NREAP has two primary targets: having 5% of energy (255 MW of installed capacity) from renewable sources by 2025, and 10% (710 MW of installed capacity) by 2035 (SEU, 2017a). The plan seeks to realize these targets by a mixture of solar, wind, and waste-to-energy technologies and involves a mixture of public and private investment. When fully implemented, it is expected to avoid about 392,000 tonnes of CO_2 per year. Three main policies have been established to realize the targets, as follows:

- Net metering: This will enable consumers to generate on-site, grid-connected, renewable energy, for example via the installation of solar panels on roofs;

- Feed-in tariffs: This is a tender-based mechanism to support renewable energy characterized by long-term power purchase agreements; and

- Mandates: This refers to renewable energy mandates for new buildings. The Bahrain Petroleum Company's (BAPCO) 5 MW solar plant, completed in 2014, is an example of efforts at increasing the contribution of renewable energy.

NEEAP is a complementary initiative (SEU, 2017b). After extensive consultations with stakeholders, the SEU established the target of a 6% reduction (about 6,000 GWh) in final energy consumption by 2025. It is estimated that this would lead to a cumulative reduction in greenhouse gas emissions of 3.4 million tonnes of CO_2 by 2025. Twenty two main initiatives have been established to realize this target, including:

- *Building codes:* This involves the integration of energy efficiency objectives into regulations governing the design, construction, and maintenance of structures. The new Bahrain International Airport, currently under construction, will be NEEAP-compliant;

- *Demand-side efficiency standards:* This involves new minimum standards for lighting, appliances, motor vehicles, and street lighting;

- *Supply-side efficiency standards:* This focuses on electricity generation, including efficiency enhancements for the transmission and distribution of electricity, and the installation of smart meters;

- *District cooling:* This involves the introduction of highly efficient, industrial-grade equipment to produce space cooling for buildings through an insulated underground piping network; and

- *Green building initiatives:* This involves retrofitting of government buildings; and other initiatives; and

- *Subsidy reform:* This involves reforms to both power subsidies and those that affect transport to offset perverse incentives for wasteful consumption.

1.4.4. Climate change

While NREAP and NEEAP are the flagship components of Bahrain's energy policy, they also represent an important pillar of Bahrain's climate change policy. Other pillars include project-based initiatives for greenhouse gas mitigation and public awareness raising about climate change, as outlined below.

- *Project-level initiatives:* Two projects have been launched. The first is BAPCO's carbon recovery plan, which finds industrial applications for the waste CO_2 associated with its oil extraction activities. The other is a carbon dioxide recovery unit launched by Gulf Petrochemicals Industries Company (GPIC) in 2009, a first for a petrochemicals company in the Middle East.

- *Education-based initiatives:* This involves improving education and awareness on climate change primarily by introducing changes in educational curricula in primary schools. In addition, specific proposals for educational reforms were delivered to the Ministry of Education on the basis of studies of how other countries have introduced climate change into educational curricula.

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2. Greenhouse Gas Inventory

2. Greenhouse Gas Inventory

2.1. Introduction

This chapter presents estimates of Bahrain's anthropogenic greenhouse gas emissions (GHG) and sinks for the year 2006, with estimates through 2015, based on the inventory assessment prepared by Alnaser et al., (2018). The inventory includes four categories: energy; industrial processes and product use (IPPU); agriculture, forestry and other land use (AFOLU); and waste.

2.1.1. Methodology

The Base Year for the inventory is 2006, with emission estimates up through the year 2015. The inventory was compiled according to the methodology for inventories described in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006). The IPCC's Inventory Software (Version 2.54) was used to assemble activity and emission factor data.

Both reference and sectoral approaches were implemented to estimate carbon dioxide (CO_2) emission levels. The difference between the two approaches was acceptable for the Base year, about 7.5%. As the sectoral approach was used to estimate methane (CH_4) and nitrous oxide (N_2O) emission levels, only sectoral results are reported in the tables that follow to allow direct comparability with the approach used to estimate CH_4 and N_2O emissions.

While the Tier-1 approach of the IPCC guidelines were primarily utilized in the calculations for all reporting categories, Tier-2 and Tier-3 methods were used where warranted by adequate data availability and data quality.

The inventory relied on several guidance documents, including the Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories (IPCC, 2000).

2.1.2. Assumptions

Activity data were obtained from the Central Statistics Organization, based on data provided by the Supreme Council for Environment. Specific properties of certain fuels (i.e., density, carbon content, higher heating value), were provided by BaPCo. Of greatest import was natural gas as it represents around 90% of all energy consumed in Bahrain. Where local data were not available, IPCC default values were used for emission factors, carbon content, and net heating value. Calculations of carbon dioxide-equivalent (CO_2e) were carried out using 100-year global warming potentials (GWP) as recommended by the IPCC in its Fourth Assessment Report.

2.2. Overall results

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

2.2.1. Total GHG emissions

Table 2-1 presents total GHG emissions and sinks for the year 2006. Total GHG emissions in 2006 were 29,153 Gg CO_2e, which includes 20,149 Gg from energy; 8,704 Gg from IPPU; and 268 Gg from waste. CO_2e emissions from AFOLU were about 33 Gg, which after accounting for carbon sinks in managed green spaces and parks totaled 8 Gg. Net national emissions in 2006 were 29,128 Gg, after accounting for these carbon sinks.

Energy-related activities accounted for the dominant portion of GHG emissions in Bahrain in 2006.

Table 2–1: GHG emissions and sinks in Bahrain, 2006 (Gg)

GHG Sources	CO_2e	CO_2 Emissions	CO_2 Sinks	CH_4	N_2O	PFCs	HFCs	SF6
1 Energy	20,149	19,686	0	16.7	0.2	0.00	0.00	0.00
2 Industrial processes and product use	8,704	2,004	0	0.9	0.0	0.81	0.03	0.00
3 Agriculture, forestry and other land	8	7	-25	1.0	0.0	0.00	0.00	0.00
4 Waste	268	0	0	9.9	0.1	0.00	0.00	0.00
Total National Emissions	**29,153**	**21,697**	**---**	**28.5**	**0.3**	**0.81**	**0.03**	**0.00**
Total Net Emissions	**29,129**	**21,697**	**-25**	**28.5**	**0.3**	**0.81**	**0.03**	**0.00**

Approximately 69% of all GHG emissions are associated with the combustion of fossil fuels or the release of fugitive emissions from oil and gas operations. Industrial processes and product use accounted for about 30% of all GHG emissions, followed by the waste sector that accounted for about 1% of total emissions. Emissions from agricultural and land use activities are negligible, less than 0.2% of total national emissions.

2.2.2. GHG emissions by type

The following bullets provide an overview of total GHG emissions by all GHG types for the year 2006.

- CO_2: Total CO_2 emissions were estimated to be 21,697 Gg, or 74% of Bahrain's total greenhouse emissions in the year 2006. Figure 2-1a summarizes the contribution associated with CO_2 emissions at both the sector and subsector levels.

- High GWP gases: Together, PFCs, HFCs, and SF_6 emissions accounted for the second largest share of greenhouse gas emissions. On a CO_2e basis, total emissions were estimated to be about 6,676 Gg, or about 23% of Bahrain's total greenhouse emissions. Of this amount, PFCs (i.e., PFC-14 and PFC-116) accounted for 6,608 Gg CO_2e, or about 99% of the high GWP gas contribution. Figure 2-1b summarizes the contribution at both the sector and subsector levels.

- CH_4: Methane accounted for the third largest share of greenhouse gas emissions. Total CH_4 emissions were estimated to be about 28.6 Gg, or about 2.5% of Bahrain's total greenhouse emissions on a CO_2e basis. Figure 2-1c summarizes the contribution associated with CH_4 emissions at both the sector and subsector levels.

- N_2O: Nitrous oxide emissions were very small compared to other GHGs. Total N_2O emissions were estimated to be only about 0.22 Gg, or about 0.2% of Bahrain's total greenhouse emissions on a CO_2e basis. Figure 2-1d summarizes the contribution associated with N_2O emissions at both the sector and subsector levels.

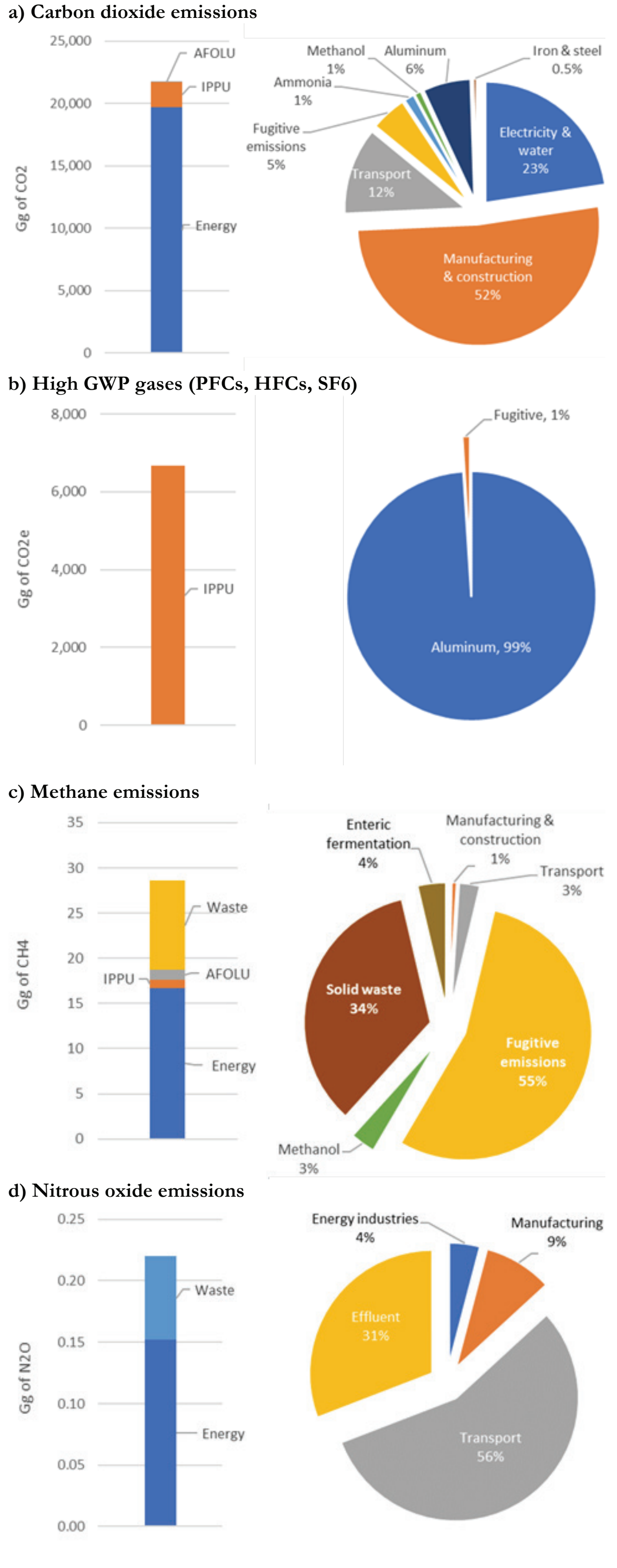

Figure 2-1 : Breakdown in GHG emissions by gas type and emitting sector and subsector, 2006

2.2.3. GHG emissions trends

Figure 2-2a presents the trend in total GHG emissions by type of GHG for the Base Year 2006 and projected GHG emissions through 2015. Over the 2006-2015 period, total emissions have increased by about 37%; from 29,153 Gg CO_2e in 2006 to about 39,902 Gg CO_2e in 2015, or roughly 3.5%/year. Emissions of CO_2 are increasing slightly above this rate, 4.0% per year. Notably, HFC emissions are experiencing the highest levels of annual growth in Bahrain, roughly 33% per year.

Figure 2-2b presents the trend in net GHG emissions by emitting sector for the Base Year 2006 and projected GHG emissions in 2010 and 2015. Energy remains the main component responsible for the overall increasing trend in GHG emission levels. Over the 2006-2015 period, CO_2e emissions from energy use have increased by 40%, or about 3.8% per year, due primarily to increased energy use for electricity generation, desalinated water production, and process heat in manufacturing. Notably, CO_2e emissions from waste, though small in absolute terms, increased by 153%, or about 11% per year.

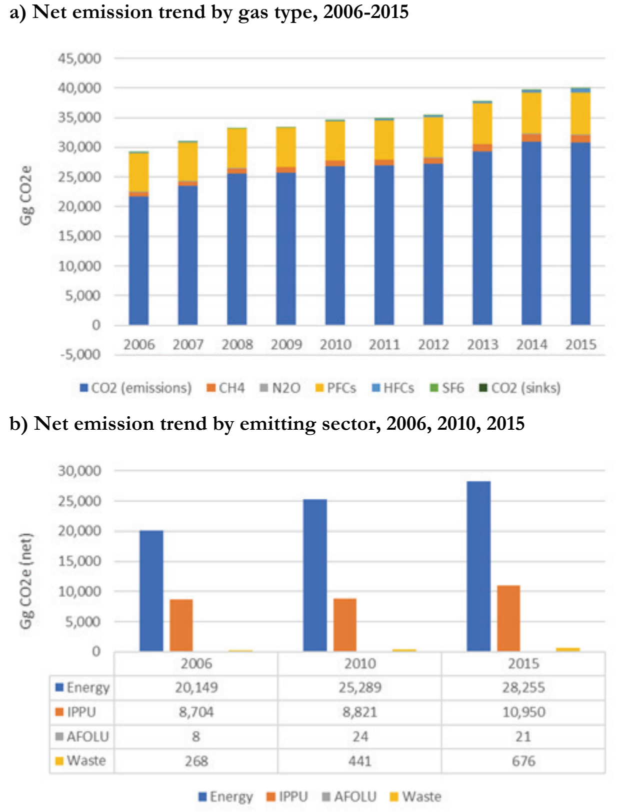

Figure 2-2: Trends in total GHG emissions by gas type and emitting sector

2.3. Sectoral results

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

2.3.1. Energy sector

The energy sector includes electricity generation, water desalination, manufacturing industries and construction, other fossil fuel combustion activities, and fugitive emissions from oil & gas operations. Table 2-2 provides a breakdown in energy sector GHG emissions for the year 2006 for these source categories. Relative to overall anthropogenic GHG emissions in Bahrain, the 20,149 Gg CO_2e represents about 69% of total national emissions.

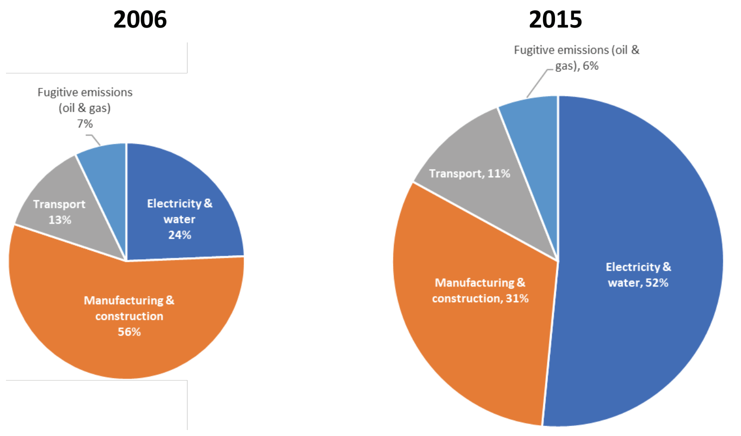

Figure 2-3: Breakdown of GHG emissions associated with energy activities, 2006 and 2015

Figure 2-3 illustrates the breakdown in energy-related GHG emissions in 2006 and 2015 by activity. In 2006, emissions from natural gas-fired electricity generated onsite at manufacturing and construction enterprises showed the highest share of GHG emissions, about 56% of total energy sector emissions, with all other electricity generation accounting for about 24%. By 2015, the largest share of emissions, 52%, is associated with electricity production at power/desalination plants, with electricity generated onsite at manufacturing and construction enterprises drops to 31%.

Transport activities are based overwhelmingly on the use of gasoline and diesel oil and accounted for about 13% and 11% of total emissions from energy-consuming activities in 2006 and 2015, respectively. Fugitive emissions of methane, a gas that has a high global warming potential, and carbon dioxide

Table 2–2: GHG emissions from energy use in Bahrain, 2006 (Gg)

GHG Sources	CO_2e	CO_2	CH_4	N_2O	PFCs	HFCs	SF6
Electricity & water	4,905	4,900	0.1	0.0	0.0	0.0	0.0
Manufacturing & construction	11,229	11,218	0.2	0.0	0.0	0.0	0.0
Transport	2,583	2,527	0.8	0.1	0.0	0.0	0.0
Other combustion activities	0	0	0.0	0.0	0.0	0.0	0.0
Fugitive emissions (oil & gas)	1,432	1,041	15.6	0.0	0.0	0.0	0.0
Total National Emissions	**20,149**	**19,686**	**16.7**	**0.2**	**0.0**	**0.0**	**0.0**

accounted for about 7% and 6% of all GHG emissions in the energy industries sector in 2006 and 2015, respectively.

Other combustion activities and manufacturing/ construction accounted for negligible amounts of the total emissions, with these shares remaining negligible throughout the 2006-2015 period.

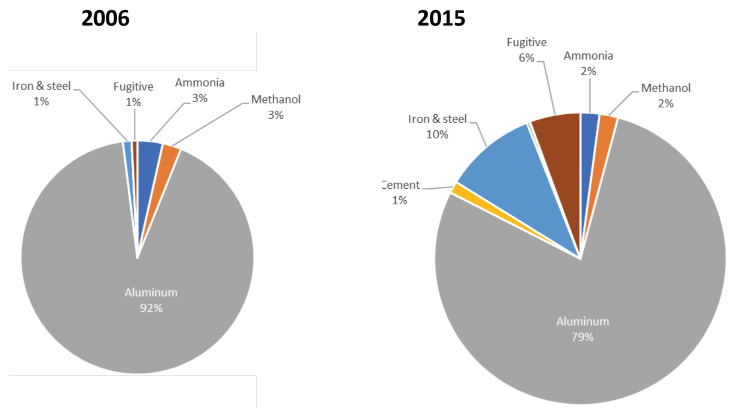

Figure 2-4: Breakdown of GHG emissions associated with IPPU activities, 2006 and 2015

2.3.2. Industrial Processes & Product Use

Table 2-3 summarizes GHG emissions associated with industrial processes and product use in 2006. Industrial processes are the second largest emitter of anthropogenic GHG emissions in Bahrain, accounting for 8,704 Gg of CO_2e, or about 30% of national CO_2e emissions in 2006. IPPU is the only sector in which high-GWP gases are emitted (i.e., PFCs, HFCs, and SF_6).

The mineral and chemical industries represent the major sources of emissions from industrial processes and product use. For the mineral industry, GHG emissions are associated with aluminum and iron & steel production. Together, they account for about 93% of total sectoral GHG emissions. For the chemical industry, about 6% of emissions are associated with ammonia and methanol production. Fugitive emissions associated with refrigeration, stationary air conditioning, and fire protection account for a negligible share of sectoral emissions.

Figure 2-4 illustrates the breakdown in industry-related GHG emissions in 2006 and 2015 by activity. While still the dominant share, emissions from aluminum production decline from 92% in 2006 to 79% in 2015. Other sharp changes in the emission profile are associated with iron and steel whose share of CO_2e emissions increases from 1% to 10%. In addition, the share of fugitive emissions from refrigeration, stationary air conditioning, and fire protection also increases substantially - from 1% to 6%. For the chemical industry (i.e., ammonia and methanol production), the relative emission shares in 2015 remain like those in 2006, with shares of CO_2e emissions showing a slight decrease slightly from about 6.1% in 2006 to 4.2% in the year 2015.

2.3.3. Agriculture, forestry, other land use

Table 2-4 summarizes GHG emissions associated with agriculture, forestry, and other land use in 2006. Agricultural practices are the smallest source

Table 2–3: GHG emissions from industrial processes and product use in Bahrain, 2006 (Gg)

GHG Sources	CO_2e	CO_2	CH_4	N_2O	PFCs	HFCs	SF6
Ammonia	305	305	0.00	0.00	0.00	0.00	0.00
Methanol	225	202	0.94	0.00	0.00	0.00	0.00
Aluminum	7,999	1,391	0.00	0.00	0.81	0.00	0.00
Cement	0	0	0.00	0.00	0.00	0.00	0.00
Iron & steel	106	106	0.00	0.00	0.00	0.00	0.00
Ferroalloys	0	0	0.00	0.00	0.00	0.00	0.00
Glass	0	0	0.00	0.00	0.00	0.00	0.00
Fugitive	68	0	0.00	0.00	0.00	0.03	0.00
Total National Emissions	**8,704**	**2,004**	**0.94**	**0.00**	**0.81**	**0.03**	**0.00**

Table 2–4: GHG emissions and sinks from agriculture, forestry and other land use in Bahrain, 2006 (Gg)

GHG Sources	CO_2e	CO_2 Emissions	CO_2 Sinks	CH_4	N_2O	PFCs	HFCs	SF6
Urea	3.3	3.3	0.0	0.0	0.0	0.0	0.0	0.0
Enteric fermentation	26.2	0.0	0.0	1.0	0.0	0.0	0.0	0.0
Aggregate sources; non-CO2 emissions sources on	3.3	3.3	0.0	0.0	0.0	0.0	0.0	0.0
Other	-24.8	0.0	-24.8	0.0	0.0	0.0	0.0	0.0
Total National Emissions	**32.8**	**6.5**	**---**	**1.0**	**0.0**	**0.0**	**0.0**	**0.0**
Net National Emissions	**8.0**	**6.5**	**-24.8**	**1.0**	**0.0**	**0.0**	**0.0**	**0.0**

of anthropogenic GHG emissions in Bahrain, accounting for only 32.8 Gg of CO_2e, or about 0.11% of total national CO_2e emissions in 2006. Most of the emissions from AFOLU activities are associated with methane production from livestock. On a net basis, AFOLU emissions are even lower, equal to 8.0 Gg after carbon sequestration of 24.8 Gg at managed green spaces are taken into account. Relative to net national emissions, emissions from AFOLU activities accounted for only 0.03%.

Figure 2-5 illustrates the breakdown in AFOLU-related total GHG emissions in 2006 and 2015 by activity. Enteric fermentation associated with livestock dominates emissions, increasing from 80% in 2006 to 95% in 2015. This is due to a large reduction in agriculture lands beyond 2007 and hence a reduction in the need for nitrogen fertilizer. Total emissions decline by about third by 2015, from to 33 to 21 Gg of CO_2e.

2.3.4. Waste

Table 2-5 summarizes GHG emissions associated with waste management activity in 2006. Relative to overall anthropogenic GHG emissions, the 268 Gg CO_2-equivalent represented about 1.0% of total national emissions. Waste-related GHG emissions are associated with solid waste disposal, including incineration, as well as wastewater treatment and discharge.

While relative shares in 2015 remain roughly similar to those in 2006, there is a sharp increase in waste sector emissions, over double, as shown in Figure 2-6.

2.4. Quality assessment

The quality of Bahrain's GHG inventory is primarily based on three key factors: methodology, modeling, and input data/assumptions. Each is briefly described in the subsections that follow.

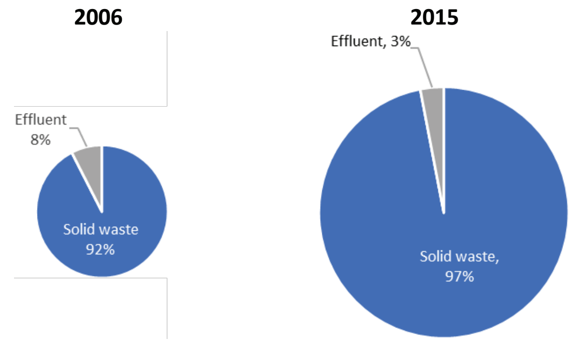

Figure 2-5: Breakdown of total GHG emissions associated with waste management activities, 2006 and 2015

2.4.1. Uncertainty assessment

There is minimal uncertainty associated with methodology as appropriate QA/QC procedures and the IPCC Software were used as the main tool in the inventory. On the other hand, there is uncertainty associated with some input data and assumptions (i.e., emission factors and activity data). Where local data were unavailable, default emission factors provided in the 2006 IPCC Guideline were adopted, thus reflecting the uncertainty embedded in such factors. Another source on uncertainty is related to the iron and steel and aluminum industries; process emissions which were identified as key categories and therefore a higher tier should be applied in future inventories. Given this information, the overall uncertainty associated with total emissions is considered to be between medium to high uncertainty.

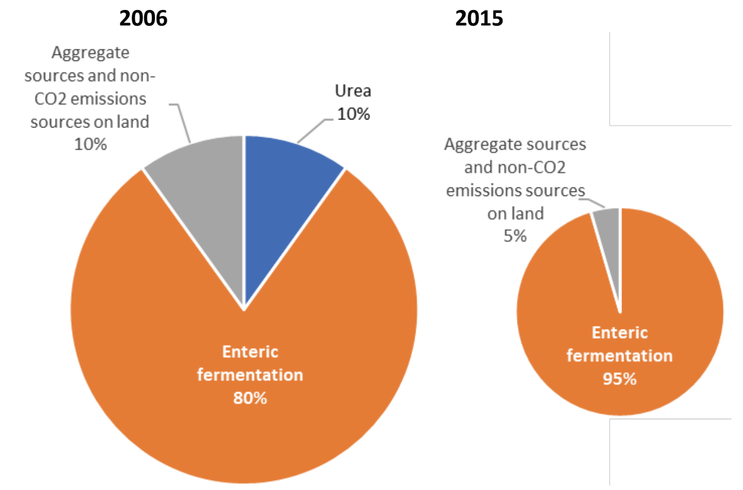

Figure 2-6: Breakdown of total GHG emissions associated with AFOLU activities, 2006 and 2015

Table 2–5: GHG emissions from waste in Bahrain, 2006 (Gg)

GHG Sources	CO_2e	CO_2	CH_4	N_2O	PFCs	HFCs	SF6
Solid waste	247.5	0.0	9.9	0.0	0.0	0.0	0.0
Incineration	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Effluent	20.2	0.0	0.0	0.07	0.0	0.0	0.0
Total National Emissions	267.7	0.0	9.9	0.1	0.0	0.0	0.0

2.4.2. Quality control

Quality control was mostly provided by experts provided by the United Nations Environment Programme. This consisted of systematic review of the information being assembled, including activity data and associated calculations. Expert feedback was communicated to the Supreme Council for Environment to ensure that improve future inventories would benefit from the process.

