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Abu Dhabi Global Environmental Data Initiative

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هيئة البيئة - أبوظبي
Environment Agency - ABU DHABI

LOCAL, NATIONAL, REGIONAL CLIMATE CHANGE PROGRAMME

REGIONAL WATER - ENERGY NEXUS UNDER CLIMATE CHANGE

- Atmospheric Modelling
- Arabian Gulf Modelling
- Terrestrial Ecosystems
- Marine Ecosystems
- Transboundary Groundwater
- Water Resource Management
- Al Ain Water Resources
- Coastal Vulnerability Index
- Desalinated Water Supply
- Food Security & Climate change
- Public Health Benefits of GHG Mitigation
- Sea Level Rise

Executive Briefing

Climate Change Research Group
NCAR
SEI STOCKHOLM ENVIRONMENT INSTITUTE

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Local, National and Regional Climate Change Programme 2013-2016

Socioeconomic Systems	Regional Climate Change	Environment	Coastal Zones	Water Resources
Public Health Benefits of GHG Mitigation (L)	Atmospheric Modelling (R)	Terrestrial Ecosystems (R)	Coastal Vulnerability Index (N)	Al Ain Water Resources (L)
Food Security (N)	Arabian Gulf Modelling (R)	Marine Ecosystems (R)	Sea Level Rise (R)	Water Resource Management (N)
Desalinated Water Supply (R)				Transboundary Groundwater (R)

L=Local **N=National** **R=Regional**

5 Thematic Areas 3 Spatial Regions 12 Sub-projects

12 Sub-projects
Assess the Impacts, Vulnerability & Adaptation to Climate Change in the Arabian Peninsula

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1. Introduction

Current water and energy planning in the Arabian Peninsula is characterized by a consideration of the energy used in providing water.

The region's growing population and growing per capita water demand for public water usage like amenities have increased the pressure on potable water resources. Water itself is not limited, since sea water is readily available for desalination. Turning sea water into potable water requires significant amounts of energy. Similarly, as groundwater withdrawals encourage saltwater infiltration into the aquifers, pumping it will incur energy costs for treating the water