Other quality control measures were undertaken at the sector and category level through consultations between and among local experts. While feedback from local reviewers was not formally documented during the process, the inventory does incorporate their feedback and the final result offer the best possible estimates of emissions given the current state of scientific knowledge and regulatory and institutional framework in Bahrain. For future inventories, the National Information System – currently under development - should greatly improve quality control aspects of the process.

2.4.3. Key category analysis

The analysis of key sources was performed in accordance with the IPCC 2006 Guidelines. To facilitate the identification of key sources, the contribution of source categories to emissions per gas was classified consistent with the potential key category list as presented in Volume 1, chapter 4, table 4.1, of the 2006 IPCC Guidelines.

A key category source analysis was carried out using the Level Assessment, and the results are shown on Table 6-2. The level assessment identifies categories that contribute to at least %76 of national emissions in the current GHG inventory.

The key category analysis allowed the national GHG inventory team to identify which category has the most significant influence on the country's emissions where the analysis helps to prioritize the national GHG mitigation measures.

The energy sector in Kingdom of Bahrain continued to be the main contributor of GHG emissions (>%85) and was found to be a key category in 2006 and subsequent years. Therefore, it is important that activity data from this sector is always available to ensure that the results are accurate. The accurate reporting of GHG emissions in this sector is also important for GHG mitigation analysis purposes. It allows the country to prioritize the sources emissions/sinks within the national inventory system..

To improve the national GHG inventory, it may be necessary to consider applying more accurate or higher Tier methodologies, collect more detailed activity data, and/or develop country-specific emission factors. Each GHG emitted from each category was considered separately. These activity data require additional resources, and it is considered not possible at this time to make improvements for every one of them.

The inventory category list resulting from this analysis can provide a quantitative framework for the national GHG inventory team to develop an inventory improvement plan by outlining more complete and transparent information.

2.5. Challenges and recommendations

The primary challenge to the development of the current GHG inventory is data-related; namely the availability, accuracy, and consistency of data. These challenges are rooted in administrative and institutional barriers that impede the application of locally available technical capacity to collect, manage, and analyze pertinent data. Recommendations to address these

Table 2–6: Key Category Analysis Results

#	Sector	Category	GHG	CO_2e emission (Gg)	%	Cumulative %
1	Energy	Manufacturing Industries and Construction	CO_2	11,218	38%	38%
2	Energy	Energy Industries	CO_2	4,900	17%	55%
3	Energy	Transportation	CO_2	2,527	9%	64%
4	Industrial Processes	Metal Industry	CO_2	1,497	5%	69%
5	Energy	Fugitive emissions from fuels	CO_2	1,041	4%	73%
6	Energy	Fugitive emissions from fuels	CH_4	391	1%	74%
7	Industrial Processes	Chemical Industry (ammonia)	CO_2	305	1%	75%
8	Industrial Processes	Chemical Industry (methanol)	CO_2	202	1%	76%
Subtotal - key categories				22,081	76%	
Total National emissions				29,153	100%	

challenges include the following:

- Establish and enforce a national statistical data system, which logs operational, and production data and information, in governmental and private organizations;

- Establish strategic collaboration agreements between SCE and public organizations to ensure a sustainable supply of related data;

- Given the above two points, a National Inventory System (NIS) is developed in cooperation with key sectors in the country;

- Hold periodic workshops for public organizations for training and educating critical authorities with the IPCC emissions inventory system;

- Call for and support the conduction of a national project to determine local emission factors related to the indigenous resources;

- Establish a GHG inventory committee with high-level representation from key ministries/ institutions, having clear oversight and coordination authority; and

- Develop an integrated database of relevant information including annual statistical abstracts and annual reports from specific entities.

2.6. List of References

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3. Vulnerability & Adaptation

3. Vulnerability & Adaptation

This chapter presents an overview of assessments of sectors that are highly vulnerable to climate change in Bahrain, namely mangroves, coastal zones, and water resources. The assessments have helped to develop a better understanding of potential adaptation priorities. All of the assessments have been peer-reviewed by local scientists and government officials and shared with a wide range of stakeholders in Bahrain, including both the general public and private sector. Some of the key findings are summarized in the sections below. Additional vulnerability assessments for fisheries and public health are in process and will be reported in future communications.

3.1. Mangrove habitats

Changing conditions in the Arabian Gulf pose incremental threats to remaining mangrove stands in Bahrain. While mangroves have historically been adversely impacted by a wide range anthropogenic influences they have become a conservation priority in recent years due to an emerging national awareness of their significant ecological and socioeconomic value. This section summarizes the results of studies to document their biological characteristics, spatial extent trends, and ecological value in order to establish important baseline information that could be used in future vulnerability assessments (Abido and Al-Jeneid, 2018; El-Kholei, 2018).

3.1.1. Background

Mangrove ecosystems have a significant ecological and socioeconomic value wherever they are found in the world's coastal areas. They form the foundation of highly productive and biologically rich habitats for a broad range of marine and terrestrial species (Bennett and Reynolds, 1993; Semesi, 1998; Ong and Gong, 2013). Moreover, mangroves can sequester carbon at a much faster rate that terrestrial forests and can do so indefinitely if protected from human activity (Windham-Myers et al., 2018). Most of the carbon taken up by these "blue carbon" ecosystems is stored below ground in coastal soils that is often thousands of years old.

In Bahrain, dense grey mangrove forests are found in the Gulf of Tubli, a sheltered and shallow bay with extensive intertidal mudflats located between Bahrain Island and Sitra island (see Figure 1-3). They are distributed across four major mangrove association areas: Ras Tubli, Sanad, Sitra1- and Sitra2-. These areas provide shelter for native species of flora and fauna and help to reduce seawater turbidity in the bay (Al-Maslamani et al., 2013).

The Gulf of Tubli offers resting and feeding sites for several resident and migratory birds as well as nursery sites for commercial shrimp (Abido & Mohammad, 2001). Mangrove ecosystems are comprised of mangrove stands (i.e., Avicennia marina), several types of mangrove-associated plants (e.g., Halopeplis perfoliata), and numerous other plants occupying high intertidal areas (e.g., Aeluropus littoralis).

Three main anthropogenic factors have adversely impacted Bahrain's mangrove forests, leading to sharp reductions in their spatial extent and health. First, extensive land reclamation has been conducted along the coasts of the Bay since the 1970's. Less than half of the initial marine area of the bay was still intact by 2008 - i.e., 12 km^2 compared to 25 km^2 before reclamation activities (Naser, 2014). This led to the uprooting of large areas of mangroves.

Second, slurry discharge from sand washing plants at the western shores and southern end of the Bay have led to excessive siltation that has damaged the fragile mangrove root system. Third, treated wastewater is discharged at a rate of 100,000 m^3 per day into the Bay

Figure 3-1: Left: Location of Tubli Bay; Right: Mangrove stands on the east coast of Sitra Island (Survey & Land Registration Bureau-Bahrain)

from the Tubli wastewater treatment plant, leading to eutrophication levels of nitrogen and phosphorus in the Bay, that adversely alter nutrition of mangroves. This is compounded by frequent illegal dumping of municipal solid wastes by tankers.

These factors have led to the loss of about a third of total mangrove area in Tubli Bay; from 150 hectares in 1980 to about 100 hectares in 1992 (FAO, 2005) In response, Tubli Bay was declared nationally as a protected area in 1995 and Law 2006/53 designated Tubli Bay as a natural reserve. In 1997, it was designated internationally as a RAMSAR Site (Public Commission for the Protection of Marine Resources, Environment and Wildlife, 2006). In 2010, the latest year for which data are available, only 31 hectares remain, about a fifth of their spatial extent in 1980.

There are indications that such efforts have begun to stabilize mangrove forest areas in Tubli Bay. Figure 3-2 shows that total mangrove and mangrove-associated vegetation area has actually increased in spatial extent over the most recent monitoring period, 2005-2010, by 0.7%/year and 3.0%/year, respectively. This growth is focused on the Ras Tubli, Sitra-1, and Sitra-2 associations, with the comparatively much larger Sanad association showing declines over the period.

3.1.2. Approach

To assess the impact of climate change in mangroves in Tubli Bay, a -3part methodology was applied. First, a preliminary qualitative assessment was undertaken to gain a better understanding of the factors that affect mangrove vulnerability to climate change. The focus of the assessment was on exposure, sensitivity, impact, and adaptative capacity. This information was then combined with known or projected climatic changes in the region to develop an indicative determination of the vulnerability of Tubli Bay mangroves to climate change.

Second, biological characteristics of Tubli Bay mangroves were assembled from available studies. This provided a baseline of information which could serve as an essential point of departure for exploring potential climate change impacts and adaptation options.

Third, an economic valuation of the services and goods provided by Bahraini mangroves was undertaken. This provided a basis by which to understand the benefits provided by mangroves within an economic context amenable for consideration in subsequent adaptation planning dialogues.

3.1.3. Results

Preliminary qualitative assessment

The bullets below summarize the results of the literature review portion of the assessment:

- *Exposure:* Key driving factors controlling mangrove growth and distribution include seawater temperature/salinity, tidal fluctuation, sedimentation rates, wave energy, sea levels, and atmospheric temperature (Kathiresan, 2001; Noor et al., 2016; Gilman et al., 2008). With climate change, many of these factors are projected to directly affect Tubli Bay - atmospheric temperatures will increase (IPCC, 2014), seawater temperature and salinity will be altered (AGEDI, 2015); and though actual levels are difficult to project, sea level rise is a virtual certainty (Church et al., 2013; Cazenave, 2014).

- *Sensitivity:* Mangroves autonomously adapt to sea tide rhythms by controlling the height and extent of above-ground root systems where the supply of oxygen continues through pores in the roots for storage and efficient O2 transport (Purnobasuki et al., 2017). However, mangroves, particularly the Avicennia marina species, are highly sensitive

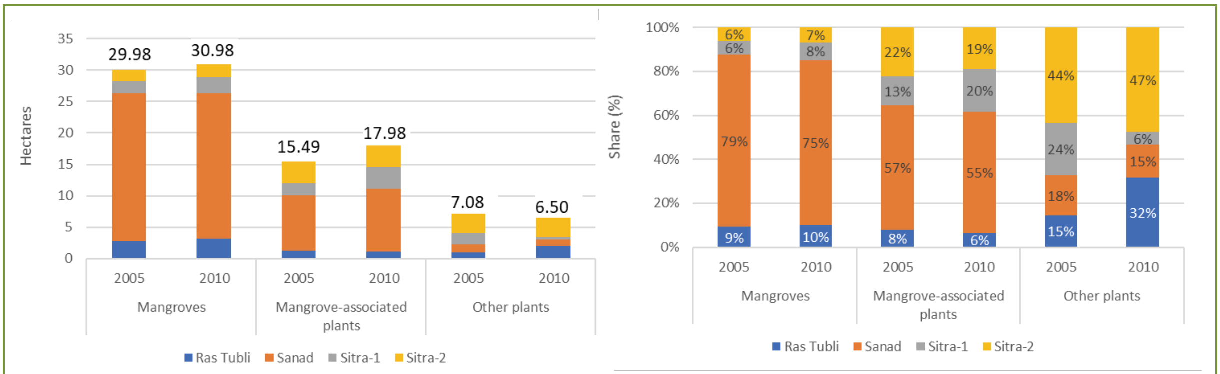


Figure 3-2: Left: Spatial extent of mangrove areas in Tubli Bay, 2005 and 2010; Right: Percent change in spatial extent of mangrove areas in Tubli Bay, 2005 and 2010 (source: Abido *et al.*, 2011).

to prolonged seawater flooding and high turbidity environments which can cause physiological degradation (Sayed, 1995; Nguyen et al., 2015). With climate change, prolonged inundation of root systems associated with sea level rise is expected, likely compromising their biological, morphological, and physiological capacity to autonomously respond.

- *Impact:* Mangroves are can be adversely impacted especially by sea level rise, depending on factors such as coastal topography and landward barriers to migration (Faraco, et al., 2010; Field, 1995; Wilson, 2017). On the other hand, higher temperatures may extend the northern and southern distribution of mangroves (Field, 1995) while increased CO_2 atmospheric concentration could enhance photosynthesis and improve water use efficiency (Reef et al., 2015). In Bahrain, future sea level rise in Tubli Bay represents the most critical potential impact of climate change. Since high-density urban areas bound the mangrove stands, there is no possibility of mangrove landward migration, and hence significant sea level rise will likely result is the eventual loss of remaining mangrove areas within the Bay, absent effective adaptation initiatives.

- *Adaptive capacity:* The adaptive capacity of mangroves to climate change is tied to its ecological and socio-economic systems in which they are found (Ellison and Zhou, 2012; Trzaska et al., 2018). In particular, the adaptive capacity of mangroves depends primarily on their tolerance to new atmospheric/marine conditions and their capacity to extend their spatial distribution. From the ecological perspective, the adaptive capacity of the Avicennia marina species found in Tubli Bay to changes in projected atmospheric/marine conditions is currently not well understood. However, from the socio-economic perspective, there is no capacity for mangroves to extend their spatial distribution landward due to surrounding densely settled urban areas.

The vulnerability of mangroves is a function of each of the above factors. First, the Bay has high exposure to climate change impacts – especially sea level rise. Second, the Avicennia marina species found in the Bay display high sensitivity to prolonged seawater flooding that would be associated with future sea level rise. Third, there is a potentially high impact from sea level rise due to the inability of landward migration, which also severely limits mangrove forest adaptive capacity. Combined, these factors suggest a high level of vulnerability of climate change in the absence of specific adaptation initiatives.

Tubli Bay Mangrove characteristics

Direct measurements of biological characteristics of Tubli Bay, as per the research of Abou Seedo et al (2017). Table 1-3 summarizes average physical parameters for the Ras Tubli, Sitra1-, and Sitra2- associations of Tubli Bay. The low P-values in the far-right column indicate a high level of statistical significance and hence high confidence in the robustness of the characterization.

Mangrove tree heights range from 1.0 to 5.5 meters, with a mean of about 2.7 meters. Each tree is composed of several trunks, and mean trunk diameter varies between 2.2 and 12.5 cm, with an average of 5.3 cm. The mean density of trees was 4,577 per hectare, with a mean basal area of 11.4 m^2 per hectare.

Based on this information, mangroves in Bahrain can be classified as a forest of low structural development. The shrubby forms of mangrove in Tubli Bay is due to the fact that the species live on the edge of its geographical distribution in a stressful condition.

While mangroves dominate plant communities in Tubli Bay, there are about 14 salt marsh species occupying more salty soils. These species include Arthrocnemum macrostachyum, Halocnemum strobilaceum, Halopeplis perfoliata, Salicornia herbacea, Suaeda

Table 3–1: *Avicennia marina* attributes

Portion	Attribute	Units	Average	Range	P-value
Tree	Height	meters	2.7	± 0.2	0.02
	Diameter	cm	5.3	± 0.1	0.0003
Stand	Basal Area	meters per hectare	11.4	± 1.2	0.4463
	Leaf Area Index	meters per m²	1.2	± 0.03	0.3308
	Density	trees per hectare	4,577	± 406	0.6178
Aerial root	Height	cm	12.4	± 0.97	<0.0001
	Diameter	cm	0.83	± 0.05	<0.0001
	Density	roots per per m²	149.6	± 16.9	0.057
Seedling	Height	cm	8.4	± 1.96	0.0012
	Density	seedlings per m²	6.9	± 2.05	0.0439
Leaf	Area	cm²	8.1	± 0.13	<0.0001
	Dry matter content	gm per kg	286.4	± 2.41	0.3384
	Specific leaf area	m² per kg	6.5	± 0.07	0.1991
	Thickness	10^{-6} meters	0.0005	± 3.4E-6	0.2271
	Sclerophylly index	gm/square decimeter	0.6	± 0.01	<0.0001
Relative water content		%	75.2	± 0.5	<0.0001
Pigment	Total chlorophyll	mg per gm of fresh weight	0.77	± 0.03	0.0643
	Chlorophyll A		0.55	± 0.03	0.1623
	Chlorophyll B		0.23	± 0.02	0.0034
	Chlorophyll A/B		2.83	± 0.20	0.2568
	Carotenoids		0.19	± 0.02	0.0095

aegyptiaca, and Suaeda maritima. Plant life includes chamaephytes, cryptophytes, hemicryptophytes, phanerophytes, and therophytes.

The relative density of mangrove ranges between 35 and 46%, while relative cover varies between 69 and 75%, and the relative frequency of the species ranges between 29 and %40. Main habitats include the mangrove submerged roots (MSR), where mangrove dominates other species, and the salt marsh habitat, which can be divided into lower salt marshes and upper salt marshes. Mangrove occupy the MSR habitat, while other species inhabit the lower salt marshes (Abido et al., 2011; Abou Seedo, 2017).

Leaf area of mangroves averages about 8.1 cm2, with leaf dry matter content averaging about 286.4 gm per kg (see Table 1-3) — the specific leaf area - which reflects energy spending - averages about 6.5 m^2 per kg. Average leaf pigment concentration is 0.55 mg per gm for Chlorophyll A and 0.23 mg per gram for Chlorophyll B. Total Chlorophyll, and the Chlorophyll A/B ratio ranges are 0.77 mg per gram and 2.83, respectively; while carotenoids average about 0.19 mg per gram.

Economic value of Tubli Bay mangroves

Mangroves provide a range of vital ecological services that can be valued within an economic framework (Costanza et al., 1997; Broadhead 2011; CI, 2008). While these services have not yet been valued in economic terms for Tubli Bay mangroves, their value is already well understood in qualitative terms relative to the following services:

- *Tourism services:* These include recreational activities, as well as intrinsic services associated with cultural heritage and support of societal values. For example, the Bahrain Tourism and Exhibitions Authority (BTEA), in collaboration with the Supreme Council for Environment, launched mangrove tourism in Tubli Bay in 2018 as a way of enhancing public awareness of their ecological and cultural value.

- *Regulating services:* These include the protection of beaches and coastlines from storm surges, waves and floods; reduction of beach and soil erosion; stabilization of land by trapping sediments; and water quality maintenance. Each of these services is relevant to the urban areas surrounding Tubli Bay.

- *Provisioning services:* This refers to a wide range of services including commercial fisheries, fuelwood, building materials, and traditional medicines For Bahrain, the most pertinent provisioning service is commercial fisheries as Tubli Bay has several nursery sites for commercial shrimp.

- *Supporting services:* These include cycling of nutrients; maintenance of hydrologic balance, habitats for species; and pollutant processing. Each of these is relevant to Tubli Bay, mainly resting and feeding habitats for resident and migratory birds.

While these services annually translate into significant benefits for Bahrain, the actual value of these services in economic terms remains unclear. Translating ecosystem structure and function to an economic framework of ecosystem goods and services is difficult (e.g., Barbier, et al., 2011; de Groot, et al., 2012). A key challenge for successful valuation of mangrove services is the ability to integrate a physical characterization of services (i.e., tourism, regulating, provisioning, and supporting services) with an economic characterization of benefits of those services (i.e., direct and indirect monetary values).

To date, only the tourism component of mangrove services has been integrated with an economic characterization of benefits (El-Kholei, 2018). Preferences and pricing signals of the local population surrounding Tubli Bay were established regarding their willingness to pay for the following benefits:

- Ecotourism as a means to minimize potential adverse impacts on mangrove ecosystems;

- Development of environmental awareness and respect of local cultural heritage among the local population; and

- Empowering visitors and hosts to actively engage in conservation efforts to protect the environmental quality of the Bay.

Based on current pricing, visitor patterns, projected operating days, and other factors the annual monetary value of tourism services provided by Tubli Bay mangroves is around US$ 33,000/year. This estimate is likely to increase over time as plans to protect Bay waters are implemented and infrastructure to support ecotouristic activities (e.g., cafes, restrooms, etc.) is built.

3.1.4. Adaptation implications

There are several adaptation strategies that are under consideration to build resilience against climate change risks Tubli Bay mangrove, as outlined below:

- *Tubli Bay observatory:* This aims to strengthen existing observation systems to better understand the ecological services provided by mangrove habitats in Tubli Bay. Activities include monitoring, species mapping, systematic documentation, and dissemination of collected information to policymakers.

- *Blue carbon inventory:* This aims to augment Bahrain's existing GHG emission tracking system to estimate and document carbon pools/fluxes in Tubli Bay consistent with international methodological guidance. This will involve data sharing across institutions, database development, information management, documentation, and dissemination of the levels and rates of carbon pool storage.

- *Ecosystem services valuation:* This aims to introduce economic valuation as a basis to account for the value of the market (i.e., tourism) and non-market (i.e., regulating, provisioning, supporting) services that, Tubli Bay mangrove habitats provide. It will leverage information developed by the Tubli Bay observatory and apply state-of-the art ecological valuation methods to in support of financial planning frameworks.

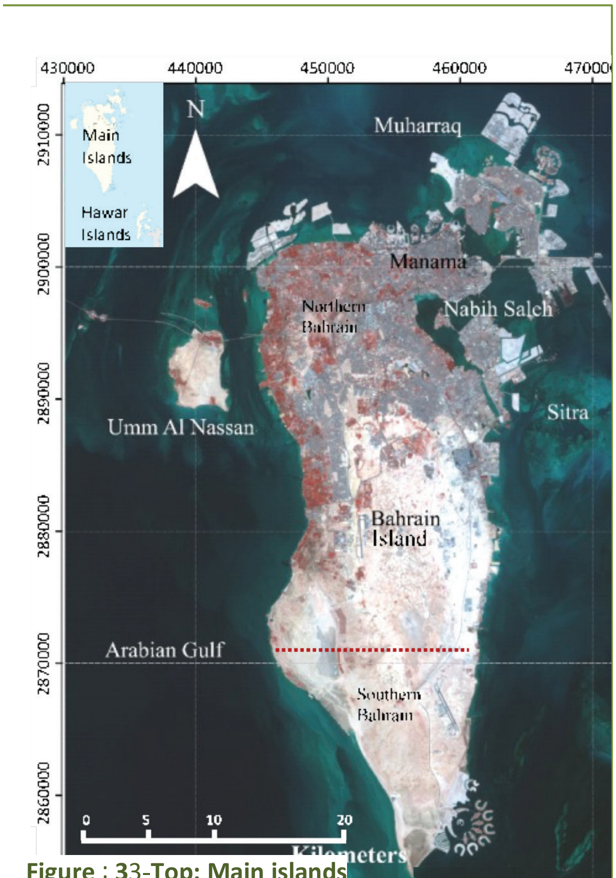
3.2. Coastal zones

Sea level rise is one of the primary and most certain indicators of climate change. As with all small island developing states, it represents an almost existential risk to Bahrain. The first and second national communications assessed this threat and quantified the extent of potential inundation throughout the Kingdom under a range of sea level rise scenarios (GCPMREW, 2005; PCPMREW, 2013). This section builds upon and refines those previous assessments in order to more precisely understand the risks to Bahrain's infrastructure, wetlands, reclaimed lands, and industrial zones from rising sea levels (Aljenaid, et al., 2018).

3.2.1. Background

Bahrain has six major areas on which most of its population and infrastructure are located. These areas include the northern and southern portions of the main island of Bahrain, as well as the surrounding smaller islands of Muharraq, Sitra, Nabih Saleh, and Umm Al Nassan. In addition, the Hawar Islands, located about 19 km southeast of the main island, are a Ramsar site famed for its many bird species, small herds of Arabian oryx, and surrounding seas that support a large population of dugong. Figure 3-3 provides the locations of these areas.

Most of Bahrain's population live near the coastline. These coastal areas – less than 5 meters above current sea levels – have very high population densities (i.e., average of 2,100 per km^2) and are also the location of most economic and social activities. Moreover, some of areas are showing evidence of land subsidence due to oil, gas, and groundwater extraction activities (Alothman, et al., 2017). Given the acute land scarcity of the country, inland retreat to accommodate rising sea levels is not a viable option. It is therefore of significant concern to policymakers because of its potentially disastrous impact on land resources,



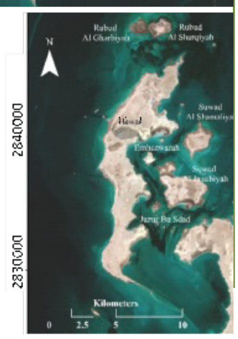


Figure : 33-Top: Main islands where most of the population and urban infrastructure is located; Right: Largely uninhabited Hawar Island group off the western coast of Qatar comprising conservation lands (source: Aljenaid, et al., 2018)

infrastructure and urban communities.

The five IPCC Assessment Reports developed sea level rise projections to 2100 by simulating contributions from individual sea level rise components, such as thermal expansion, and melting ice from glaciers and ice sheets. Each subsequent assessment differed from its previous estimate for the high emission, business-as-usual scenario (see Figure 3-4). The upper bound of these estimates ranges from 0.59 to 1.1 meters of sea level rise, with most of the uncertainty associated with difficulties in projecting ice mass loss from the Greenland and Antarctica ice sheets. Combined, these ice sheets contain the equivalent of about 64 meters of sea level rise; 58 meters for the Antarctic ice sheet and 4 meters for the Greenland ice sheet (Bamber et al., 2001; NSIDC, 2014). The implication is that any scenarios developed for Bahrain should account for this uncertainty and establish an upper bound for sea level rise that exceeds IPCC estimates. For the purposes of the assessment, the deglaciation component was assumed to be an additional 4 meters of sea level rise.

3.2.2. Approach

The objective of the coastal zone vulnerability assessment was to quantify the extent of seawater inundation by land type and location for a set of plausible sea level rise scenarios for the year 2100. The study area consisted of all land area from the coastline to inland areas up to 5 meters above MSL for seven distinct land segments, namely Northern Bahrain, Southern Bahrain, Muharraq, Sitra, Nabih Saleh, Umm Al Nassan, and the Hawar Islands.

A 3-part methodology was applied that included data acquisition, data preprocessing, and seawater inundation modeling. The overall approach is briefly described in the subsections that follow.

Data acquisition

There were four main data sets that were used to undertake this study:

- *Aerial photographs:* To establish detailed land use land cover (LULC) maps of coastal areas, very-high-resolution (i.e., 0.1-meter grid size) aerial photographs for the year 2017 were acquired for all Bahrain Islands except Hawar Island for which WorldView-3 satellite imagery (0.45-meter grid size) for 2017 was used. A large image database was developed that was saved in Tagged Image File Format (TIFF). The accuracy of the vertical and horizontal percentage errors was estimated as 20 cm.

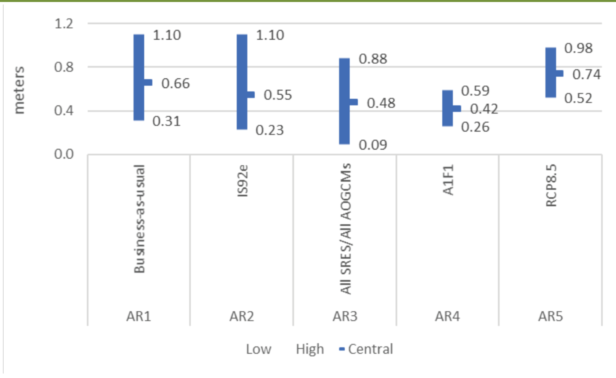


Figure 3-4: Range in the IPCC's global mean sea level rise projections in 2100 under high emission scenarios (source: IPCC)

- *Sensitive lands:* To identify land areas sensitive to sea level rise, two sets of DGN-CAD (Computer Aided Design) tiles were acquired. The first set was "Bahrain Tile, SLRB2017" which served as a reference layout to identify and aggregate land areas sensitive to inundation (see Figure 3-5). These files consisted of undefined-coordinate system polygons. The second set of DGN-files was "Bahrain Island coastline, 2017", produced by Survey & Land Registration Bureau-Bahrain (SLRB). These files represent the most current edited boundary for all Bahrain islands and was used to distinguish coastal areas from the sea.

- *Digital land elevation:* To establish the elevation of North Bahrain Island, Muharraq, Sitra, and Nabih Saleh Island, hundreds of spot height files with a horizontal spatial resolution of 0.1 meters were assembled from SLRB (2017) and stored in DGN-CAD format. Each file contained more than a million elevation points. and model for. For South Bahrain Island and the Hawar Islands, approximately 2 million spot elevation points were assembled; for Umm Nassan Island about 825 thousand spot elevation points were assembled.

- *Land classification maps:* To establish land use types, the Bahrain Zoning layer map, 2017 with around 50 classes, was obtained from Ministry of Works (MEW), (2017) (see Figure 3-6). This map provided detailed zoning classifications for all lands included in the study area. It was used as a baseline shapefile to compare with - and edit as necessary – the LULC classes that were developed from the previously acquired aerial photographs.

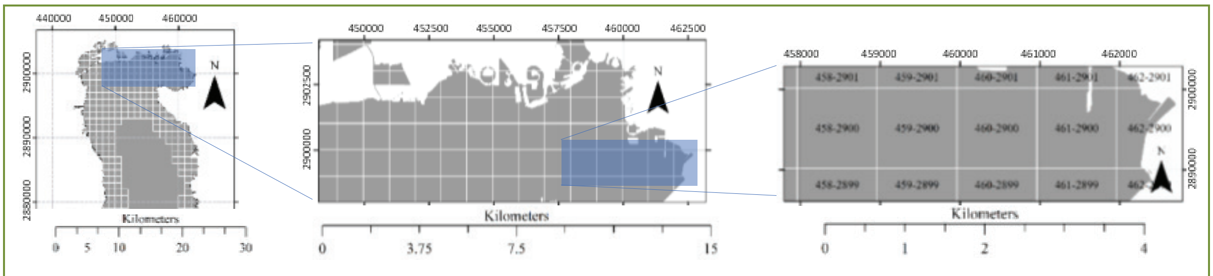


Figure 3-5: Excerpt of the reference layout of sensitive land area in northern Bahrain from the "Bahrain Tile, SLRB2017" DGN File

Data Preprocessing

There were several steps to ensure that all the data used in this study were adequately georeferenced and stored with all the descriptive information needed to perform the subsequent inundation modeling. Each is briefly discussed in the bullets below.

- Initial data were saved as shapefiles then imported to a geodatabase. All undefined data files were georeferenced to Universal Transverse Mercator (UTM) coordinate system Zone 39 with the World Geodetic System 1984 (WGS84) datum.

- The DGN tile files were converted to Environmental Systems Research Institute (ESRI) shapefile format. The attributes of these tile files were added from the annotation text of the DGN files. These files were used to mosaic the aerial photographs and prepare the spot-elevation data sets.

- Aerial photographs tiles were mosaiced in strip lines, with these strips then compiled into a single scene. This process was applied to all the islands separately.

- The Bahrain coastline was modeled by using rules of the topological structural model which established the demarcation of coastal areas from the sea.

- The detailed spot elevation data were transformed from DGN-CAD format to a shapefile and then converted to raster format, tile-by-tile.

- The tiles corresponding to the study area were converted to a single high-resolution Digital Elevation Model (DEM) in strips in a similar manner as with the aerial photograph tiles. This full set of DEM data was then clipped with the boundary shapefile.

- Sensitive coastal areas of each island were differentiated by LULC and then extracted using an algebraic model.

- The final outputs of the above steps consisted of seven vector maps, one for each of the island areas, that depicted surface relief and 3-dimensional elevation data, thus establishing the boundaries of sensitive coastal areas for subsequent use in processing LULC data.

- Additional manipulations using ArcGIS 10.6 and ENVI 5.4 were undertaken to establish sensitive LULC areas and coastal areas for all islands. The output of these efforts was a boundary shapefile that was used as the base layer of 0-5 meters above mean sea level from the land area (see Figure 3-7).

- For all islands except Umm Nassan and the Hawar Island group, LULC maps were produced by combining and analyzing data in the Bahrain

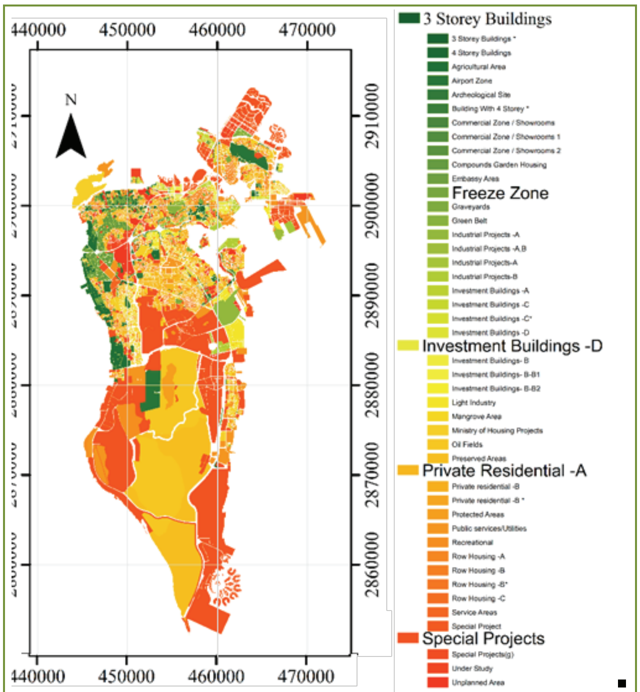


Figure 3-6: Bahrain zoning layer, SLRB2017 with around 50 classes, Base map of LULC classification (MEW, 2017)

zoning shapefile, aerial photograph maps, and the boundary shapefile for sensitive coastal areas. Nine land classes were established: agriculture, airport zone, archaeological sites, bare land, built-up, industrial, reclamation, vacant and wetlands (see Box 3-1). These classes were compiled into one polygon for each class for each island and saved as a high-resolution zoning shapefile (i.e., 1:250 meter). Topographical rules were applied to ensure the integrity of the LULC data structure. Figure 3-8 summarizes the extent of sensitive land area by class, island, and elevation.

- For Umm Nassan and the Hawar Island group, Worldview-3 satellite images were used to create the LULC maps using ENVI 5.4 software. The resulting LULC maps were exported to ArcGIS software. The extent of sensitive coastal areas (i.e., 0-5 meters above MSL) was developed from the LULC maps using the coastline boundary layer, ArcGIS and Excel software.

Seawater inundation modeling

The point of departure for modeling the landward extent of seawater inundation was the establishment of a set of plausible sea level rise scenarios for the years 2050 and 2100. For the year 2100. scenario development was premised on the additive contributions to sea level rise described in the bullets below.

- *Global average:* This contribution was assumed to be the range in the most recent IPCC projections (i.e., 0.52-0.98 meters), or an upper bound of 0.98 meters by 2100. This estimate corresponds to all components of sea level rise;

- *Uncertainty:* This contribution is associated with the rate of deglaciation in Greenland and Antarctica; an upper bound of 4 meters by 2100 was assumed; and

- *Regional land subsidence:* This contribution is associated with the impact on land subsidence in the western Arabian Gulf region from past oil, natural gas and groundwater extraction; an annual rate of about 0.33 ± 0.20 mm per year, or 0.03-0.04 meters by 2100 was assumed.

Taken together, these contributions imply an upper bound of sea level rise of about 5 meters above MSL by 2100 (i.e., 0.98+4.00+0.04). For the year 2050, intermediate values were assumed. Altogether, 6 sea level rise scenarios were analyzed, namely 3 scenarios (i.e., 0.5, 1.0, and 1.5 meters) to capture the potential range of sea level rise through 2050, and 2 scenarios (i.e., 2.0 and 5.0 meters) to capture the range of sea level rise through 2100.

To estimate inundated areas under the scenarios, an overlay process in ArcGIS was applied to combine sea level rise maps with the LULC maps. The extent of inundated area was calculated by comparing the different inundation scenarios with the LULC by land class, island and scenario.

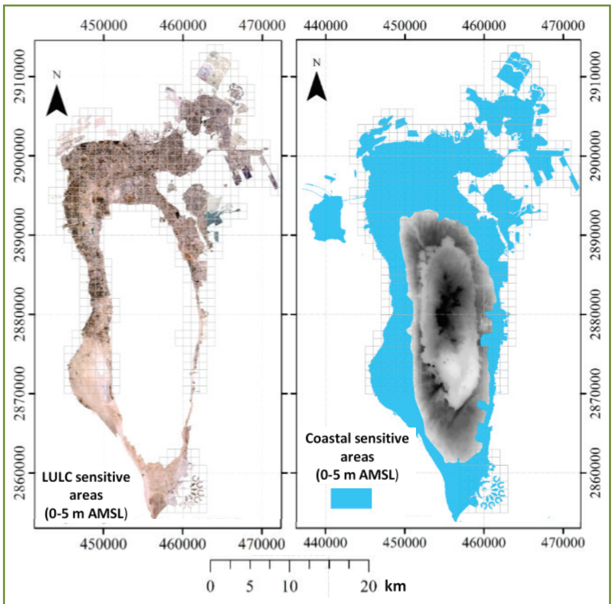


Figure 3-7: Areas less than 5 meters above MSL. Left: Sensitive areas by LULC; Right: Sensitive areas aggregated across coastal areas

Box 3–1: Land use and land cover categories

- *Bare Land:* Areas of sparse vegetation, thin soil, bare soil, sand, or rocks
- *Reclamation:* Shallow marine areas reclaimed with soil and other materials and converted into urban/industrial areas
- *Wetlands:* Marshes, mudflats and sabkhas on the shallow margins of the coast
- *Built-up:* Urban areas adjacent to public roads, shopping centers, commercial/industrial parks, and other infrastructure
- *Vacant:* Open parcels of land in residential, commercial, and industrial areas, including sites cleared of old buildings
- *Archeological:* Important sites of cultural heritage
- *Agricultural:* Land cultivated for agriculture, whether seasonal or permanent
- *Airport:* Airport zone located on Muharraq
- *Industrial:* Areas containing factories, power plants and other types of industrial production

3.2.3. Results

Figure 3-8 summarizes the extent of seawater inundation under the various scenarios for all of Bahrain. The results confirm that the country is highly sensitive to sea level rise. Significant inundation impacts are projected for certain land use categories, even at small levels of rising seas. Some key national implications of the assessment are outlined in the bullets that follow.

- Wetlands are projected to experience significant inundation. Approximately 27 km², or nearly half of all wetlands in Bahrain would be inundated if sea levels rise by up to 0.5 meters, with nearly three quarters lost if sea levels rise by up to 1.5 meters.

- Only modest areas of reclamation lands would be affected with small amounts of sea level rise. Of the total of 50 km² of reclaimed land, only about 2% (1 km²) would be inundated at 0.5 meters, but nearly 30% (14 km²) would be inundated at 2 meters of sea level rise.

- Built-up areas in Bahrain are best situated to withstand sea level rise. Less than 2% (2 km²) would be inundated up to 1 meter of sea level rise and only 10% (13 km²) of these lands would be inundated up to 2 meters of sea level rise.

- Industrial areas are somewhat more sensitive that built-up areas to withstand sea level rise. About 15% (4 km²) of these lands would be inundated with 2 meters of sea level rise, with under 3% (1 km²) inundated with 1 meter of sea level rise.

- All land use categories are severely affected under the high sea level rise scenario of 5 meters. The airport would be completely inundated while wetlands, reclaimed lands, and industrial areas would lose at least 94% of their total area. Built-up areas would experience a loss of 74% of its total area. Of the total sensitive land area of 470 km², only 72 km² (15%) would not be under water as these areas are above 5 meters above MSL.

The rest of this section provides a summary of sea level rise impacts for each of the islands, as well as on the national road transport system, and exposure of population centers.

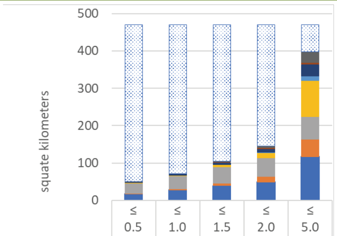
Northern Bahrain Island

Northern Bahrain Island is the most urbanized part of Bahrain, accounting for over 70% of all built-up areas and nearly half of its industrial area. It is also where most of the agricultural and vacant lands, about 87% and 67%, respectively, are located.

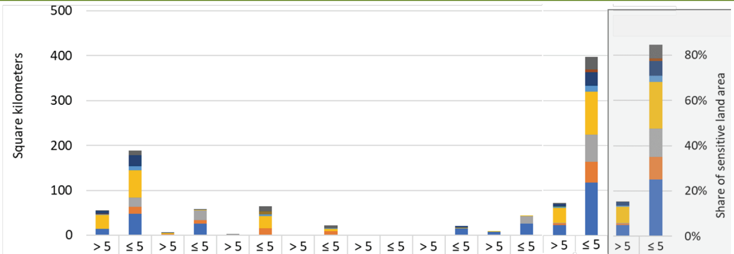
Figure 3-9 summarizes land use characteristics as well as the spatial extent and magnitude of seawater inundation under the various scenarios for Northern Bahrain Island. Some key implications of the assessment are as follows.

- Wetlands are the hardest hit by seawater inundation. Approximately 7 km², or nearly 36% of all wetlands in northern Bahrain would be inundated if sea levels rise by up to 0.5 meters, with nearly 90% lost if sea levels rise by up to 2 meters.

- Reclamation lands would be somewhat affected with low sea level rise. Of the total of about 16 km² of reclaimed land, about 4% would be inundated



Sea level rise scenario (meters AMSL)	≤ 0.5	≤ 1.0	≤ 1.5	≤ 2.0	≤ 5.0
Not inundated	419	398	365	324	72
Industrial	1	1	2	4	28
Airport Zone	0	0	2	4	6
Agricultural	3	3	5	9	30
Archeological	0	0	0	0	0
Vacant	0	0	0	2	13
Built-up	1	2	5	13	96
Wetlands	27	35	44	50	60
Reclamation	1	2	7	14	46
Bare Land	18	28	40	50	118



	Northern Bahrain > 5	Northern Bahrain ≤ 5	Southern Bahrain > 5	Southern Bahrain ≤ 5	Muharraq > 5	Muharraq ≤ 5	Sitra > 5	Sitra ≤ 5	Nabih Saleh > 5	Nabih Saleh ≤ 5	Umm Al Nassan > 5	Umm Al Nassan ≤ 5	Hawar > 5	Hawar ≤ 5	Total > 5	Total ≤ 5	Share of total land area (%) > 5	Share of total land area (%) ≤ 5
Industrial	2	10	0	0	0	12	0	6	0	0	0	0	0	0	2	28	0%	6%
Airport Zone	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0	6	0%	1%
Agricultural	7	25	0	1	0	1	0	0	0	0	0	3	0	0	7	30	1%	6%
Archeological Site	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0%	0%
Vacant	2	8	0	0	0	4	0	1	0	0	0	0	0	0	2	13	0%	3%
Built-up	30	62	2	1	1	27	0	5	0	1	0	1	0	1	34	96	7%	20%
Wetlands	0	20	1	23	0	0	0	0	0	0	0	0	0	17	1	60	0%	13%
Reclamation	1	16	1	7	1	15	0	8	0	0	0	0	0	0	3	46	1%	10%
Bare Land	14	48	1	26	0	0	0	1	0	0	0	16	8	26	23	118	5%	25%
Total	56	189	5	58	2	64	1	21	0	1	0	20	8	44	72	397	15%	85%
Share of total land area (%)	12%	40%	1%	12%	0%	14%	0%	5%	0%	0%	0%	4%	2%	9%	15%	85%		

Figure 3-8: Left: Overall area of sensitive land in Bahrain under range of sea level rise scenarios, by LULC; Right: Area of sensitive land by LULC class, island, and elevation 5 meters above and below MSL

at 0.5 meters, and 34% inundated at 2 meters of sea level rise.

- Less than 1% (0.8 km^2) of Northern Bahrain's built-up areas would be inundated with up to 1 meter of sea level rise, and about 8% (7 km^2) inundated with 2 meters of sea level rise.

- Agricultural areas are sensitive above 0.5 meters of sea level rise. Less than 1% (0.1 km^2) of these lands would be inundated up to this amount of sea level rise. An additional 17% (5.4 km^2) would be inundated with 2 meters of sea level rise.

- All land use categories are severely affected under the high sea level rise scenario of 5 meters. Wetlands and reclaimed lands would lose at least 96% of their total area. Built-up areas would experience a loss of 67% of its total area in Northern Bahrain. Of the total sensitive land area of 245 km^2, only 56 km^2 (23%) would remain above water.

Southern Bahrain Island

The most prominent feature of Southern Bahrain Island is the extent of wetlands, which account for nearly 40% of all sensitive land area in southern Bahrain and about 5% of total sensitive land area in the country. It is also where significant shares of Bahrain's bare lands and reclaimed lands, about 19% and 16% of southern Bahrain's sensitive land area, respectively, are located.

Figure 3-10 summarizes land use characteristics as well as the spatial extent and magnitude of seawater inundation under the various scenarios for Southern Bahrain Island. Some key implications of the assessment are as follows.

- Wetlands are the hardest hit by seawater inundation. Approximately 12 km^2, or nearly 52% of all wetlands in southern Bahrain would be inundated if sea levels rise by up to 0.5 meters, with nearly 93% lost if sea levels rise by up to 2 meters.

- Agricultural areas are also very sensitive to even small amounts of sea level rise. About 31% (0.2 km^2) of these lands would be inundated with up to 0.5 meters of sea level rise. An additional 53% (0.4 km^2) would be inundated with 2 meters of sea level rise.

- Reclamation lands in the southeastern part of the island would be somewhat affected with low sea level rise. Of the total of about 8 km^2 of reclaimed land, about 10% (0.3 km^2) would be inundated at 1 meter, and 21% (0.3 km^2) inundated at 2 meters of sea level rise.

- About 10% (0.3 km^2) of Southern Bahrain's built-up areas would be inundated with up to 1 meter of sea level rise, and about 21% (0.7 km^2) inundated with 2 meter of sea level rise.

- All land use categories are severely affected under the high sea level rise scenario of 5 meters. Wetlands and agricultural lands would lose at least 98% of their total area. Built-up and reclamation areas would experience a loss of 25% and 88%, respectively, of their total area in Southern Bahrain. Of the total sensitive land area of 63 km^2, only 5 km^2 (9%) would not be under water.

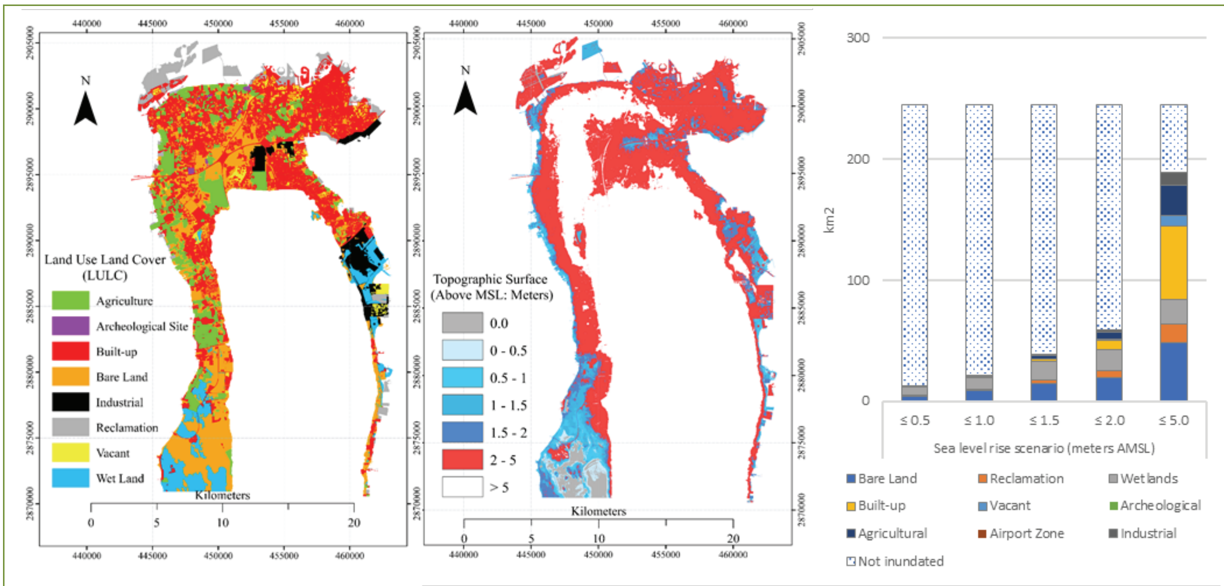


Figure 3-9: Northern Bahrain Island results. Left: LULC map; Middle: Map of inundation by sea level rise scenario; Right: Magnitude of inundation by sea level rise scenario by LULC class

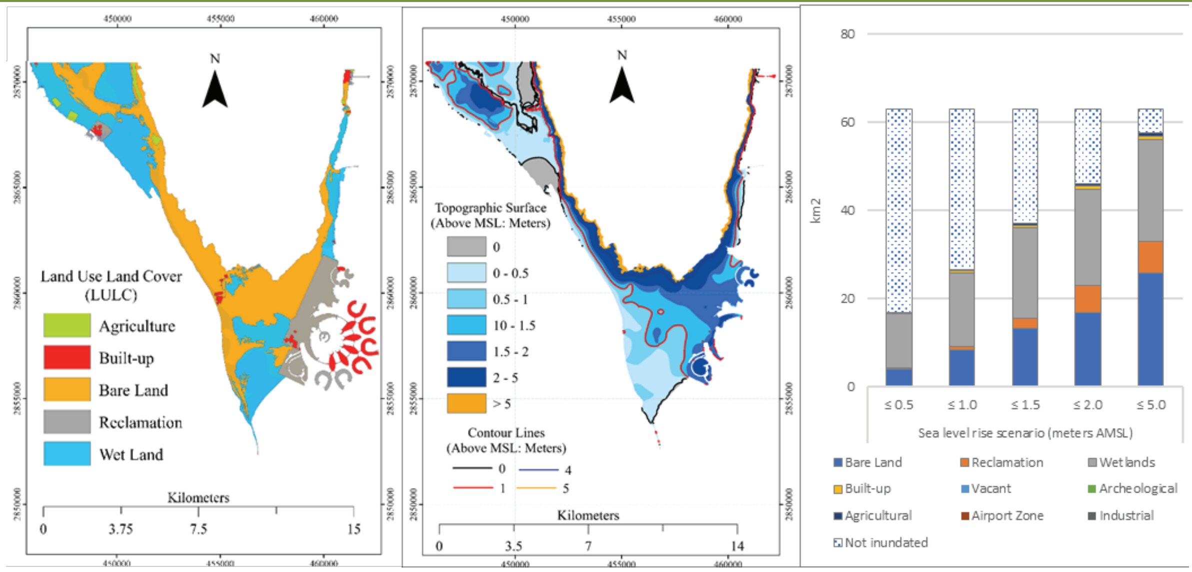


Figure 3-10: Southern Bahrain Island results. Left: LULC map; Middle: Map of inundation by sea level rise scenario; Right: Magnitude of inundation by sea level rise scenario by LULC class

Muharraq

The most prominent features of Muharraq Island are the presence of Bahrain International Airport; the significant amount of the island taken up by built-up and reclaimed lands, about 42% and 25%, respectively; and the absence of any wetlands or bare lands.

Figure 3-11 summarizes land use characteristics as well as the spatial extent and magnitude of seawater inundation under the various scenarios for Muharraq Island. Some key implications of the assessment are as follows.

- With sea level rise under 1 meter, only 1% (0.8 km^2) of the land area would be affected. Industrial areas would be hardest hit, accounting for half the total inundated area on the island.
- With sea level rise under 1.5 meters, only 5% (3.5 km^2) of the land area would be affected. The airport and agricultural areas would be hardest hit, accounting for 3% (1.7 km^2) and 0.3% (0.2 km^2) of total inundated area on the island.
- Reclamation lands would be somewhat affected with low sea level rise. Of the total of about 16.5 km^2 of reclaimed land, only about 2% (0.3 km^2) would be inundated at 1.5 meters, and only 6% (1.0 km^2) inundated at 2 meters of sea level rise.
- Less than 2% (0.8 km^2) of Muharraq Island's built-up areas would be inundated with up to 1.5 meters of sea level rise, and about 14% (3.9 km^2) inundated with 2 meters of sea level rise.

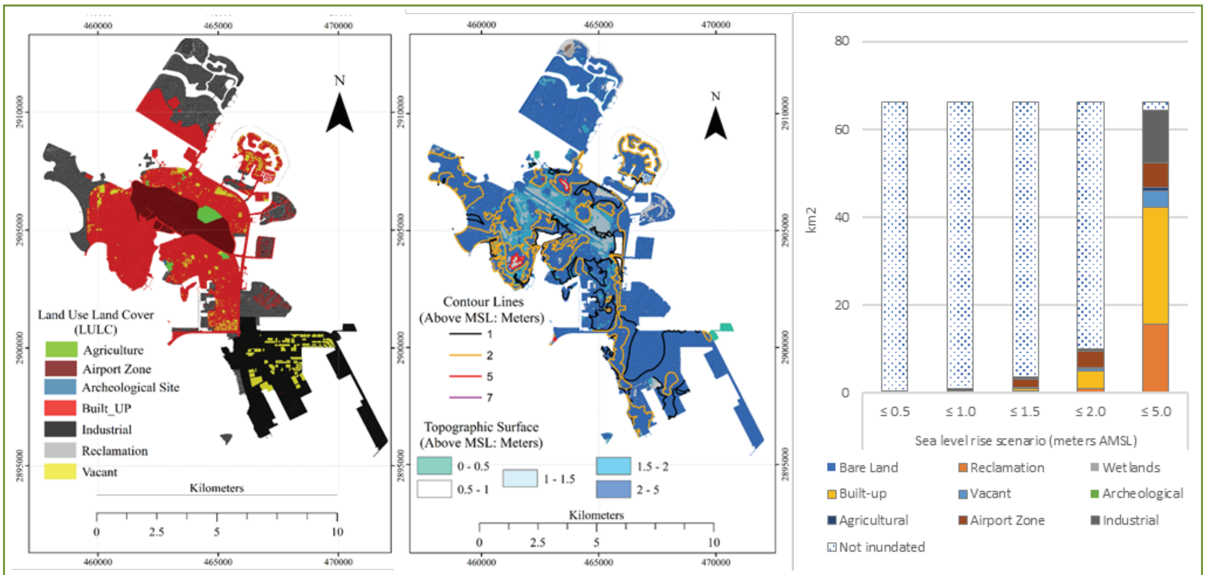


Figure 3-11: Muharraq Island results. Left: LULC map; Middle: Map of inundation by sea level rise scenario; Right: Magnitude of inundation by sea level rise scenario by LULC class

- Agricultural areas are sensitive above 0.5 meters of sea level rise. Less than 1% (0.1 km^2) of these lands would be inundated with this amount of sea level rise. An additional 17% (8.5 km^2) would be inundated with 2 meters of sea level rise.

- All land use categories are severely affected under the high sea level rise scenario of 5 meters. The airport and agricultural areas would be 100% inundated. Built-up areas and reclaimed lands would experience a loss of at least 94% of their total area in Muharraq. Of the total sensitive land area of 66 km^2, only 2 km^2 (3%) would not be under water.

Sitra

The most prominent feature of Sitra Island is the extent of its reclaimed land areas, which account for about 40% of the island's total area. It also is characterized by extensive industrial areas and built-up areas, accounting for about 28% and 21% of total island area, respectively. There are virtually no agricultural lands on the island.

Figure 3-12 summarizes land use characteristics as well as the spatial extent and magnitude of seawater inundation under the various scenarios for Sitra Island. Some key implications of the assessment are as follows.

- With sea level rise under 0.5 meters, only 1% (0.3 km^2) of the land area would be affected. Reclaimed land would be hardest hit, accounting for all inundated area on the island.

- With sea level rise at or below 1 meter, only 4% (0.9 km^2) of the land area would be affected. Reclaimed land would account two-thirds (0.6 km^2) of total inundated area on the island.

- Less than 2% (0.1 km^2) of Sitra Island's built-up areas would be inundated with up to 1.5 meters of sea level rise, and about 8% (0.4 km^2) inundated with 2 meters of sea level rise.

- Reclamation lands would be somewhat affected with low sea level rise. Of the total of about 8.7 km^2 of reclaimed land, about 6% (0.6 km^2) would be inundated at 1 meter, and 18% (1.6 km^2) inundated at 2 meters of sea level rise.

- All land use categories are severely affected under the high sea level rise scenario of 5 meters. Built-up areas would be totally under seawater while reclaimed lands and industrial areas would lose 95% of their total area. Of the total sensitive land area of 22 km^2, only 0.6 km^2 (3%) would not be under water.

Nabih Saleh

The most prominent feature of Nabih Saleh Island is the extent of its built-up areas which account for about 64% of the island's total area. Bare lands and reclaimed lands account for about 12% and 14% of total area, respectively. There are no industrial, agricultural, or vacant areas on the island.

Figure 3-13 summarizes land use characteristics as well as the spatial extent and magnitude of seawater inundation under the various scenarios for Nabih

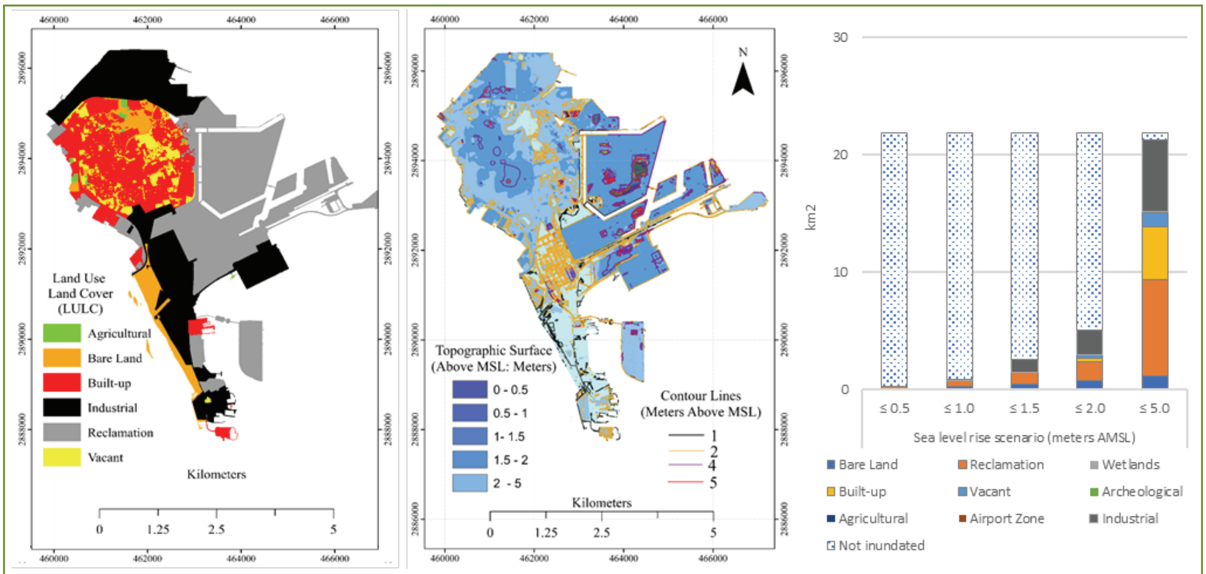


Figure 3-12: Sitra Island results. Left: LULC map; Middle: Map of inundation by sea level rise scenario; Right: Magnitude of inundation by sea level rise scenario by LULC class

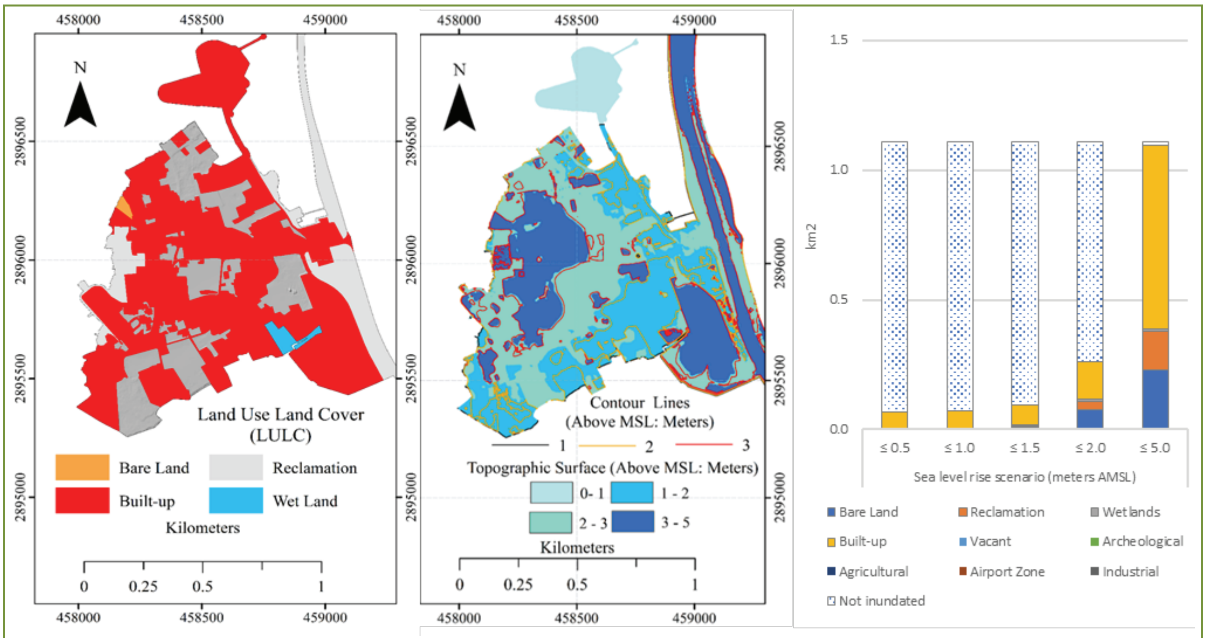


Figure 3-13: Nabi Saleh Island results. Left: LULC map; Middle: Map of inundation by sea level rise scenario; Right: Magnitude of inundation by sea level rise scenario by LULC class

Saleh Island. Some key implications of the assessment are as follows.

- With sea level rise from 0.5 to 1.5 meters, built-up areas would be hardest hit with a loss of 0.08 km^2, representing about a maximum of about 7% of the island's total area. About 92% of the island would be above water

- With 2 meters of sea level rise, significant areas of Nabih Saleh Island would experience inundation. About 13% (0.2 km^2) and 3% (0.03 km^2) of built-up and reclaimed areas would be inundated with 2 meters of sea level rise.

- All land use categories are severely affected under the high sea level rise scenario of 5 meters. Built-up areas would be totally under seawater while reclaimed lands and bare lands would lose at least 94% of their total area. Of the total sensitive land area of 1.1 km^2, only 0.02 km^2 (1%) would not be under water.

Umm Al Nassan

The most prominent features of Umm Al Nassan Island are the extent of bare lands and agricultural areas which take up about 80% and 16%, respectively. Built-up areas account for the remaining 4% of land area.

Figure 3-14 summarizes land use characteristics as well as the spatial extent and magnitude of seawater inundation under the various scenarios for Umm Al Nassan Island. Some key implications of the assessment are as follows.

- With sea level rise from 0.5 to 2.0 meters, bare lands would be hardest hit with a loss of 6.3 km^2, representing about a maximum of about 31% of the island's total area. About 5% of the island would be above water.

- A similar situation is evident for the island's agricultural and built up areas. With sea level rise from 0.5 to 2.0 meters, agricultural areas would experience a loss of 70% (2.3 km^2) and built-up areas would experience a loss of 57% (0.4 km^2).

- All land use categories are severely affected under the high sea level rise scenario of 5 meters, losing at least 99% of their total area. Of the total sensitive land area of 20 km^2, only 0.1 km^2 (1%) would not be under water.

Hawar Islands

The Hawar Island group consists predominantly of bare lands and wetlands, which account for nearly 65% and 33% respectively. Built-up areas account for the remaining 2% of land area.

Figure 3-15 summarizes land use characteristics as well as the spatial extent and magnitude of seawater inundation under the various scenarios for the Hawar Island group. Some key implications of the assessment are as follows.

- With sea level rise from 0.5 to 2.0 meters, wetlands

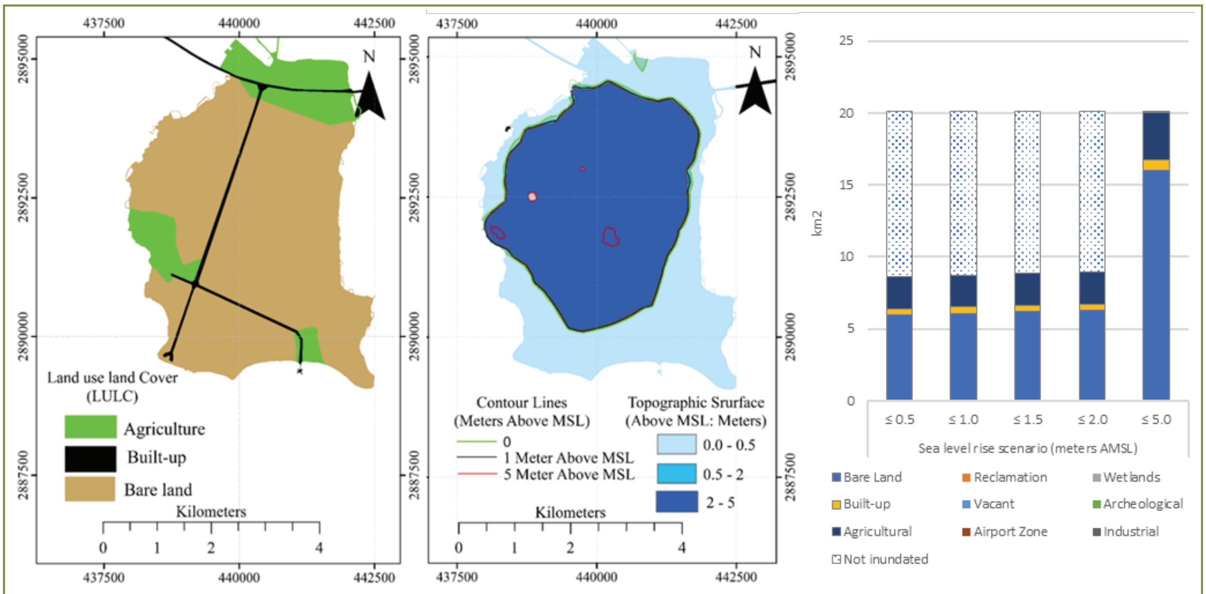


Figure 3-14: Umm Al Nassan Island results. Left: LULC map; Middle: Map of inundation by sea level rise scenario; Right: Magnitude of inundation by sea level rise scenario by LULC class

would be hardest hit with a loss from 7.6 km² to 10 km², representing about 15% to 19% of the island's total area. About 68% of the island would be above water.

- A similar situation is evident for the island's bare lands. With sea level rise from 0.5 to 2.0 meters, these areas would lose between 3.3 km² to 6.0 km², representing about 6% to 11% of the island's total area.

- All land use categories are severely affected under the high sea level rise scenario of 5 meters. Bare lands would experience a loss of 77% of its total area, while wetlands and built-up areas would lose at least 96% of their area. Of the total sensitive land area of 2 km², only 8 km² (16%) would not be under water.

Road system

Bahrain's road system consists of paved and unpaved roads across all of the islands including the Hawar Island Group. Since road lengths are reported on a national basis, the estimate of sea level rise impacts on to the road system was limited to a national scale assessment.

Paved roads consist of three major types: main roads (i.e., highways); secondary roads (i.e., avenues); and other roads (i.e., smaller roads & lanes). Over the past 6 years, there has been active paved road construction in Bahrain, increasing total length of all paved roads from 3,517 km in 2012 to 3,708 km in 2018, an average annual growth rate of about 0.9% per year. Unpaved roads have remained constant at 730 km over this time period. Sea level rise will adversely impact Bahrain's paved and unpaved roads. The extent of this impact is summarized in Table 3-2 for each of the sea level rise scenarios. Notably, toads are less affected by sea level rise than land areas. For example, under 5 meters of sea level rise, 51% of all road surfaces are projected to inundated, compared to about 85% of all land area (see earlier Figure 3-8). This is even more evident under smaller sea level rise scenarios, with only 1.5% of the road infrastructure inundated with 0.5 meters of sea level rise, compared to 11% of total land area in this scenario. This is due to the fact that there is not a strong alignment of the location of roads with lands sensitive to sea level rise.

Population exposure

Sea level rise will negatively impact people's wellbeing by inducing relocation to higher elevations within Bahrain, or otherwise forcing them to respond to the prospects of future inundation.

To estimate the number of persons affected by sea level rise, low, median, and high population estimates were obtained from the United Nations Populations

Table 3–2: Impact of sea level rise on Bahrain's road network

Type of Road		Current length (km)	Loss of road (km) under sea level rise scenario (meters AMSL): ≤ 0.5	≤ 1.0	≤ 1.5	≤ 2.0	≤ 5.0
Paved roads	Main Roads (Highways)	581	9	18	42	94	294
	Secondary Roads (Avenues)	796	12	25	58	128	402
	Other Roads (Roads & Lanes)	2,331	35	74	169	376	1,178
	Subtotal	3,708	56	118	269	597	1,874
Unpaved roads		730	11	23	53	118	369
Total		4,438	67	141	321	715	2,243
Share of total road length (%)		100%	2%	3%	7%	16%	51%

division for 2050 and 2100 (UNDESA, 2017). To estimate where this population would reside, it was assumed that the population density of each island would remain the same from 2016 through 2100.

Figure 3-16 (top) illustrates the range in the number of affected people in 2050 and 2100 (corresponding to the higher sea level rise scenarios; 2.0, 5.0). By 2050, between 3,000 and 16,000 are projected to be negatively affected, corresponding to between 54% and 74% of the total population. By 2100, between 29,000 and 438,000 are projected to be negatively affected, corresponding to between 62% and 65% of the total population.

Figure 3-16 (bottom) illustrates a comparison in 2050 and 2100 of the share of land inundated with the share of people affected by inundation. In both years and for all sea level rise scenarios, the share of land inundated is much high than the share of people affected. The difference is greatest in 2050 where the share of land inundated is between 11% and 22%, compared to 0.1% to 0.6% for the share of people impacted, suggesting the population is already inhabiting higher elevations. By 2100 the difference is much less: the share of land inundated is between 31% and 85%, compared to 2% to 14% for the share of people impacted, suggesting a greater number of people inhabiting areas exposed to sea level rise.

3.2.4. Adaptation implications

The potential damage of rising seas on the eight assessed land use classes is evident, especially at high levels of sea level rise. Yet, even at smaller levels of sea level rise, substantial land areas, roads, and communities

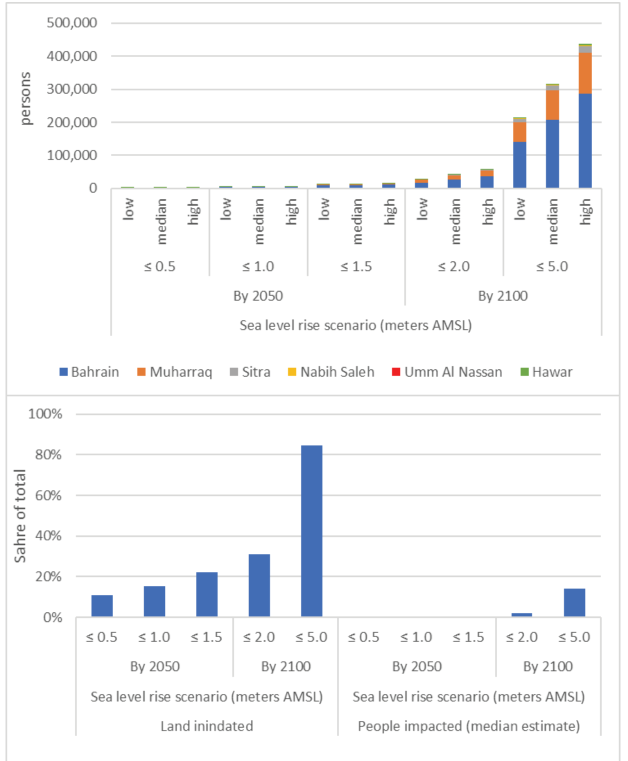


Figure 3-15: Top: Range of people in Bahrain impacted by sea level rise, 2050 and 2100; Bottom: Share of land and people in Bahrain impacted by sea level rise, 2050 and 2100

will eventually be at risk of seawater inundation in the absence of effective adaptation measures.

This is well illustrated by mangroves which are found in low-lying wetlands. The current 56 hectares of mangroves along the coasts of Tubli Bay in Northern Bahrain Island are under threat even at the lowest sea level rise scenario because of their inability to migrate landward due to the built-up urban nature of adjacent lands. Another example is Bahrain's international airport which occupies about 5.7 km^2 on Muharraq

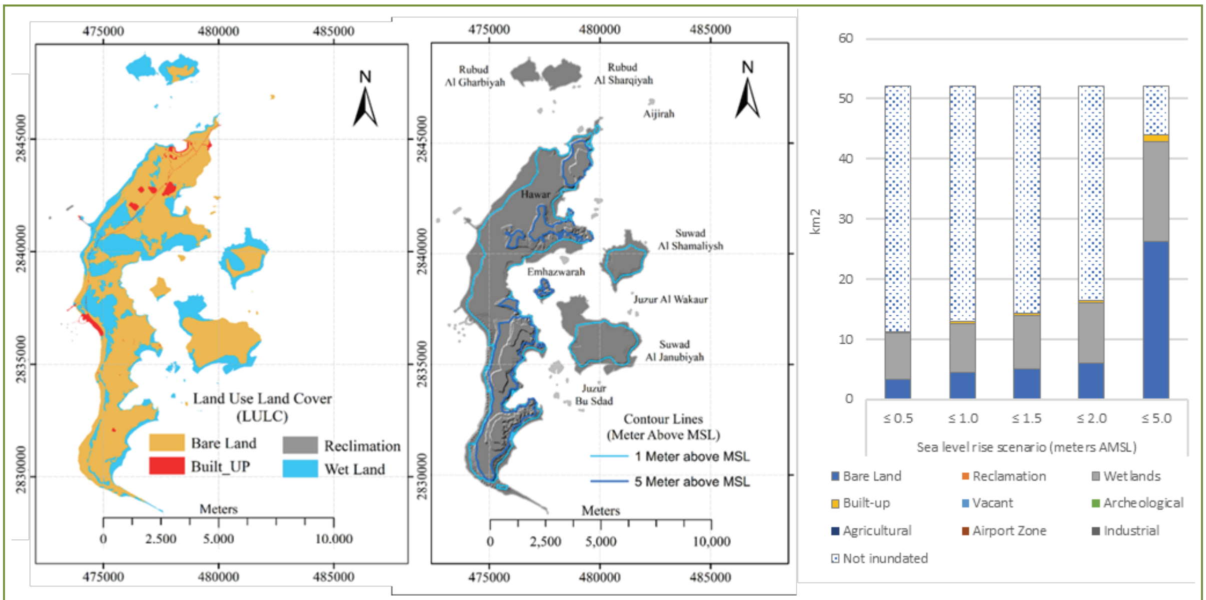


Figure 3-16: Hawar Island Group results. Left: LULC map; Middle: Map of inundation by sea level rise scenario; Right: Magnitude of inundation by sea level rise scenario by LULC class

Island. With sea level rise of 1.5 meters, facilities would experience flooding of about 30% of this area.

Some adaptation measures have already taken place in certain sectors. For example, while not explicitly in reference to sea level rise, Bahrain's building codes enacted in 2009 call for the height of the ground floor of a new building being 1.5 meters above the level of the pavement surface (KoB, 2009). This can build resilience of future buildings against future sea level rise, at least in a scenario where future sea level rise is limited to 1.5 meters above current MSL.

Much remains to be done in Bahrain to ensure climate resilience. Adaptation planning dialogues are mostly confined to specialist communities within the country limited impact on national planning and policy dialogues. Going forward, it is recommended that systematic adaptation planning efforts be organized within an adaptation framework that address strategies for protection, accommodation, retreat, and avoidance. In the near-term, the focus should be on the following elements, with the aim of increasing institutional capacity to incorporate sea level rise risks within development planning:

- *Planning tools:* Planning tools include activities of setting an overall policy to mitigate the effect of sea level rise. At minimum, it should incorporate assessment of coastal hazards, coastal risk modeling/management, and development of emergency preparedness strategies.

- *Regulatory tools:* These include tools such as enacting land use regulations (e.g., zoning offsets from the coastline), adjusting building codes (e.g., increasing the distance from pavement to ground floor) and accounting for sea level rise in real estate development permits (e.g., identification of no-build zones).

- *Land use tools:* These refer to tools in support of strategic adaptation and include such as land acquisition (i.e., purchase/transfer of development rights), reclamation (e.g., adding more restrictions on top of basic zoning requirements for certain high-risk areas), zoning (i.e., reclassifying highly vulnerable land for low risk uses) and subdivision regulation (e.g., minimum conservation requirements)

- *Hard and soft structural tools:* Structural tools include assessment frameworks by which to assess the optimality of coastal protection with either hard measures (e.g., dikes, breakwaters) or soft measures (e.g., mangrove plantations, beach nourishment).

Regardless of specific tools or combination of tools applied, a framework for adaptation to sea level rise is an urgent need in Bahrain. The launch of such an effort should be premised on the use of high-quality data, an informed and engaged public, and suitable monitoring & evaluation protocols.

3.3. Water resources

Bahrain is extremely poorly endowed with water resources, having per capita freshwater availability levels that are among the lowest in the world. Over the past 45 years, rapid population and economic growth - combined with low efficiency/conservation and inadequate recycling/reuse - has contributed to a decline in per capita freshwater availability of 4.4% per year – from 525 m^3/yr in 1970 to about 70 m^3/yr in 2015. At current rates, per capita freshwater availability could decline to less than 50 cubic meters by 2030.

In response, water authorities have focused on increasing water supply, primarily by expanding seawater desalination capacity. While this has increased per capita total water availability, there has not been adequate attention to the demand side. As a result, sectoral water demands have escalated, water production and distribution costs have increased, and remaining groundwater resources have further deteriorated in terms of quantity and quality.

Climate change will exacerbate an already unsustainable situation. Direct threats include rising sea levels, lower precipitation, and higher temperatures. Sea level rise is expected to lead to seawater intrusion into fresh groundwater lenses and adverse impacts on inlets/outlets of desalination plants. Lower precipitation could lead to lower groundwater recharge rates. Higher temperatures could lead to unsustainable levels of groundwater and desalinated water use by agriculture, households, and businesses.

Indeed, the main water resource management challenge facing Bahrain is how to balance decreasing water supply and increasing water use (i.e., the supply-demand gap) in the context of a changing climate.

Implementing sustainable long-term water resource management strategies and investments while promoting national development with the least social, economic, environmental and other costs is now recognized as a national priority.

The rest of this section describes the results of a country-wide assessment of the impacts of climate change on Bahrain's water resources, based on a study by Zubari et al., 2018. The aim of the assessment was twofold; to identify impacts posed by climate change on future water supply and demand under the current business-as-usual water policy environment, and analyze the costs and benefits associated with increasing efficiency and decreasing water distribution losses.

3.3.1. Background

An acutely water-scarce country in a hyper arid environment, Bahrain has experienced increasingly high deficits in its water budget since the early 1970s. Implementing policies and measures that promote a sustainable balance between water supply and water demand is central to building climate resilience against a background of strong economic growth.

There are three main sources of water supply in Bahrain: groundwater, desalinated water, and treated wastewater. On the demand side, there are three main water consuming sectors: municipal, agricultural, and industrial. Key characteristics of each supply source and demand sector are outlined in the subsections below.

Groundwater supply

Groundwater represents the only natural, relatively freshwater source available for Bahrain. It is contained in the Dammam aquifer system which extends from central Saudi Arabia and consists of two zones, the

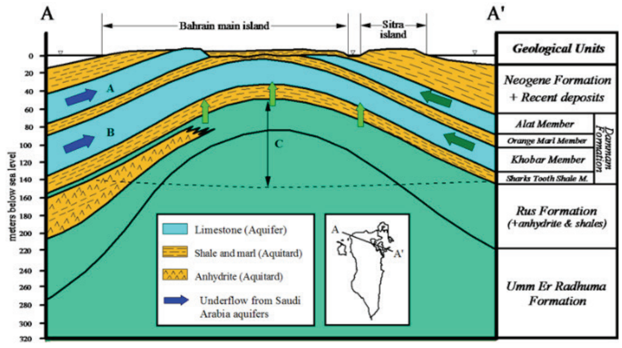


Figure 3-17: Bahrain's groundwater system (Zubari, *et al.*, 1997).

Alat zone, termed the 'A' aquifer and the Khobar zone, termed the 'B' aquifer, (see Figure 3-17). The 'B' aquifer zone is developed in highly fractured limestones and dolomites and is the principal aquifer in Bahrain. The 'A' aquifer zone has limited hydraulic properties and due to its salinization is used at very local scales by farmers. Underlying these layers are the highly brackish Rus and Umm Er Radhuma aquifers.

Heavy and unsustainable dependence on fresh groundwater, particularly by the agricultural and municipal sectors has led to excessive abstraction rates. Since 1965, annual withdrawals have exceeded the recommended groundwater safe yield, peaking at more than twice the safe yield level in 2010. This has resulted in a severe decline in aquifer water levels, causing the flow of natural springs to stop and a 5-meter drop in the groundwater table compared to the aquifer's pre-development levels (Zubari, 2004).

This unsustainable pattern of groundwater abstraction has disturbed the aquifer natural equilibrium conditions and led to seawater and underlying brackish/saline water to migrate into the aquifer leading to a continuous salinization and deterioration of the groundwater

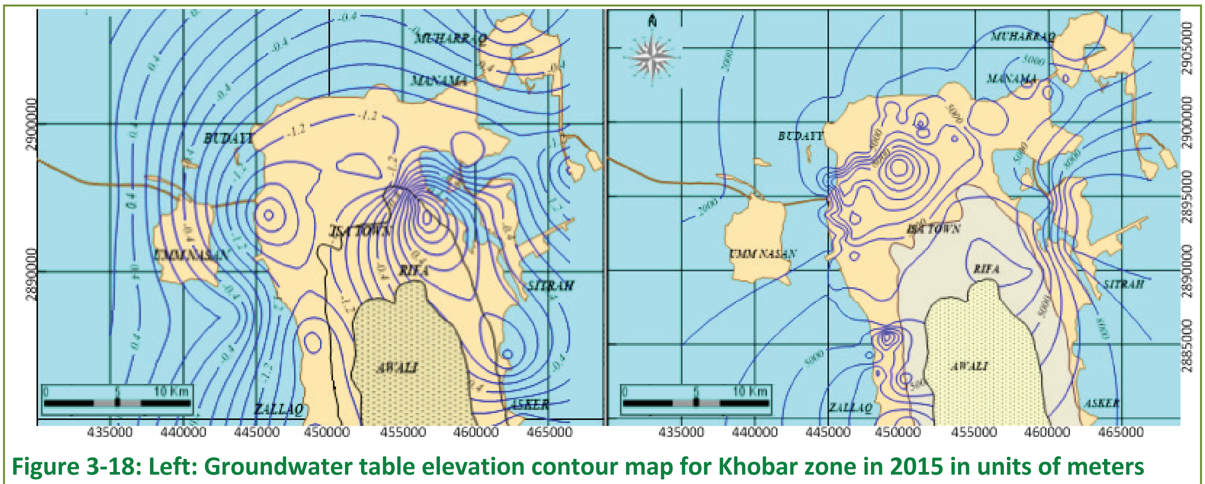


Figure 3-18: Left: Groundwater table elevation contour map for Khobar zone in 2015 in units of meters relative to mean sea level; Right: Salinity contour map for the Khobar zone in 2015 in units of mg of total dissolved solids per liter (Source: Zubari, 2018 (contour maps prepared by Zubari; well data obtained from MEW))

quality. This is illustrated in Figure 3-18 (left) which shows that the elevation of the groundwater table in the densely populated northern part of Bahrain is between 0.4 and 1.2 meters below mean sea level. The deterioration of groundwater quality is illustrated in Figure 3-18 (right) which shows groundwater salinity contours of 5,000 mg/l in northern Bahrain, a level greatly significantly exceeding previous levels.

Desalinated water supply

The share of desalinated water production has increased rapidly since the mid 1970s, at roughly 5.6% per year or 1.5 times the annual average population growth rate. Today, Bahrain's desalination capacity is about 892,000 m^3/d (309 Mm^3/yr) consisting of Reverse Osmosis (RO), Multistage-Flash (MSF), and Multi-Effect Distillation (MED) plants that correspond to 38%, 28%, and 34% of total capacity, respectively. Almost all of the raw water input comes from the Arabian Gulf, with only a small percentage (about 8%) coming from brackish water for use in RO units.

Together, these units satisfy nearly all drinking requirements in the country as well as a significant portion of industrial and commercial needs. From a share of only 7% in 1980, desalinated water now represents about 96% of total municipal water supply, with the balance provided by groundwater resources (see Figure 3-19).

The desalination process produces several adverse environmental impacts. At today's production levels, roughly 1 billion m^3/yr of highly saline and hot brine is discharged directly to the Gulf with little to no remedial measures. The salinity of the brine can reach up to 76,300 mg/l, or about double the average salinity of the already highly saline Arabian Gulf. The temperature of the brine ranges from 28-33°C for RO units to about 35-40°C for the MSF and MED thermal plants. In addition, brine contains residual chemicals from the pretreatment process, heavy metals from corrosion or intermittently used cleaning agents. The effluent from desalination plants is a multi-component waste, with multiple harmful effects on the marine environment.

Treated wastewater supply

In 1976, the main portion of a domestic wastewater network was installed in Bahrain. Shortly thereafter, in 1982, the opportunities associated with the use of treated wastewater as a non-conventional water source for agricultural purposes became increasingly apparent.

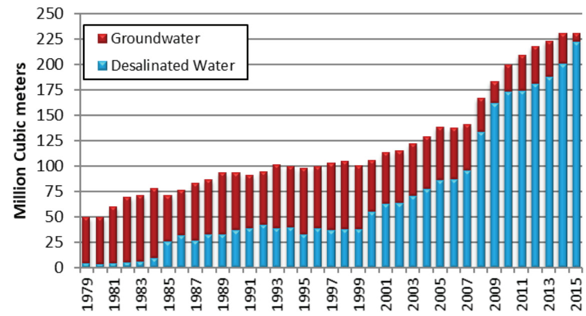


Figure 3-19: Profile of municipal water supply in Bahrain, 1980-2015 (Source: EWA)

In 1985, treated wastewater was used for the first time in limited amounts. Today, bolstered by 11 wastewater treatment plants with a total capacity of about 352,770 m^3/d, treated wastewater has become an increasingly important component in Bahrain's water budget.

The main wastewater treatment facility in Bahrain is the Tubli Water Pollution Control Center (WPCC) which handles a flow of over 328 thousand m^3/d, or about 73% of daily wastewater flow. The Tubli WPCC is equipped with tertiary treatment technology to bring a portion of total effluents to acceptable quality, with TDS levels lower than groundwater. Other minor treatment facilities are equipped with less than tertiary treatment systems (i.e., activated sludge and membrane bioreactors) but represent less than 1% of total treatment capacity.

The newest tertiary treated wastewater plant is on Muharraq Island, with private sector ownership. The plant has a capacity of about 100,000 m^3/d (expandable to 160,000 m^3/d) of tertiary treatment and is serving the island of Muharraq as part of a decentralization policy. Though total treated amounts for 2017 were about 73,700 m^3/d, only about 1% is being reused (about 1,000 m^3/d). Such large amounts of unused tertiary treated wastewater represent major lost opportunities under the prevailing water scarcity conditions, especially given that an estimated annual amount of about US$ 12.2 million is being paid by the government to the private sector to treat these waters to a tertiary level.

At present, Bahrain is pursuing a policy of expansion in the re-use of treated wastewater in irrigation. The primary objectives are to protect groundwater from further lowering of the groundwater table, deterioration in water quality, and satisfying demands for irrigation and landscaping. The policy incentivizes farmers to use treated wastewater instead of groundwater by providing free delivery of treated wastewater to the farmer lands. Currently, an average of 154 thousand m³/d of treated wastewater is delivered to 547 farms with a total area of 3,100 hectares. This represents about 92% of all agricultural land area in Bahrain Island, Muharraq Island, and Sitra Island.

Nevertheless, the reuse of treated wastewater remains a largely untapped opportunity in Bahrain. Much of the wastewater in only treated to secondary levels and discharged to the Gulf. Trends in treated wastewater are illustrated in Figure 3-20 for the Tubli WPCC. Tertiary treated wastewater ranges from roughly 29% to 42% and is used for farm irrigation, landscaping, and within the plant itself. The rest of the wastewater received is treated only to a secondary level and discharged to Tubli Bay, with the associated environmental impacts especially on the mangrove stands in the Bay.

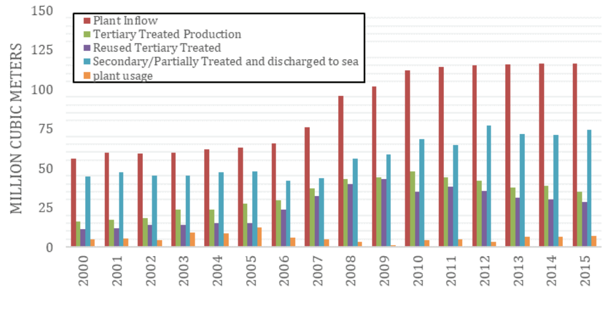


Figure 3-20: Amounts of wastewater received in Tubli WPCC, tertiary treated, reused, and discharged to the sea, 2000-2015 (data source: Sanitation Directorate, Ministry of Works, Municipalities and Urban Planning)

Municipal water demand

Municipal water demand encompasses all end users that are supplied by the municipal distribution network. This includes households, businesses, government buildings, as well as some industrial facilities and farms. It currently represents about 60% of annual water consumption and has experienced high growth due to urban growth, expansion in tourism, and increased desalinated water availability (see Figure 3-21; left).

Historically, per capita municipal water consumption has been relatively high, reaching 690 liters per day in the late 1980's. With the introduction of block water tariffs in 1986, these rates have been declining at an average rate of about 1.2% per year. Currently, municipal water consumption is about 500 liters per person day (see Figure 3-21; middle). Notably, this level includes all water losses from leakages in the distribution system as well as illegal connections. Net per capita daily water consumption typically ranges between 325 and 360 liters.

Municipal water quality has improved substantially since 1985, primarily due to desalinated water displacing groundwater, which typically has high levels of total dissolved solids (TDS). Major reductions in TDS content occurred in 1999, 2008, and 2014, coinciding with desalination capacity expansion coming online (i.e., mix of new units and expansion of existing units). Today, with about 95% of municipal water demand met by seawater desalination, TDS levels are well below the national standard of 1,000 mg/l and half the WHO standard of 600 mg/l (see Figure 3-21, right). Declining levels of other contaminants such as magnesium and sulphates are also evident over the 2005-2016 period.

Agricultural water demand

Agricultural water demand is associated with irrigated agriculture using traditional (i.e., flood irrigation) and modern methods (i.e., drip and sprinkler irrigation). It currently represents about 30% of annual water consumption in Bahrain. While agricultural water demand increased at an average annual rate of 4.1% during 1980s and 1990s, peaking at about 185 Mm³ in 1999, it has steadily declined by an average of 2.1% per year since then, totaling 125 Mm³ in 2015. This parallels the reduction in agricultural land area due to widespread groundwater salinization; from a high of 10,000 hectares in 1999 (FAOSTAT) agricultural land dropped to about 3,700 hectares in 2015.

Until 1985, irrigated agriculture in Bahrain relied

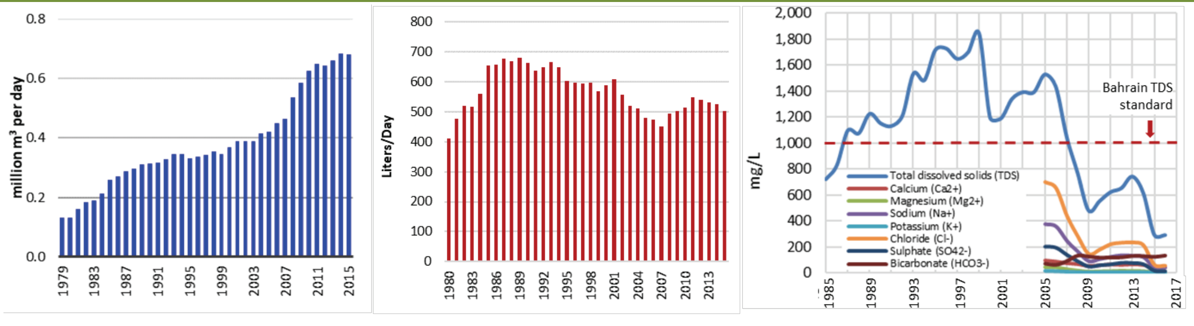


Figure 3-21: Left: Average daily water consumption in the municipal sector, 1979-2015; Middle: Average per capita daily consumption in the municipal sector, 1980-2015; Right: Average annual municipal water quality, 1985-2016 (source: EWA)

exclusively on groundwater to meet its water needs. Since then, treated wastewater has taken up an increasing share of water supply, reaching about 23% of the sector's water requirements by 2015 (see Figure 3-22). The replacement of increasingly brackish groundwater with higher quality water has arrested the loss of agricultural lands in providing reliable water sources for irrigation and this has stabilized the farmers income.

The heavy dependence on inefficient flood irrigation methods is a major contributor to excessive water consumption rates. Typically, flood irrigation accounts for 65% of all irrigated lands and has an efficiency of only 25-40% (Al Masri, 2009). More efficient methods such as drip irrigation and sprinkler irrigation are applied to only 32% and 3% of agricultural areas, respectively. As a result, average losses represent about 30% of all water used for agriculture.

There are several other contributors to excessive water consumption. These include the cultivation of high water-consuming crops (e.g., alfalfa) and the absence of agricultural water tariffs. In addition, farm size is typically small (i.e., 84% of farm holdings are 5 hectares in size, or less) with short tenancy agreements, generally for only three years. These factors discourage investments in efficient irrigation even with government subsidies, suggesting an urgent need for strategic policy intervention.

Industrial water demand

Industrial water demand is associated with industries such as aluminum, food & beverages, pharmaceuticals, textiles, petrochemicals, and construction. It currently represents about 8% of annual water consumption in Bahrain.

Prior to 1980, the industrial sector relied on groundwater to meet all of its water requirements. In an effort to diminish stress on the Alat and Khobar freshwater zones of the Dammam aquifer, industry was largely prohibited by government decree (i.e., Amiri Decree No. 12/1980 and Ministerial Order No. 23 of 1980) from using these zones. Instead, the sector was mostly limited to the use of the deeper Rus-Umm Er Radhuma aquifer, a brackish to saline water lens (TDS of 5,000-25,000 mg/L) in central Bahrain island.

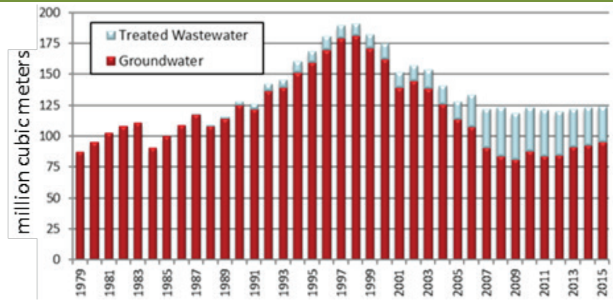


Figure 3-22: Agricultural sector water consumption, 1979-2015 (source: Ministry of Municipalities Affairs and Urban Planning)

After 1980, industrial production has increasingly relied on on-site desalination at large- and medium-sized industries while small industries have turned to the municipal distribution network. Currently, the industrial sector relies on on-site desalination for nearly 40% of its annual water requirements. Nevertheless, brackish groundwater and the municipal water network still account for significant shares of industrial water use (see Figure 3-23). Going forward, dependence on the Alat and Khobar zones of the Dammam aquifer are expected to further decline, offset mostly by on-site desalinated water.

3.3.2. Approach

The objective of the vulnerability assessment was twofold: to quantify the impact of climate change on Bahrain's sensitive municipal water supply-demand equilibrium and to quantify the costs and benefits of adaptation policies and measures that can build resilience in the equilibrium between supply and demand in the municipal water distribution network.

The municipal sector was selected for analysis because of its crucial role in the country's socio-economic development. It currently accounts for most of the water consumption, about 60%, and unlike the agricultural and industrial sectors, is expected to grow rapidly. Moreover, the municipal sector is the main driver for the wastewater sector. Changes in municipal water consumption directly lead to changes in quantities of treated wastewater reuse, which in turn affects the use of groundwater for agricultural purposes.

A dynamic mathematical model representation of the municipal water system was developed using Water Evaluation And Planning (WEAP) software. Population data were obtained from the Information and e-Government Authority (IeGA); desalination data were obtained from EWA; groundwater and treated wastewater data were obtained from the Ministry of Works, Municipalities and Urban Planning. A planning period from 2016-2035 was assumed.

Methodology

The assessment involved several major steps, as briefly described in the bullets below.

- *Situation Analysis:* This involved an assessment of current water sector conditions, main problems and issues in Bahrain's water sector through literature review, data collection, and trend analysis;

- *Model development:* This involved the construction of a simple mathematical model using WEAP21 for municipal water supply/demand. The model was validated using available data for the period 2010-2015 and then used as the basis for projections from a 2015 base year through 2035. Figure 3-24 provides a schematic diagram of the Bahrain water supply and demand model;

- *Adaptation option screening:* This involved developing an inventory of available water management options that can reduce the gap between water supply and demand, and selection of priority adaptation intervention options for analysis;

- *Analytical framework:* This involved the development of two types of scenarios of future water supply and demand. The first was a set of Reference scenarios that assumed no adaptation interventions, with and without climate change; the second type was a set of Policy scenarios, with and without climate change.

- *Adaptation policy modeling:* This involved modeling the impact on water supply and demand from the implementation priority adaptation interventions using the validated mathematical model. The impacts from climate change, as well as the costs and benefits from transitioning to a climate resilient water supply and demand system were calculated as the difference between the Reference and Policy Scenarios.

Adaptation interventions

Two strategic interventions were considered to ensure a stable equilibrium between future water supply and demand under climate change.

The first intervention aims to achieve a 33% reduction in per capita municipal water demand, from the current level of 183 to 122 m^3 per person per year by 2035, with a policy start year of 2016. To achieve this target, three complementary demand side management policies

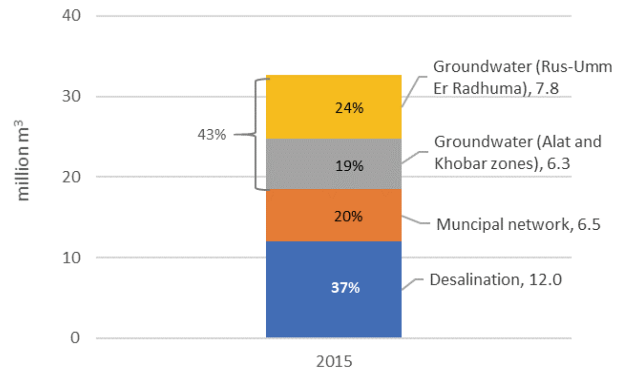


Figure 3-23: Water use in industrial sector by source, 2015 (source: EWA)

would be advanced, as outlined in the bullets below.

- *Awareness raising:* This would involve social campaigns and government incentives to emphasize the importance of water efficiency and conservation among the general population.

- *Strengthened block tariffs:* Up until recently water tariffs were heavily subsidized and did not recover minimum production and distribution costs. Effective 1 March 2016, water tariffs for commercial, industrial, touristic, and other non-household users are being gradually strengthened in accordance with the new tariff schedule established by EWA. The block water tariff structure is shown in Figure 3-25.

- *New legislation:* To promote water use efficiency and conservation, new legislation would be needed to strengthen existing building codes, promote water saving devices such as low-flow shower heads, faucet aerators, automatic shut-off nozzles and

Figure 3-24: Conceptual WEAP Model for water resources system in Bahrain

others for new buildings while existing buildings would be retrofitted. Such devices can reduce water consumption by 20% to 40% (Ababa and Alhaji, 2001; Al-Rumikhani, 2001).

The second intervention aims to reduce leakage in the water distribution network. Significant quantities of desalinated water and groundwater that enter the pipeline network are lost through surface leaks from above- and below-ground pipelines or unseen leaks due to material failure or faulty fittings. Currently, about 19% of all municipal water production does not reach the end user due to leakage. Through investments in detection and repair, this second intervention aims to achieve a 22% reduction in per capita municipal water demand, from the current level of 183 to 142 m^3 per person per year by 2035, with a policy start year of 2016. To achieve this target, two complementary leak mitigation policies would be advanced, as outlined in the bullets below.

- *Leak detection:* This would involve the strengthening of the leak detection programme within EWA's Leakage Detection and Control Group to perform more frequent leak detection surveys and expand the use of leak detection technologies (e.g., leak noise correlators, thermography free-floating inline leak detectors, etc).

- *Leak control:* This would involve several available currently technologies including Active Leakage Control, Pressure Management, Networks Rehabilitations and Speed & Quality of Repair (Lambert, 2003).

Scenario development

Reference and policy scenarios were constructed to reflect plausible potential futures of water supply and demand in Bahrain. Specifically, nine scenarios were considered as described in the bullets that follow:

- *Reference scenarios:* Three Reference scenarios were analyzed. One scenario assumed no policy interventions to improve the water supply/demand equilibrium or any change in the future climate. Existing expansion plans for desalination and wastewater treatment plants were incorporated. The other two Reference scenarios incorporated the impacts on water demand from RCP4.5 and RCP8.5.

- *Policy scenarios:* Six Policy scenarios were analyzed, as summarized below:

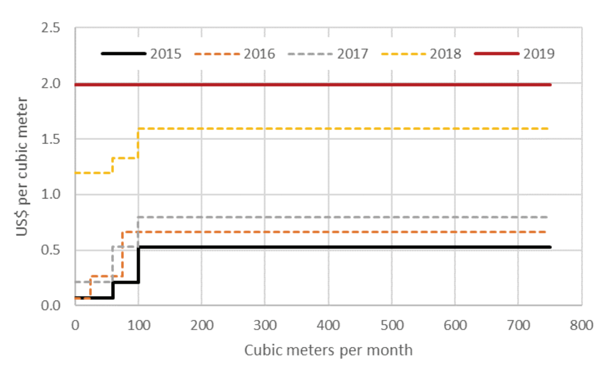


Figure 3-25: Schedule for strengthening water block tariffs in Bahrain for non-household users. (Source: National Energy Efficiency Action Plan)

- *Demand side management scenarios:* Two scenarios considered the impact of policies to achieve a 33% reduction in per capita municipal water use by 2035 through awareness raising, strengthened block tariffs, and new legislation; with one scenario analyzed under RCP4.5, the other under RCP8.5.

- *Leakage reduction scenarios:* Two scenarios considered the impact of policies to achieve a 22% reduction in per capita municipal water use by 2035 through the installation of the variety of water leakage reduction measures; with one scenario analyzed one under RCP4.5, the other under RCP8.5.

- *Integrated policy scenarios:* The last two scenarios considered the integration of both demand side management and leakage reduction policies; with one scenario analyzed one under RCP4.5, the other under RCP8.5.

Table 3–3: Assumptions underpinning the water resource adaptation policy assessment

Parameter	Value (2015-2035)
Cost of water supply (2015 US$/$m^3$)	1.9
Desalination energy requirement (kWh/m^3)	20
Desalination technology mix:	100%
Reverse osmosis	38%
Multistage flash	28%
Multi-Effect Distillation	34%
Brine production (m^3/m^3 potable water)	3.8
Share of intake converted into potable water:	
Reverse osmosis	87%
Multistage flash	13%
Multi-Effect Distillation	15%
Electricity use shares	100%
Desalinated water production	97%
Transmission & distribution	3%
Wastewater treated (% of municipal use)	50%
Wastewater treatment cost (2015 US$/$m^3$)	1.1
Desalination GHG emission factor (kg CO_2e/m^3)	13

Key assumptions

- The assessment involved several key assumptions, as briefly described in the bullets below. A summary of other key assumptions is provided in Table 3-3.

- *Temporality:* Average annual water demands were modeled, as opposed to seasonal or daily water demands;

- *Groundwater availability:* This was estimated to be about 12.5 billion cubic meters in the 2015 Base Year, with annual aquifer recharge rate assumed a constant 110 Mm^3 (Al-Noaimi, 1999);

- *Municipal water demand:* Overall per capita municipal water consumption - including consumption by industry and farms through the municipal distribution system - was assumed constant at 500 liters per day (183 m^3/year) in the reference scenarios for the projection period;

- *Population growth:* From a population of about 1.44 million in 2015, Bahrain's population is assumed to reach 2.6 million by 2035, an average annual growth rate of 3.0%;

- *Desalinated water share:* Desalinated water, as a share of total municipal water supply, remains a constant at 96% over the planning period, with the balance met by groundwater; and

- *Climate change:* Average annual temperature increases associated with RCP 4.5 and 8.5 climate were considered and assumed to reach 0.22°C and 0.96°C by 2035, respectively, leading to an additional 1.38 m^3 per °C of per capita water consumption in that year, on average.

- *Policy phase-in schedule:* The per capita reduction policy was assumed to be implemented starting in 2016 and ramped up linearly up to its 2035 target. The leakage reduction policy was assumed to be implemented starting in 2020 and ramped up linearly up to its 2035 target.

- *Capital and O&M costs:* These costs are associated with the various technologies and measures for implementing the two policies. For the purpose of the current analysis, they have been assumed to be zero due to the difficulty in accurately estimating local costs for the intervention schemes. It is recommended that future analyses ensure that such costs are accounted for.

- *Present value of costs and benefits:* A societal discount rate of 5% (real) was applied to calculate cumulative costs over the planning period.

3.3.3. Results

The results described below make clear that it is imperative for Bahrain to formulate a clear comprehensive national water policy and strategy based on integrated water resource management (IWRM) principles and to account for future climate change. In 2016, Bahrain moved one step in this direction by establishing a National Water Resources Council (Royal Decree No. 36/2009) to reactivate the previously formed High Water Council in 1982, seen as the most suitable organizational framework to ensure sustainable water resource management.

Indeed, the effective implementation of policies aiming at per capita municipal water consumption reduction and controlling leakage losses are is closely

Table 3–4: Reference scenario results (with and without climate change)

Parameter		Units	Annual totals				Cumulative by 2035		
			In 2015	In 2035 Reference	RCP4.5	RCP8.5	Reference	RCP4.5	RCP8.5
Consumption	Water consumption	Mm^3	263	474.7	475.5	478.2	7,601	7,608	7,632
	Electricity for desalinated & water distribution	GWh	5,042	9,114	9,129	9,181	145,943	146,076	146,536
Supply	Water production	Mm^3	252	456.2	456.9	459.5	7,304	7,311	7,334
	Reverse osmosis		92	165.4	165.7	166.6	2,649	2,651	2,660
	Multistage flash		76	137.6	137.9	138.6	2,204	2,206	2,213
	Multi-Effect Distillation		85	153.1	153.4	154.2	2,452	2,454	2,462
	Groundwater		11	18.99	19.02	19.13	304	304	305
Waste	Wastewater generated/treated	Mm^3	131	237.4	237.7	239.1	3,801	3,804	3,816
	Brine discharge	Mm^3	987	1,784	1,787	1,797	28,567	28,593	28,683
Cost	Discounted cost of water production & treatment	million 2015 US$	643.3	438.3	439.1	441.6	11,330	11,339	11,369
Emissions	CO_2e	million tonnes	3.3	5.92	5.93	5.97	94.86	94.95	95.25

tied to the responsibilities of Water Resources Council, as outlined below:

- *Priority-setting*: Formulation of the overall water resources policies and strategies for the country, including setting up of appropriate institutional and legislative frameworks;

- *Management:* Coordination of government water policies and ensuring integration of these policies; and

- *Monitoring:* Follow up the implementation of water policies and plans and set up priorities for the implementation of the developed strategies and programs.

Such institutional reform will have a key role in addressing the water sector challenges in Bahrain, and lead to the formulation of a clear comprehensive, integrated, national water policy and strategy. This is understood as an indispensable first step forward in the long intricate path to sustainable water management under conditions of acute water scarcity, socio-economic growth, and climate change. The rest of this section provides a brief summary of the vulnerability assessment.

Reference scenarios

Key results for the three Reference scenarios are summarized in Table 3-4. Municipal water supply in Bahrain is associated with relatively high costs (financial, economic, and environmental), and are projected to nearly double by 2035 under current policies and management approach. Water-related CO_2e emissions show a similar trend, increasing from 3.3 million tonnes in 2015 to nearly 6 million tonnes in all Reference scenarios.

Impacts of climate change

Figure 3-26 shows cumulative impacts of climate change over 2015-2035 for total municipal water use, wastewater generation/treatment, brine discharge, and desalinated water production. Key climate change impacts include:

- While climate change will lead to an additional 6.9 and 30.9 Mm^3 of cumulative water use under RCP4.5 and RCP8.5, respectively, this impact is negligible when compared to cumulative water use, reaching 0.4% under RCP8.5;

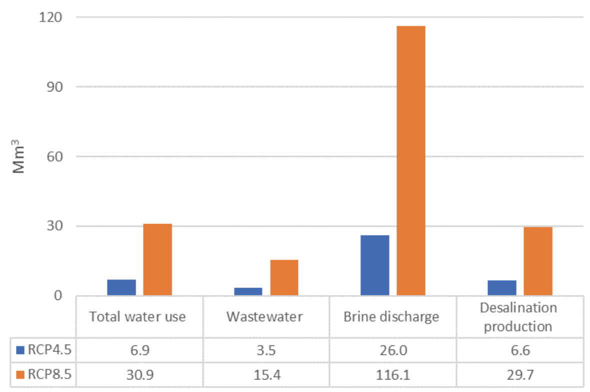


Figure 3-26: Cumulative impacts of climate change relative to the Reference scenario

- Climate change will increase desalinated water demand, thus aggravating environmental impacts on the Arabian Gulf. The need for desalinated water will increase discharges to surrounding Gulf waters of between 26 Mm^3 and 116 Mm^3 of brine under RCP4.5 and RCP8.5, respectively, increasing the salinity and temperature footprints of municipal water supply significantly;

- The impact of climate change on water-related CO_2e emissions and electricity use show similar trends. Under RCP8.5, Cumulative additional CO_2e emissions reach about 0.4 million tonnes while an additional 593 GWh of natural gas-fired electricity is required over the period; and

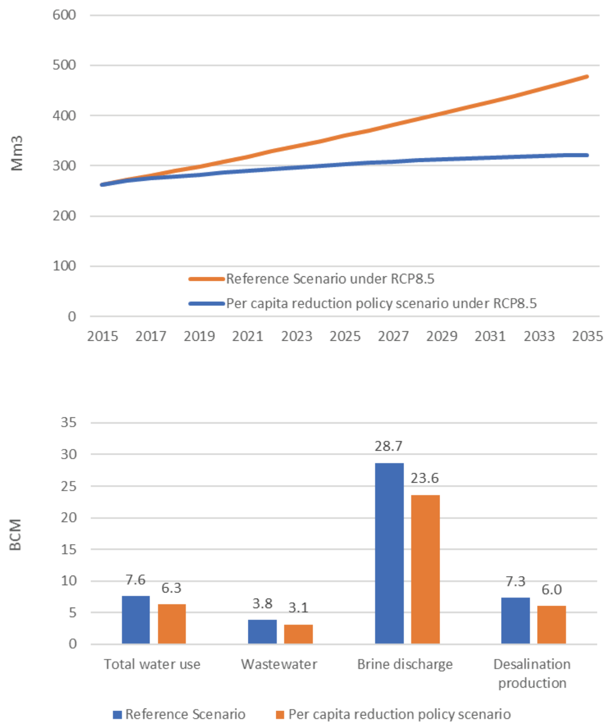


Figure 3-27: Top: Annual impacts of the per capita water demand reduction policy on municipal water demand; Bottom: Cumulative impacts of the per capita water demand reduction policy

- In absolute terms, the above impacts would also come at a significant present value cost to the Bahraini economy, totaling about US$ 8.7 cumulative discounted costs (2015$) under RCP4.5 and US$ 37.9 million cumulative discounted costs under RCP8.5. As with the other impacts of climate change on the municipal water system, these cost impacts are negligible when compared to cumulative water costs.

Impacts of reduced per capita demand policy

Figure 3-27 summarizes key results for the reduced per capita demand Policy scenario, compared to the Reference scenario, both under RCP8.5 conditions.

The top figure shows annual water consumption with and without the economic, efficiency and conservation measures to reduce per capita municipal water consumption. By 2035, total municipal water consumption with the policy is about 33% less than the Reference scenario and about 23% above 2015 levels.

The bottom figure shows cumulative levels for total municipal water use, wastewater generation/treatment, brine discharge, and desalinated water production. The cumulative reduction of 5.1 BCM of brine discharge limits the salinity and temperature footprints on surrounding Gulf waters significantly. Policy scenario levels are about 18% lower than Reference scenario levels.

In addition, reducing per capita water demand will lead to a cumulative reduction of 26 TWh of natural gas-fired electricity, which would avoid 17 million tonnes of CO_2e. These benefits come at a significant present value cost savings to the economy, totaling about US$ 1.7 billion.

Impacts of leakage mitigation policy

Figure 3-28 summarizes key results for the leakage mitigation Policy scenario, compared to the Reference scenario, both under RCP8.5 conditions. The top figure shows annual water consumption with and without the measures to reduce leakage in the municipal water distribution system. While total municipal water consumption in 2035 is about 42% higher than 2015 levels, consumption is 22% lower than what it otherwise would be in 2035. The bottom figure shows cumulative levels for total water use, wastewater generation/treatment, brine discharge, and desalinated water production. Policy scenario levels are about 13% lower than Reference scenario levels.

In addition, reducing per capita water demand will lead to a cumulative reduction of 18 TWh of natural gas-fired electricity, which would avoid 12 million tonnes of CO_2e. These benefits come at a significant present value cost savings to the economy, totaling about US$ 1.2 billion.

Impacts of both policies

Figure 3-29 summarizes key results for the Integrated Policy scenario, compared to the Reference scenario, both under RCP8.5 conditions. The integrated Policy combines both the per capita water reduction and leakage mitigation policies into a single integrated scenario that accounts for overlaps and synergies between the policies.

The top figure shows annual water consumption for each integrated policy, with and without the measures to reduce per capita water demand and leakage in the municipal water distribution system. Total municipal water consumption in 2035 is about 4% less than 2015 levels, and about 47% lower than what it otherwise would be in 2035.

The bottom figure shows cumulative levels for total water use, wastewater generation/treatment, brine discharge, and desalinated water production. The Integrated Policy scenario levels are about 27% lower

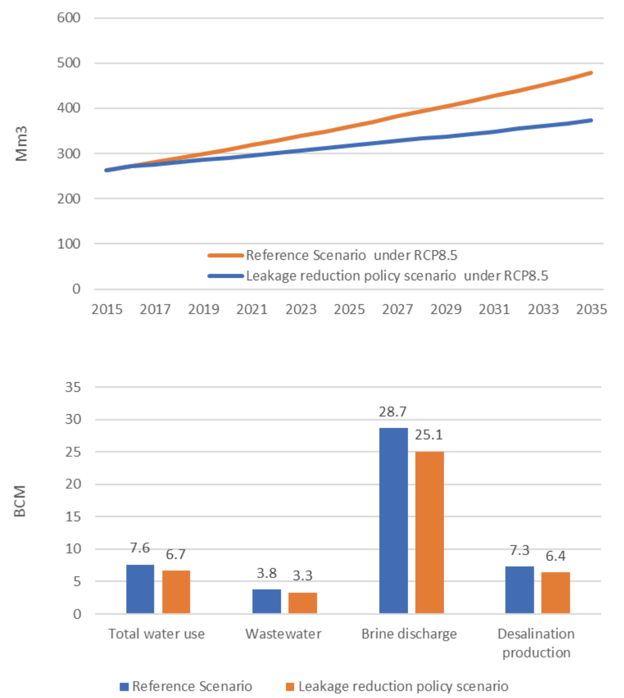


Figure 3-28: Top: Annual impacts of the leakage reduction policy on municipal water demand; Bottom: Cumulative impacts of the leakage reduction policy

than Reference scenario levels.

In addition, combining both policies will lead to a cumulative reduction of 40 TWh of natural gas-fired electricity, which would avoid 26 million tonnes of CO_2e. These benefits come at a significant present value cost savings to the economy, totaling about US$ 2.6 billion.

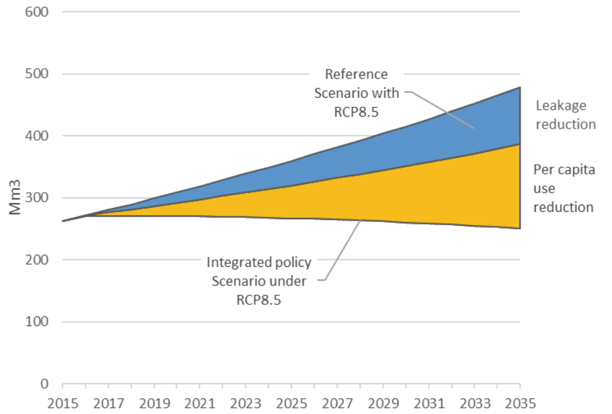
3.3.4. Adaptation implications

The current water situation in Bahrain is not sustainable. Water resource management challenges will only deepen under climate change. Issues such as groundwater depletion/salinization, rapidly increasing municipal water demand, lagging wastewater treatment/reuse plans will intensify financial, economic, environmental and social burdens in the absence of strategic adaptation interventions.
The results of the vulnerability assessment demonstrate that the main water management and planning challenge facing Bahrain is how to effectively balance water availability and water use in the long-term in the face of the escalating demands and climate change. Doing so while imposing the least economic and environmental costs and without endangering socio-economic development remains the central adaptation challenge.

Hence, the point of departure for responding the results of the vulnerability assessment is the need to focus on the demand side of water resource management. This contrasts significantly with the current policy focus emphasizing supply-side management. The two adaptation policies (i.e., per capita water reductions and leakage reductions) will not only mitigate the impacts of climate change but build an adaptive management capacity in Bahrain. Indeed, every cubic meter of water saved in the municipal sector results in energy, economic and environmental benefits.

Moreover, water demand side management will lead to benefits not addressed in the vulnerability assessment. These include reducing air pollution, reducing environmental burdens on human health, and protecting marine ecosystem services. Subsequent vulnerability assessments are needed to explore and quantify these benefits.

Several key recommendations for future adaptation planning in Bahrain are outlined in the bullets below



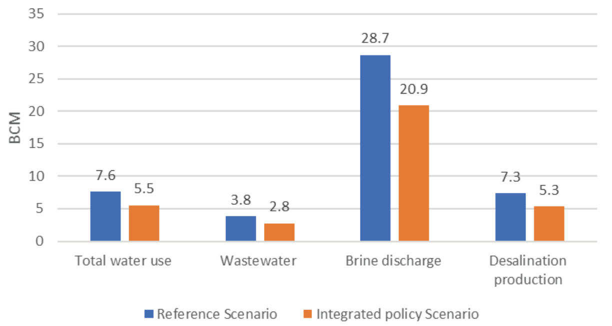


Figure 3-29: Top: Annual impacts of the integrated policies on municipal water demand; Bottom: Cumulative impacts of the integrated policies

- *Urgent action needed:* It is imperative for the Kingdom of Bahrain to formulate a clear, comprehensive, and integrated water resources policy and strategy in order to manage its water resources efficiently and obtain a considerable degree of sustainability under conditions of climate change. Institutional reforms that build upon the reactivation of the National Water Resources Council in 2016 are essential.

- *Protect groundwater resources:* Further deterioration of groundwater resources should be addressed by establishing a cooperation mechanism between Bahrain and Saudi Arabia in the development and management of transboundary groundwater resources, including groundwater artificial recharge/storage enhancement using surplus tertiary treated wastewater.

- *Enhance modeling work:* Two improvements in the modeling approach are recommended. First, a stochastic methodology should be applied in future modeling work to better understand uncertainty. The deterministic modeling approach used in the current study is limited in its ability to adequately represent the level of uncertainty in the results. Second, previous groundwater modeling that addressed sea level rise impacts on the aquifer should be updated and integrated within the WEAP model. This will enable dynamic modeling of the groundwater system with non-conventional water sources and their interaction.

- Expand water sector coverage: The vulnerability assessment focused on the municipal sector, with limited accounting of water use in the agricultural and industrial sectors. This was necessary due to absence of data. While water use in these two sectors is significantly less than that of the municipal sector, with limited interaction with the rest of the water resource system, there are as yet unexplored opportunities for efficiency and conservation.

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4. Greenhouse Gas Mitigation

4. Greenhouse Gas Mitigation

In 2015, Bahrain submitted its Intended Nationally Determined Contribution (INDC) toward confronting the challenge of climate change. The INDC committed to a set of measures for reducing the future growth of GHGs in the country. This chapter presents an overview of how these commitments have been codified into concrete action plans for increasing energy efficiency across the economy as well as promoting an increased role for renewable energy. Some of the major implications for greenhouse gas mitigation are summarized in the sections below based on a GHG mitigation analysis of these action plans (AlSabbagh, 2019).

4.1. Background

As discussed in Chapter 1, Bahrain's Economic Vision 2030, provides a long-term vision to reduce dependence on oil & gas, pursue economic diversification, and promote environmental quality. Specifically, the vision calls for the development of sustainable energy strategies that will lead to reductions in carbon emissions. To operationalize this vision, as well as reflect commitments under the INDC, concrete action plans have been established to increase the role of energy efficiency and renewable energy in the country.

4.1.1. Energy efficiency

The National Energy Efficiency Action Plan (NEEAP) lays out a comprehensive set of initiatives to increase energy efficiency potential in Bahrain. The Plan was prepared by the Sustainable Energy Unit which has recently been transformed by Royal Decree 22/2019 which established the Sustainable Energy Center (SEC). The SEC is an independent centre, which reports directly to Cabinet via the Minister of Electricity and Water Affairs. The SEC replaces the previous Sustainable Energy Unit (SEU) which had been established in 2014. The NEEAP was prepared in consultation with a wide range of stakeholder groups, including the National Oil and Gas Authority; all line ministries, the Supreme Council for the Environment; the Bahrain Defense Force; large industry groups; and academia (SEU, 2017a). It has been officially endorsed through Cabinet Resolution No 2392-1.

NEEAP identifies specific programs and new initiatives across various sectors to achieve a national target for energy savings. Implementation modalities, governance mechanisms, and monitoring protocols are described in detail within the Plan. In all, 22 initiatives have been established that together will contribute to a reduction in energy use of 6% by 2025 relative to average energy use over the period 2009-2013. On a primary energy equivalent basis, this amounts to savings of 5,792 GWh (or 498 kTOE) by 2025.

4.1.2. Renewable energy

The National Renewable Energy Action Plan (NREAP) complements NEEAP by identifying feasible renewable energy options for Bahrain, establishing targets, and proposing actions to harness renewable energy opportunities (SEU, 2017b). It represents concrete action to support the sustainable energy transition outlined in Economic Vision 2030. The Plan was also prepared by the SEU and relied extensively upon a similarly wide range of stakeholder groups. It has been officially endorsed through Cabinet Resolution No 2392-1.

NREAP identifies specific policies and technologies to create a renewable energy market and achieve a national target for renewable electricity generation. The plan addresses ways to foster an enabling environment to attract future investment in renewables, including strategies to overcome regulatory and market barriers. The plan also identifies a set of specific policies to incentivize increasing the share of renewable energy throughout the economy.

In all, 3 policies have been established that together will contribute to a national renewable energy target of 5% of peak capacity by 2025 and 10% by 2035, relative to the projected peak capacities in those years. On an electric generation basis, this amounts to 478 GWh and 1,456 GWh of renewable electricity by 2025 and 2035, respectively.

4.2. Approach

Considered individually or together, the policies and measures established under the NEEAP and NREAP will lead to significant levels of annual avoided CO_2e emissions. The scope of the GHG mitigation assessment focused on these plans due to the prominence of energy in the GHG emission profile of Bahrain. As discussed earlier in Chapter 2, the energy sector accounts for nearly 70% of all GHGs emitted in Bahrain, much of which is associated with the very activities and sectors targeted by the Plans.

Hence, the goal of the GHG mitigation assessment was to codify the energy efficiency and renewable energy targets, of both Plans within an integrated energy modeling framework. The outputs of the assessment provide a basis to understand details regarding annual CO_2e emission reductions, sectoral impacts, synergies across policies and other details. The analytical framework provides a useful basis to analyze additional policies and measures going forward.

The rest of this section describes the overall methodology for the assessment, including the analytical framework policies analyzed, energy savings modeled, and renewable energy capacity additions.

4.2.1. Analytical framework

The Long-range Energy Alternatives Planning (LEAP) modeling tool was used to estimate future annual CO_2e emission reductions associated with implementation of the NEEAP and NREAP. A 4-step process was followed, as outlined below:

- *Model setup:* An integrated representation of the Bahrain energy system was developed using LEAP. The Bahrain energy model represented all energy demand sectors and current/planned energy supply sources. A Base Year of 2015 was assumed, with an End Year of 2030 to be consistent with the planning period in Economic Vision 2030.

- *Model validation:* The Bahrain energy model was validated against the results of the GHG inventory for the period 2006-2015. The model was able to reproduce the estimates from the inventory to reasonable accuracy (i.e., an average difference over 2006-2015 in CO_2e emissions of less than 2%). As a result, it was considered a valid model for simulating the impact on future GHG emissions from energy efficiency and renewable energy initiatives.

- *Scenario construction:* The Business-As-Usual (BAU) scenario assumed no major policy changes in the future and incorporated currently planned capacity additions and industrial production increases. A summary of key assumptions is provided in Table 4-1. Three mitigation scenarios were developed. The energy efficiency scenario considered NEEAP initiatives only; the renewable energy scenario considered NREAP renewable capacity additions only; and the combined scenario considered both energy efficiency initiatives and renewable energy capacity additions from the Plans.

- *Emissions accounting:* Consistent with the GHG inventory, IPCC default values were used for emission factors, carbon content, and net heating value. Calculations of annual CO_2e emissions under the scenarios were carried out using 100-year GWPs as recommended by the IPCC in its Fourth Assessment Report.

Table 4–1: Major assumptions underlying the BAU scenario in the Bahrain LEAP model

Parameter	Assumption	
Electricity demand growth	• Only the 2016 electricity tariff increases are reflected	• Average annual electricity production grows at 2.3%/yr; 2015-2030
Levelized cost of electricity (US cents/kWh)	• 8.17 - Generation • 0.87 - Transmission • 0.97 - Distribution • 10.02 - Total	
Fuel use growth	• Alba natural gas use of 14.8 Mm3/d from 2020-2030	• BAPCO refined oil production increases to 360,000 barrels/day; 2021-2030
Capacity additions (natural gas; cogeneration)	• 350 MW AlDur (2019) • 1,000 MW AlDur (2021) • 1,131 MW AlDur2 (2028) • 1,750 MW Abu Jarjour (2024)	• 5 MW solar/wind power station (2019)
Retirements	• Sitra 125 MW (2024) • Riffa 700 MW (2024)	
T&D losses	• Losses of 9.8% assumed constant over 2015-2030	

4.2.2. Energy efficiency initiatives

A total of 22 energy efficiency initiatives across 5 key sectors are part of the NEEAP and were incorporated into the GHG mitigation assessment. In addition, several supporting measures that are cross-cutting in nature were analyzed. These are identified in Figure 4-1 (top) together with the projected energy savings by 2025 for each sector to meet the national target. To integrate the savings into the Bahrain energy model, these levels were assumed to be constant over the 2026-2030 period. Figure 4-1 (bottom) shows total primary energy savings for each sector over the period 2015-2030

Two estimates of energy savings potential were developed by the NEEAP process. Identified energy savings correspond to the maximum amount of energy savings that is cost effective. Target energy savings, as are shown in Figure 4-1, correspond to the amount of energy savings achieved through the

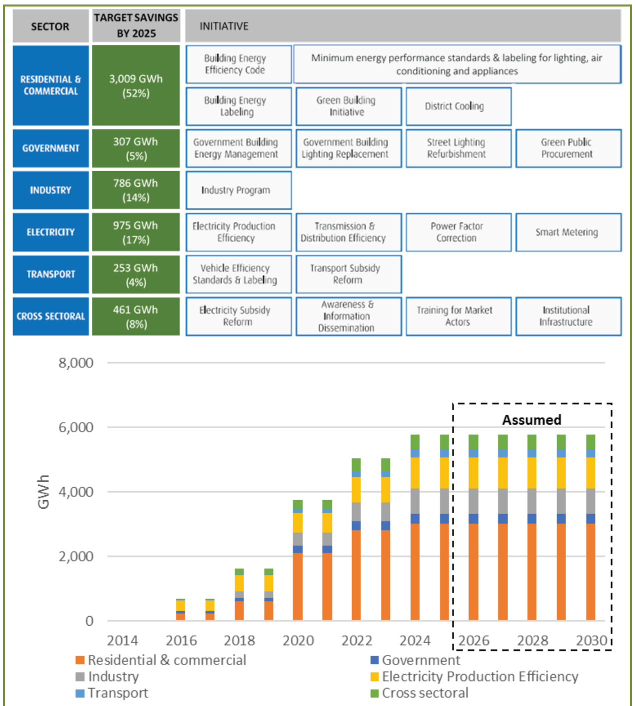

Figure 4-1: Top: Energy efficiency measures by sector considered in the GHG mitigation assessment; Bottom: Annual primary energy savings for all initiatives (adapted from SEU, 2017a)

actual implemented initiatives to meet the national target. Each of the initiatives is briefly described in the subsections below relative to target energy savings. Residential and commercial initiatives

Residential and commercial properties account for about 93% of Bahrain's total building stock. Combined, the residential and commercial sectors consume about 87% of annual electricity consumption, the majority of which is devoted to meet space cooling needs. These sectors are projected to increase substantially in the future to keep pace with socioeconomic growth. The housing sector, in particular, is projected to grow at roughly 5.4% per year between today and 2030.

There were 5 major initiatives that were considered, as described in the bullets below.

- *Building energy efficiency codes:* This initiative aims to reduce energy demand in buildings by putting in place comprehensive mandatory energy efficiency specifications for the construction of new buildings and renovation of existing buildings.

- *Minimum energy performance standards and labeling for lighting, air conditioning, appliances:* This initiative implements minimum energy performance standards (MEPS) for household and commercial lamps, small and large air conditioning units, and appliances. It also makes energy performance an explicit part of the purchase decision through energy labeling. In September 2015the MEPS for household lamps were implemented, while MEPs for small air conditioning were implemented in 2016.

- *Building energy labeling:* This initiative aims to reduce energy consumption in buildings through making energy performance of buildings explicit through the use of building energy labels.

- *Green building certification:* This initiative aims to promote the construction of more resource-efficient buildings by establishing a green building certification program.

- *District cooling:* This initiative aims to revitalize and expand the existing capacity of district cooling in Bahrain, by establishing a regulatory framework.

Figure 4-2 (top) summarizes projected target energy savings over the 2015-2030 period for the residential and commercial sectors. By 2025, projected annual savings total 3,009 GWh, or about 52% of the target. Cumulative energy savings total 32,655 GWh through 2030, with building energy efficiency codes and MEPS & labeling providing 56% and 41% of the savings, respectively. Figure 4-2 (bottom) summarizes the present value of the costs and benefits over the 2015-2030 period, showing cost savings for each measure. The present value of net savings for all residential and commercial energy efficiency measures is US$ 554 million.

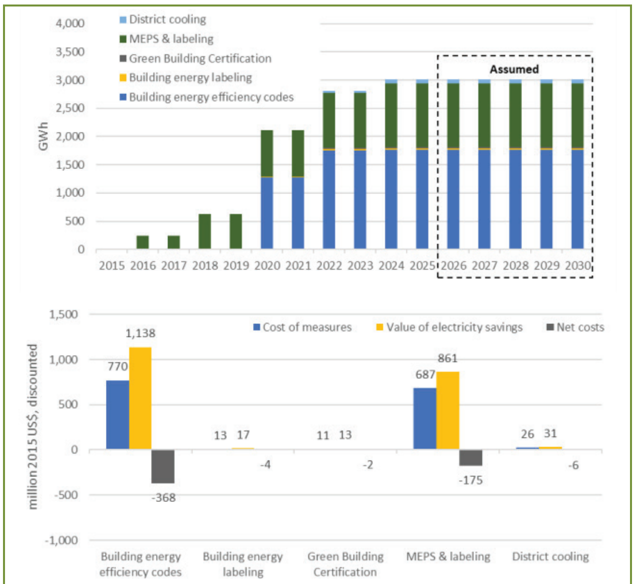

Figure 4-2: Top: Target residential & commercial primary energy savings, 2015-2030; Bottom: Costs and benefits associated with target primary energy savings in residential & commercial sectors

Government initiatives

Bahrain's government sector will play a strategic role in promoting energy efficiency through the exercise of its purchasing power and leading by example. The government sector consists of governmental, non-commercial state bodies, the defense force, the police, hospitals and other health facilities, local municipalities, schools and universities, as well as housing for which the Ministry of Housing is responsible.

There were 4 major initiatives that were considered, as described in the bullets below.

- *Government Buildings Energy Management:* This initiative aims to pursue energy efficiency on a continuous basis in government buildings by establishing an energy management system for government buildings.

- *Government Buildings Lighting Replacement:* This initiative aims to improve the energy efficiency of lighting in all government premises.

- *Street Lighting Refurbishment:* This initiative aims to improve energy efficiency in street lighting through the replacement of existing high-pressure sodium lamps with LED lamps.

- *Green Public Procurement:* This initiative aims to improve energy efficiency in government operations through requiring all public institutions to give preference to energy efficient and sustainable products when purchasing products, equipment and services.

Figure 4-3 (top) summarizes projected target energy savings over the 2015-2030 period for the government sector. By 2025, projected annual savings total 307 GWh, or about 5% of the target. Cumulative energy savings total 3,455 GWh through 2030, with street lighting refurbishment and green public procurement accounting for 35% and 30% of savings, respectively. Figure 4-3 (bottom) summarizes the present value of the costs and benefits over the 2015-2030 period, showing cost savings for each measure. The present value of net savings for all governmental energy efficiency measures is US$ 45 million.

Industrial initiatives

Bahrain's industrial sector contributes over 40% to GDP, and in 2014 employed over 16% of the workforce (SEU, 2017a). It is also the largest single energy consuming sector, typically accounting for

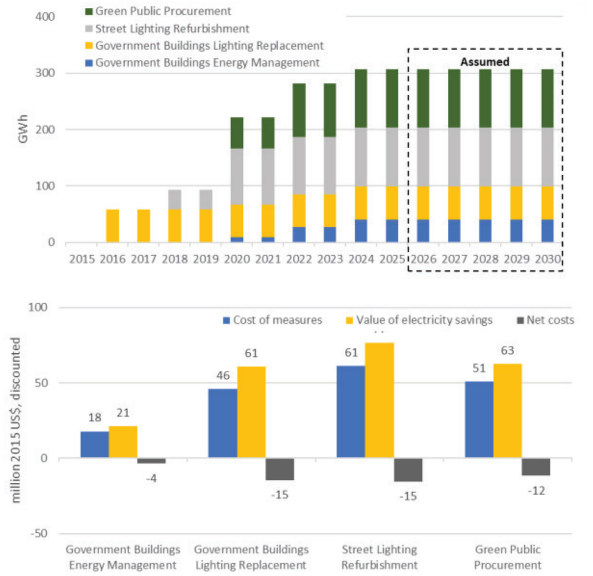

Figure 4-3: Top: Target governmental primary energy savings, 2015-2030; Bottom: Costs and benefits associated with target primary energy savings in government sector

about 41% of total energy use. While many industrial facilities provide their own electricity through on-site generation facilities, they still account for over 10% of annual grid electricity sales. There was a single initiative considered, as described below.

- *Industry Program:* This initiative aims to drive a 1% improvement in annual energy consumption to reach a 4% energy efficiency improvement by 2020.

The Industry Program initiative has a three-fold purpose: to coordinate the energy efficiency activities of the major industry players and large energy consumers; to share best practice between the

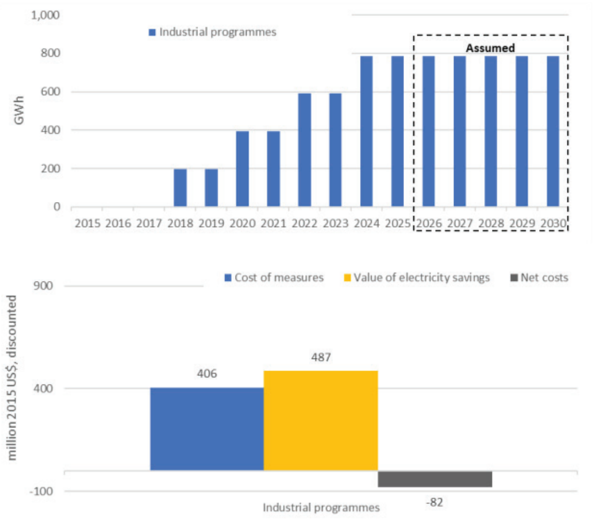

Figure 4-4: Top: Target industrial sector primary energy savings, 2015-2030; Bottom: Costs and benefits associated with target primary energy savings in industrial sector

companies through workshops and other knowledge-sharing activities; and to facilitate the collection of energy saving data between the companies and SEU, in order to demonstrate that each party is making progress towards meeting its target (SEU, 2017a).

The industry programme has two parts. First, the five major energy users that dominate the sector (i.e., ALBA for aluminum smelting; GPIC for chemicals; BAPCO for oil refining; Tatweer for oil and gas operations, and Bahrain Steel will sign a compact with the Minister of Electricity and Water Affairs, committing to meeting the energy savings targets. Other major companies and large energy consumers will also sign the compact. Second, a network will be introduced to help coordinate and share best practice between the members.

Figure 4-4 (top) summarizes projected target energy savings over the 2015-2030 period for the industrial sector. By 2025, projected annual savings total 786 GWh, or about 14% of the target. Cumulative energy savings total 7,862 GWh through 2030. Figure 4-4 (bottom) summarizes the present value of the costs and benefits over the 2015-2030 period, showing cost savings for the initiative. The present value of net savings for industrial energy efficiency measures is US$ 82 million.

Electricity initiatives

The electricity sector typically accounts for about half of primary energy use in Bahrain and has been growing at about 4% per year. Electricity initiatives include supply side measures to reduce losses for both the production and transmission & distribution

(T&D), as well as demand side measures to better manage daytime peak consumption. There were 4 major initiatives that were considered, as described in the bullets below.

- *Electricity Production Efficiency:* This initiative aims for a 1% improvement by 2025 in combustion. It will accomplish this through a number of complementary measures including reducing reliance on least efficient plants; using aggregated demand reduction/response as an alternative to new capacity; using demand side frequency response as an alternative to spinning reserve; and using real-time tariffs to better utilize existing capacity.

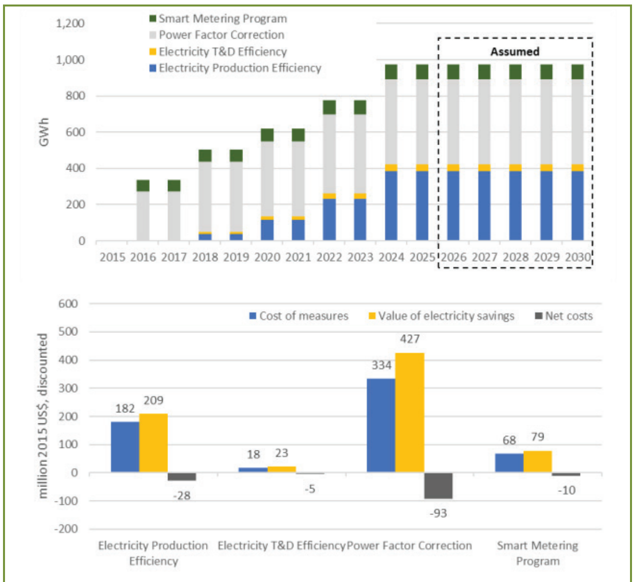

Figure 4-5: Top: Target electric sector energy savings, 2015-2030; Bottom: Costs and benefits associated with target primary energy savings in power supply sector

- *Electricity T&D Efficiency:* This initiative aims to improve the efficiency of the electricity delivery system and reduce current system losses of 9.8%. It will involve conducting dynamic line rating trials; using capacity banks and battery storage to better manage the system; and upgrading conductors, transformers and cables.

- *Power Factor Correction:* This initiative aims to improve the power factor to be 0.9 or greater. A low power factor can result in overall higher electricity consumption due to overheating of equipment; low efficiency of connected devices; and high voltage drops in alternators and transformers.

- *Smart Metering Program:* This initiative aims to introduce smart meters to high electricity consumers and new developments. Smart meters record electricity use and communicates the information to the electricity supplier for monitoring. It promotes better ability to manage daytime consumption peaks and electricity consumption through the use of real-time pricing.

Figure 4-5 (top) summarizes projected target energy savings over the 2015-2030 period for the electric sector. By 2025, projected annual savings total 975 GWh, or about 17% of the target. Cumulative energy savings total 11,293 GWh through 2030, with power factor correction and electricity production efficiency improvements accounting for 56% and 31% of savings, respectively. Figure 4-5 (bottom) summarizes the present value of the costs and benefits over the 2015-2030 period, showing cost savings for each measure.

The present value of net savings for all electric sector energy efficiency measures is US$ 135 million.

Transport initiatives

The transport sector typically accounts for about 31% of primary energy use in Bahrain and has been growing rapidly, at about 5.3% per year, a rate that exceeds both population and GDP growth rates. Most travel is by personal vehicle and fuel prices are heavily subsidized. Until recently, public transport infrastructure has been minimal. Transport initiatives include market-based measures that send better fuel price signals to drivers, as well as regulatory measures to advance high efficiency vehicle purchases, as described in the bullets below.

- *Transport Subsidy Reform:* This initiative aims for a 4% reduction in annual fuel use in the light duty vehicle fleet. It will accomplish this through modification to the retail price of gasoline and diesel fuel, a reform process that has been underway since 2016. The price of regular grade gasoline (91 Octane) is being increased by 42%, from US$ 0.21 to US$ 0.30, while the price of premium grade gasoline (95 Octane) is being increased by 60%, from US$ 0.26 to US$ 0.42.

- *Vehicle Efficiency Standards & Labeling:* This initiative aims to improve efficiency in the transport sector by setting minimum fuel economy standards for light duty vehicles; and by making vehicle fuel economy an explicit part of the purchase decision by ensuring that labels are appropriately displayed thereby increasing consumer awareness. The fuel economy labels for light duty vehicles were implemented on all new vehicles of model 2018.

Figure 4-6 (top) summarizes projected target energy savings over the 2015-2030 period for the transport sector. By 2025, projected annual savings total 22 kTOE (253 GWh), or about 4% of the target. Cumulative energy savings total 219 kTOE (2,549 GWh) through 2030, with fuel subsidy reforms accounting for 74% of the savings. Figure 4-6 (bottom) summarizes the present value of the costs and benefits over the 2015-2030 period, showing cost savings for each measure. The present value of net savings for all governmental energy efficiency measures is US$ 55 million.

Cross sectoral initiatives

These initiatives refer to actions that can support the implementation of the previous measures by establishing an enabling environment. Hence, cross-sectoral initiatives include actions to overcome barriers to energy efficiency such as lack of awareness, competing priorities, hidden costs, and access to timely and accurate information.

There were 4 major initiatives that were considered, as described in the bullets below.

Electricity Subsidy Reform: This initiative aims to gradually increase electricity tariffs to reflect the actual costs of power generation and promote more efficient electricity consumption. Electricity tariff reform has been underway since 2016. For the first 3,000 kWh per month, the residential rate will be gradually increased from US$ 0.008/kWh to US$ 0.08/kWh by 2019. For consumption above 5,000 kWh per month, the industrial rate will be gradually increased from US$ 0.04/kWh to US$ 0.08/kWh by 2019. When the effects of these new tariffs are fully realized, they are projected to result in a 14% reduction in electricity use compared to the 2009 – 2013 baseline.

- *Raising Awareness & Information Dissemination:* This initiative aims to augment information campaigns that focus on ways to reduce energy use, including habits and behaviors that should be modified and energy-consuming equipment and appliances that should be replaced.

- *Training for Market Actors:* This initiative aims to build and increase capacity in the energy services market, including energy efficiency training, accreditation and certification programmes

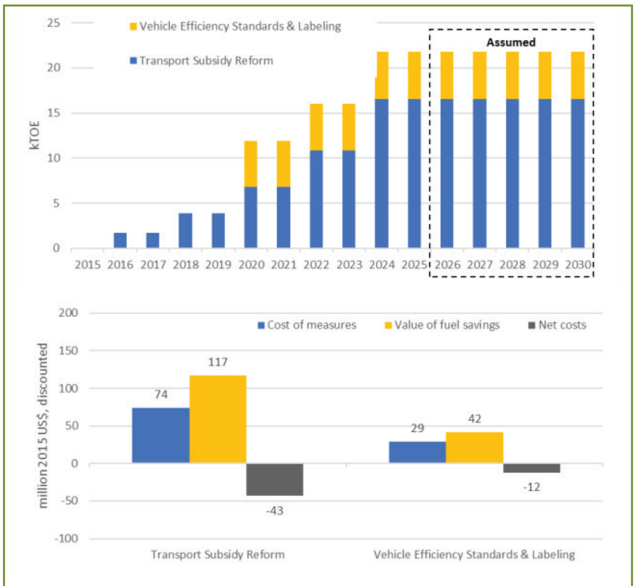

Figure 4-6: Top: Target transport sector energy savings, 2015-2030; Bottom: Costs and benefits associated with target primary energy savings in transport sector

tailored to energy auditors, energy managers and energy service providers.

- *Institutional Infrastructure:* This initiative aims strengthen institutional capacity to implement the various initiatives for achieving the national energy efficiency target. Its focus will be on the SEU as the designated agency to coordinate implementation of the NEEAP.

Figure 4-7 (top) summarizes projected target energy savings over the 2015-2030 period for cross-cutting initiatives. By 2025, projected annual savings total 461 GWh, or about 8% of the target. Cumulative energy savings total 4,969 GWh through 2030, with electricity subsidy reforms accounting for 77% of the savings. Figure 4-7 (bottom) summarizes the present value of the costs and benefits over the 2015-2030 period, showing cost savings for each measure. The present value of net savings for all governmental energy efficiency measures is US$ 54 million.

4.2.3. Renewable energy initiatives

Currently the share of renewable energy in Bahrain's electricity generation mix is negligible. To date, there have been two pilot projects: a 0.5 MW building-integrated wind project at the Bahrain World Trade Center; and BAPCO's 5 MW solar PV system deployed at three locations.

Yet, Bahrain has significant renewable energy potential, as outlined in the bullets below.

- *Solar:* Average solar radiation has been estimated at about 5.2 kWh/m²/day, with an average sunshine duration of 9.2 hours (Alnaser, et al., 2014).

- *Onshore wind:* Preliminary wind mapping findings show large areas of the country with average annual wind speeds at 50 meters of 6.0 meters per second, indicating Bahrain has a wind resource suitable for power generation (SEU, 2017b).

- *Offshore wind:* Bahrain has shallow waters suggesting offshore wind could be a cost-competitive option if the resource potential is confirmed through subsequent studies to be as favorable as the onshore potential.

- *Biogas:* With more than 1.7 million tonnes of mostly organic municipal solid waste landfilled each year, biogas energy generation through anaerobic digestion can yield benefits as both a renewable energy source and sustainable waste management practice.

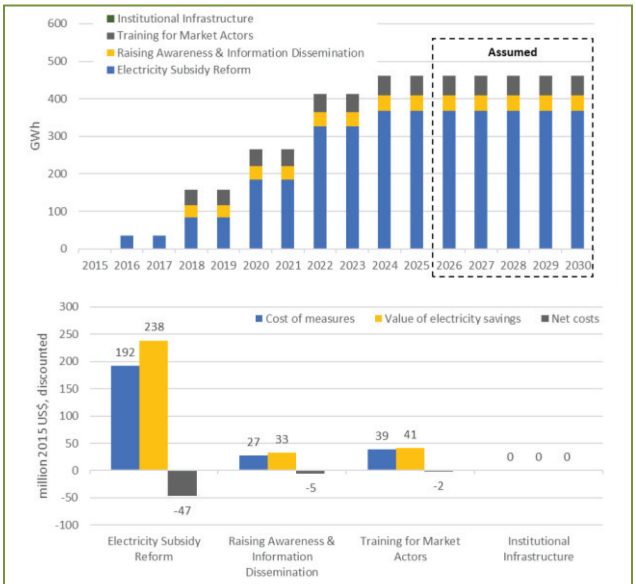

Figure 4-7: Top: Target cross-cutting energy savings, 2015-2030; Bottom: Costs and benefits associated with target primary energy savings for cross-cutting initiatives

To tap into these renewable resources, the NREAP identified 3 policies to achieve a national renewable energy target of 5% of peak capacity by 2025 and 10% by 2035. The combined impact associated with the implementation of these policies have been included in the GHG mitigation assessment. Renewable capacity additions in 2030 were interpolated from the above targets. Figure 4-8 identifies the specific policies together with the corresponding type of renewable energy capacity installed and annual renewable electricity generation in 2025 and 2035. Each of these renewable resources are briefly described in the subsections below.

Solar PV initiatives

Solar PV systems will be deployed as decentralized renewable energy applications in urban areas as well as large-scale installations on available land. Decentralized

POLICY	PEAK LOAD CAPACITY ADDITIONS (MW)		INCREMENTAL GENERATION (GWH)	
	BY 2025	BY 2035	BY 2025	BY 2035
Net Metering Tender-based feed-in tariffs Renewable energy mandate for new buildings	• Solar PV: 200 • Onshore wind: 50 • Offshore wind: 0 • Biogas: 5	• Solar PV: 400 • Onshore wind: 250 • Offshore wind: 50 • Biogas: 10	• Solar PV: 340 • Onshore wind: 125 • Offshore wind: 0 • Biogas: 13	• Solar PV: 680 • Onshore wind: 625 • Offshore wind: 125 • Biogas: 26
	Total: 255 (5% of peak load capacity	Total: 710 (10.3% of peak load capacity)	Total: 478 (2% of generation)	Total: 1,456 (4.6% of generation

Figure 4-8: Policy-induced renewable electricity penetration levels considered in the GHG mitigation assessment (adapted from SEU, 2017b)

applications include the following:

- Solar systems for new housing units;
- Solar systems for government buildings;
- Decentralized solar in urban developments (solar lighting, solar parking); and
- Decentralized rooftop solar on existing residential and commercial buildings.
- Large-scale installation opportunities on available land include the following:
- Utility-scale renewable solar PV farms by large industry groups; and
- Solar farms in new town developments.

The costs for solar PV systems have dropped significantly over the past decades. By 2025 in Bahrain, the levelized cost of energy at a weighted average cost of capital of 7.5% is projected to be between US$ 0.049/kWh and US$ 0.063/kWh (SEU, 2017b). By 2035, this cost is projected to drop to between US$ 0.036/kWh and US$ 0.055/kWh. For the GHG mitigation assessment, the average levelized cost of electricity for solar PV systems was assumed to be $0.058/kWh.

Figure 4-9 (top) summarizes projected target capacity additions over the 2015-2030 period for solar PV. By 2030, projected capacity totals 300 MW, generating about 510 GWh. Figure 4-9 (bottom) summarizes the present value of the costs and benefits over the 2015-2030 period, showing cost savings of US$ 83 million.

Onshore wind initiatives

Aside from some micro wind opportunities in urban areas, onshore wind systems will be mostly deployed as large-scale installations on available land. These opportunities on available land include the following:

- Utility-scale wind farms by large industry groups; and
- Wind farms on other available land.

The costs for onshore wind systems have also dropped significantly over the past decades. Levelized cost of energy can vary substantially depending on the wind

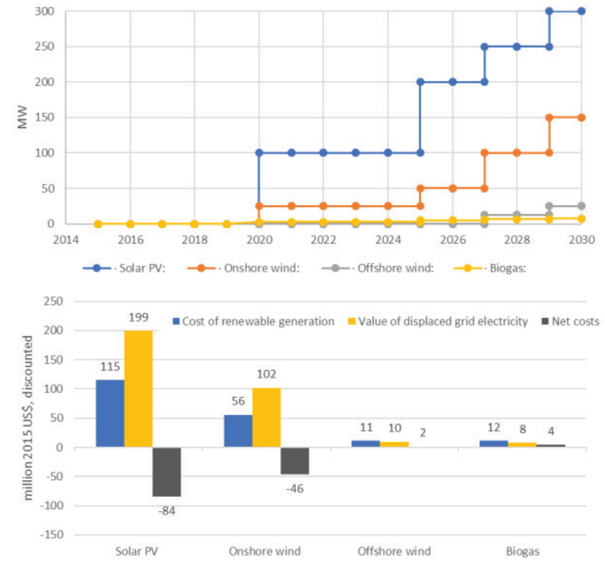

Figure 4-9: Top: Assumed renewable capacity expansion plan; Bottom: Costs and benefits associated with target renewable energy generation

regime. By 2025, installed costs of onshore wind could fall by 12% by 2025, resulting in a 34% reduction of today's levelized cost of onshore wind energy (SEU, 2017b). For the GHG mitigation assessment, the average levelized cost of electricity from onshore wind farms was assumed to be $0.055/kWh, consistent with estimates available from the US Energy Information Administration (USEIA).

Offshore wind

Offshore wind systems will be mostly deployed as large-scale installations on available land. These opportunities on available land include the following:

- Near shore or offshore wind farms; and
- Integrating renewable energy technologies in large infrastructure projects (causeways and railway systems).

The costs for offshore wind systems are typically between 1.5 and 3.3 times onshore wind system costs due to the fact that marine environment exposes the units to high humidity, salt water, and salt-water spray making installation and operation and maintenance more challenging (SEU, 2017b). For the GHG mitigation assessment, the average levelized cost of electricity for offshore wind farms was assumed to be $0.118/kWh (USEIA, 2018).

Figure 4-9 (top) summarizes projected target capacity additions over the 2015-2030 period for offshore wind. By 2030, projected capacity totals 25 MW, generating about 62 GWh. Figure 4-9 (bottom) summarizes the present value of the costs and benefits over the 2015-2030 period, showing net costs of US$ 2 million.

Biogas initiatives

Biogas systems will be deployed as large-scale installations on available land. Opportunities include landfill gas capture at the Askar landfill site and a waste-to-energy plant at the Tubli wastewater treatment plant.

The costs for biogas systems are highly dependent on economies of scale. Current estimates are between US$ 0.14/kWh and US$ 0.17/kWh. For the GHG mitigation assessment, the average levelized cost of electricity for biogas systems was assumed to be $0.155/kWh (USEIA, 2019).

Figure 4-9 (top) summarizes projected target capacity additions over the 2015-2030 period for biogas systems. By 2030, projected capacity totals 7.5 MW, generating about 20 GWh. Figure 4-9 (bottom) summarizes the present value of the costs and benefits over the 2015-2030 period, showing net costs of US$ 4 million.

4.3. Results

Table 4-2 provides an overall summary of the costs and benefits associated with the energy efficiency and renewable energy initiatives of the NEEAP and NREAP. The following bullets highlight key findings:

- *CO_2e reductions:* The 22 energy efficiency initiatives provide most of the cumulative emission reductions, about 77%, over 3 times the cumulative emission reductions from renewable energy initiatives.

- *Investment costs:* Both the energy efficiency and renewable energy initiatives can be implemented at substantial cost savings to society. The net present value of cost savings from energy efficiency investments is nearly US$ 1 billion, roughly 8 times that of renewable energy.

- *Costs of avoiding carbon:* While both energy efficiency and renewable energy investments reduce carbon emissions while also reducing costs, energy efficiency is roughly 2.3 times more cost-effective per unit of carbon avoided.

Figure 4-10 (top) provides a summary of the change in annual primary energy in the combined scenario. Figure 4-10 (bottom) provides a summary of annual carbon emission reductions in the combined scenario. Annual emission reductions in 2030 in the combined scenario, while representing a substantial impact in absolute terms (i.e., 1.9 million tonnes), are small relative to overall projected emissions in 2030 across the Bahrain economy in that year. The impact of the NEEAP and NREAP is more significant when only the electric sector – where most of the savings are based - is considered. On a primary energy basis, electric generation reaches 88,254 GWh in the BAU scenario in 2030. The 20 energy efficiency initiatives result in 5,538 GWh in savings while renewable energy displaces another 3,383 GWh in that year. Combined, this represents about 10.8% of BAU grid electricity in that year. Cumulatively over 2015-2030, energy efficiency measures lead to 55,301 GWh of reductions, with another 19,349 GWh of grid electricity displaced by electricity from renewables.

4.4. Next steps

Additional CO_2e reductions could be achieved through deepening energy savings across the 22 options up to the identified savings, which would annually result in about 1.6 million tonnes in additional CO_2e reductions when fully implemented, or an additional 17.6 million tonnes, cumulatively over the 2015-2030 period.

While not accounted for in the current GHG mitigation assessment, additional CO_2e reductions could be achieved through introducing other types of initiatives. This is particularly true for the oil and gas, transport, and residential sectors, where additional annual emission reductions of about 0.329 million tonnes of CO_2e. These initiatives are outlined in the bullets below and summarized in Table 4-3.

- *Oil & gas sector:* A total of 16 efficiency and renewable energy projects are planned for 2017–2025. When fully implemented, these projects would annually lead to reductions of about 0.165 million tonnes of CO_2e.

Table 4–2: Costs and benefits associated with energy efficiency and renewable energy generation targets

Scenario	CO_2e reductions (million tonnes) In 2025	In 2030	2015-2030	Costs (million PV 2015 US$)	Cost of Saved Carbon (2015 US$/t$CO_2e$ saved)
Energy efficiency	1.2	1.2	12.8	-926	-72
Renewable energy	0.3	0.7	3.9	-123	-32
Combined efficiency & renewable	1.5	1.9	16.7	-1,050	-63

- *Transport sector:* A total of 8 Several initiatives have been investigated relative to their emissions reduction potential (AlSabbagh, 2018, 2019; AlSabbagh et al., 2017). When fully implemented, these projects would annually lead to reductions of about 0.164 million tonnes of CO_2e.

- *Residential sector:* A total of 2 initiatives have been investigated relative to their emissions reduction potential (AlSabbagh, 2018). When fully implemented, these projects would annually lead to reductions of about 0.001 million tonnes of CO_2e.

Furthermore, there are numerous other initiatives planned or underway in Bahrain which have not yet been assessed relative to their GHG reduction potential. These include the National Air Quality Strategy which calls for deployment of more efficient combustion technologies, such as combined cycle gas turbines and combined heat and power generation; a carbon recovery plant by BAPCO in which CO_2-rich waste stream gas would be used for industrial applications, and a carbon recovery project by GPIC in which CO_2 in the flue gases of a methanol plant would be captured (GoB, 2015).

There are several high-level policy implications and recommendations that have emerged from the national GHG mitigation assessment. These are briefly outlined in the subsections below relative the work of policymakers, practitioners, and researchers.

4.4.1. Policymakers

Assigning clear mandates to a responsible authority constitutes the first step toward successfully addressing and managing climate change and this step has already been accomplished. In 2007, the Joint National Committee on Climate Change was initiated. In addition to the assigned fundamental tasks of the Committee, the following actions are recommended.

- *Climate change strategy:* This is the first fundamental task of the Committee, which is still in process. The strategy is critical for promoting climate-resilient green growth.

- *Priority-setting:* A set of priorities could be established regarding GHG mitigation research, capacity building, and funding for green energy innovation.

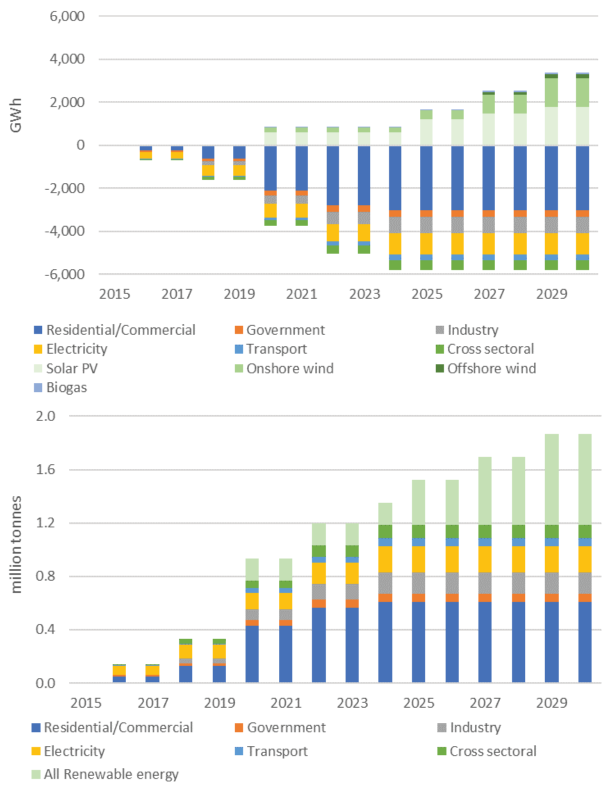

Figure 4-10: Top: Annual change in primary energy use in the combined scenario; Bottom: Annual CO_2e reductions in the combined scenario

- *CO_2e emission reduction targets:* Concrete emission reduction targets could be established that reflect substantial cost-effective mitigation opportunities across the economy.

- *Carbon emission credits:* An emissions reduction fund could be established where emitters are granted credits for projects that reduce verifiable carbon emissions. When validated, the government would purchase these credits to encourage further reductions. These credits could be financed by the removal of electricity tariff subsidies.

- *Industrial energy efficiency:* ISO50001 Energy Management certification could be mandated to ensure that energy efficiency is addressed in industrial processes that lead to substantial carbon emissions.

- *Technology transfer:* Access to environmentally sound technologies should be pursued through a number of mechanisms including bilateral or multilateral agreements, foreign direct investment, joint ventures, licensing agreement on Trade Related Aspects of Intellectual Property Rights (TRIPS) and opportunities under the UNFCC (AlJayyousi, et al., 2018).

- GCC engagement: The GCC can play a critical leadership role in promoting regional policies that promote a transition to low-carbon economy and resource efficiency. Such policies could include market-based instruments such as carbon taxes, cap-and-trade systems, as well as incentives to promote low-carbon fuels and high-efficiency vehicle purchases (AlJayyousi, et al., 2018).

- Monitoring and evaluation: Periodic assessments of the effectiveness of emission reduction policies could be institutionalized to ensure actual reductions are consistent with stated targets as well as to identify necessary modifications.

Table 4–3: Additional GHG reduction opportunities in Bahrain

No.	Project	Annual reduction (million tonnes of CO_2e/yr)
Oil & gas (Tatweer)	Casing Vapor Recovery (CVR) Compression	0.010
	More utilization of solar power	0.002
Oil & gas (BAPCO)	Steam Trap Management system	0.014
	Mass loss reduction (Flaring & Fugitive Loss)	0.007
	Insulation repair	0.007
	Slop generation reduction program	0.014
	Visual MESA software project	0.028
	Increase Efficiency of 5CDU Heaters	0.026
	Improve performance of Platformer/ Unifiner heaters	0.009
	ISO 50001 (Energy Management System)	0.028
Oil & gas (GPIC)	LED lights in the Complex	0.000
	LED lights in Bulk storage	0.001
	Provide solar energy to Buildings in the complex	0.000
	Reduction of fuel natural gas in CDR unit	0.008
	Interconnection of Boiler Feed Water pumps	0.008
	Medium Pressure Stripper (Ammonia/Methanol plant	0.003
	Subtotal	0.165
Residential	Behavioral change	0.0004
	Solar water heaters	0.0002
	Subtotal	0.001
Transport	Ban on less efficient cars	0.0087
	Penetration of battery-electric cars	0.0181
	Penetration of hybrid gasoline cars	0.0181
	Introducing pay-as-you-drive insurance	0.0047
	Penetration of plug-in electric cars	0.0181
	Car registration fees based on car CO_2 emissions	0.0062
	Increasing the share of school buses	0.0588
	Scrappage of old cars	0.0313
	Subtotal	0.1640
	Total	0.3294

4.4.2. Practitioners

Establishing clear protocols for GHG mitigation assessment is essential to ensuring a system that adheres to international standards. The following actions are recommended.

- *Templates:* A standardized template could be developed for reporting the assessments of mitigation projects or initiatives in different sectors, an approach adopted in many countries.

- *Energy balance:* Given the importance of energy in Bahrain's GHG emission profile, a detailed national energy balance could be prepared that includes regular updated projections of energy demand per sector and energy type, population, and economic growth.

- *Database development:* A mitigation assessment database could be established that includes all relevant data and initiatives within a single informational platform to encourage research in GHG mitigation and other relevant topics.

- *Networking:* Lessons learned could be shared with other GCC countries in order to learn from best practices. This would inform the process of policy appraisal enhance decision-making. The office of the GCC Secretary General could play a vital role in this regard.

- *National team:* A permanent national team for mitigation assessment and energy modeling could be established to ensure appropriate updating of energy consumption and CO_2e emissions data, as well as to promote institutional memory and ensure continuity.

4.4.3. Researchers

Establishing an enabling environment for GHG mitigation assessment is essential for ensuring state-of-the-art methods and analytical tools are applied. The following actions are recommended.

- *Bottom-up analysis:* It is imperative to encourage researchers to calculate CO_2e emissions based on a bottom-up approach – as opposed to a top-down or econometric approach - because it provides greater granularity in the investigation of the physical and economic implications of GHG mitigation measures.

- *University curricula:* The IPCC's inventory and mitigation assessment methodology could be introduced in higher education institutions to contribute toward building national capacities in conducting mitigation assessments.

- *Future research:* It is recommended that future research focus on how CO_2e emissions from industrial processes and product use can be mitigated. Additionally, conducting energy consumption surveys for the different sectors along with exploring the potential for carbon capture, utilization and storage in Bahrain are highly recommended.

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5. Other information

5. Other information

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

5.1. Raising awareness of climate change

The level of knowledge and awareness of climate change was assessed through a questionnaire that was completed at a workshop held at the Arab Gulf University (Abahussain, et al., 2018). The workshop was held under the slogan "Climate change issue and its effects in the kingdom Bahrain". The workshop was attended by 41 specialists of which 26 completed the questionnaire.

The results of the survey showed that 88% of the study sample believed that the climate had changed and that 85% of the study sample considered the climate change phenomenon to be severe and deserved to be addressed. This is evidence of the importance of climate change to respondents in the study sample.

Most believe that climate change is due to human causes due, in part, to the increased concentration of greenhouse gases, especially CO_2. The sample study could not identify the current CO_2 concentration level (about 408 ppm), which would imply a level of technical knowledge, and suggest the need to raise awareness of climate science issues, at least to some rudimentary level while linking it to the importance of reducing emissions.

The results also showed a lack of awareness of gases other CO_2 in contributing to climate change. This was notable especially since some GHGs have a greenhouse effect that exceeds the global warming potential of CO_2 by tens, hundreds, and thousands of times. These gases included HFC and PFCs. The results of this portion of the survey suggest the need to build awareness of the full set of gases that contribute to climate change.

There was good awareness of the potential physical impacts of climate change on Bahrain's infrastructure and environment. About 70% of respondents were aware of sea level rise and increasing temperatures. However, more than 55% of the study sample has no awareness of other impacts of climate change. Notably, this includes impact of climate change on rainfall patterns and dust storm frequency and intensity. Nor was there an awareness of the links between electricity use and greenhouse gas emissions.

There were numerous suggestions from respondents to make better use of social media to build awareness. This could be augmented by print and televised media, including the use of slogans (see figure below). The

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use of brochures leaflets and publications was deemed less effective. Media organizations such as the Shura Council and members of Parliament, as well as civil society and education associations are the most critical target audiences in future awareness campaigns.

The survey also requested that information on ways to address climate change, the causes of the phenomenon and the policies to deal with it be provided. This suggests an interest in better understanding the scope of policies that are being considered in Bahrain regarding GHG mitigation and adaptation.

Finally, 81% of the survey sample agreed to a voluntary association to raise awareness of climate change, which is an encouraging result, especially since most of the sample study is specialized or academic. Based on these findings, a climate change awareness plan was developed, as outlined in Table 5-1.

5.2. Educational initiatives

Climate change concepts have thus far not been largely incorporated into science and social science curricula at the elementary school level. To remedy this situation, several activities were undertaken as summarized in the subsections below, based on the work the TNC Educational Group (Educational Group, 2018).

5.2.1. Assessment of climate change coverage in science curricula

This involved an analysis of science and social sciences curricula for grades 1 through 6. The analysis focused on better understanding the coverage of climate change issues within elementary school level science curricula. The results showed that the 92% of fifth and sixth grade science topics related, directly or indirectly, to climate change. In fourth grade, this level was 83%. There was no incorporation of climate change topics within second grade science subjects.

5.2.2. Assessment of educational materials in social sciences

This involved an assessment of educational materials regarding climate change concepts aimed at the elementary school level. The analysis focused on a content analysis of the social science curriculum to investigate the extent to which 23 specific climate change concepts were addressed by books used within elementary grades. The results showed that in the fourteen lessons for the first-grade social science, 64% of the topics involved climate change concepts to some degree.

In the second-grade book, the percentage of the topics that included climate change concepts was 28.5% of the fourteen lessons. In the third-grade book, the percentage of the topics that relate directly to climate change was only 13.3% of the fifteen lessons. For grades four through six, fourth fifth and sixth grade, climate change concepts were incorporated, either directly or indirectly, into 34% of the 99 lessons.

5.2.3. Integration of climate change in practicum course

This involved incorporating the topic of climate change in practicum course for the academic year 2017-1018 for master's students specializing in early education. Two lessons a week were allocated to address climate change content and activities. In one lesson, the learning material was delivered within the curriculum. In the other lesson training activities were provided using creative problem-solving strategies. The lessons were given to seven classes in three elementary schools for 175 male and female students during the second semester.

The engagement of elementary school students was measured through final projects. Students were given open-ended instructions to come with final products. The form and the content of the product were left to the students. This resulted in a variety of creative products, such as producing and performing a play about climate change, recycling activities, art work about climate change, planting some spaces in schools, writing and distributing some informational leaflets and brochures about climate change.

Table 5–1: Framework of the public awareness programme on climate change

Planned Activity	Target Groups	Requirement	Responsible Party
Three workshops to raise awareness	✓ Media organizations ✓ *Shura* Council and Members of Parliament ✓ Civil Society Organizations ✓ Educators	Holding training workshops for: ✓ Ministry of Information Affairs ✓ *Shura* Council and members of Parliament ✓ Civil society Associations ✓ Education sector in the Ministry of Education (Training of trainers)	The Supreme Council for Environment to begin correspondence with these bodies and arrange for the holding of workshops as soon as possible.
Update the content of awareness workshops	Climate change Awareness Team - Arab Gulf University	Preparation of a new training material in the upcoming training workshops containing the following topics: ✓ Results of the emissions inventory for the third National Communication Report (abbreviated) ✓ All GHGs gases causing climate change and demonstrating their impact over time, raising awareness of the impacts of climate change on various sectors in the Kingdom of Bahrain. ✓ Explain the Paris 2015 agreement, Nationally determined contributions (NDCs), the Sustainable development agenda (SDGs 2030) and its intersection with climate change, especially Goal 13 . Also, raise awareness of the causes of climate change, ways to address them, and climate change policies in the areas of adaptation and mitigation, nationally and globally. ✓ Highlight the needs of cooperation of all countries, even low-emitting countries like Bahrain, promoting the concept of "thinking globally and acting locally".	✓ The Supreme Council for Environment to provide the Panel with a summary of the results of the GHG emissions inventory of the third national communication report ✓ The Arabian Gulf University outreach team to prepare scientific material of new training workshops for the target groups.
Use of social media to raise awareness about climate change	Population of Bahrain	✓ Set up a mental map (mind map) for awareness messages ✓ Logo Design (proposal of five logos required for approval by the Supreme Council for Environment) ✓ Preparation of scientific material for awareness messages	Arabian Gulf University Awareness team
NGOs/CSOs	Population of Bahrain	Establishing an association to raise awareness of climate change and its impacts on Bahrain	Ministry of Labor and Social Affairs

5.2.4. Development of educational materials

This involved the development of educational materials for building climate change awareness aimed at fourth and fifth graders. The focus was on augmenting curricula with climate change concepts and developing students' abilities and skills through projects related to climate change. Educational activities were divided into six units, as briefly described below.

- Unit 1: This unit focused on weather and climate. It includes the concepts of climate change and global warming;
- Unit 2: This unit focused on causes of climate change. It includes causes related to human activities, GHGs, and natural causes;
- Unit 3: This unit focused on the global impact of climate change (on ecosystems, human, health, drinking water resources, biodiversity animals, plants, etc);
- Unit 4: This unit focused on the impact of climate change on Bahrain (e.g., temperature changes, humidity changes, sea level rise, biodiversity, etc);
- Unit 5: This unit focused on suggested solutions (e.g., reduced water consumption, reducing use of electricity, renewable energy, expanding farming-activities, recycling, using of clean fuel, awareness);
- Unit 6: This unit focused on what can we do? :

Sixteen teachers (8 males, and 8 females) were trained on implementing the six units during the second semester 2017-2018. After completion of the units, a survey of 391 fifth and sixth grade students indicated statistically significant evidence of an increase in the students' awareness of climate change, as evidenced by post-test scores (see Table 5-2).

5.2.5. Engage female students

This involved getting a better understanding of the degree to which female sixth graders are benefiting from climate change focused education materials. A study was conducted using a sample 20 female students exposed to climate change materials and a control group of 20 female students who did not have access to the climate change materials. The results indicated that there were statistically significant differences in cognitive and emotional indicators in favor of the experimental group.

5.2.6. Recommendations

Going forward, several recommendations are offered based on the research undertaken the Educational Team:

- Introduce the climate change educational in the curriculum for fourth, fifth and sixth grade throughout Bahrain;
- Build awareness of climate change topics among all elementary school staff;
- Conduct an analysis of the science and social science curriculum relative to climate change in the higher grades; and
- Introduce educational activities related to climate change in other curricula like languages, mathematics and Islamic studies.

5.3. Technology transfer

As discussed previously, Bahrain is mainstreaming a set of initiatives to support sustainable energy consistent with Economic Vision 2030, which calls to reduce GHG emissions per capita, to improve energy, and water efficiency, and develop renewable energy resources. In addition, Bahrain is embarking on a set of energy efficiency projects in key industries such as Aluminum Bahrain, Bahrain Petroleum Company, and the Gulf Petroleum Industries Company.

Bahrain faces several barriers for reaching the technology transfer goals implied by Economic Vision 2030. Key barriers include:

- Limited market-based incentives;
- Limited access to information and knowledge creation;

Table 5–2: Mean and standard deviation for pre- and post-test for experimental group

Parameter	Pre- test Mean	Pre- test SD	Post-test Mean	Post-test SD	t-value	Statistical significance
Cognitive	2.28	0.32	2.52	.36	-10.77	.000
Emotional	2.32	0.39	2.35	0.36	-1.46	.144
Behavioral	2.25	0.34	2.33	0.31	-3.31	.001
Composite Score	2.28	0.27	2.40	0.26	-7.37	.000

- High cost of some renewable energy technologies.

For Bahrain to overcome these barriers, it will need to increase engagement with the private sector by providing economic incentives and supporting public-private partnerships. Specifically, the government has a key role to promote strategic technology transfer though making advancement on the following measures:

- Provision of an enabling environment for technology transfer in renewable energy technologies in light of the findings of a previously conducted technology needs assessment;

- Enforcing intellectual property rights to provide confidence to prospective private sector investors;

- Improving knowledge management processes and platforms for knowledge sharing;

- Enhancing funding for R&D in green technology and climate technologies for small- and medium-sized enterprises;

- Developing technology transfer policies and integrating them within technology actions plans; and

- Enhancing human capacity to support science-policy dialogues, build public awareness, and manage technology information.

Going forward, priorities for technology transfer are focused on the following:

- Introduction of solar thermal technologies (i.e., concentrated solar power), and advanced natural gas technologies for the power sector (i.e., combined cycle);

- Introduction of energy efficient technologies in the aluminum smelting industry (e.g., efficient motors, pumps, waste heat recovery).

- Development of incentive regimes to facilitate investments in clean energy technologies, sustainable practices, and innovative research.

- Encouragement of emerging niche markets for energy services through regulatory reform and new incentive regimes.

- Support of regional cooperation on renewable energy through network development, harmonization of standards, sharing of technical research, and improving the GCC interconnection grid.

- Integration of green development strategies within the ongoing economic diversification strategy and tapping into international cooperation opportunities like the clean development mechanism.

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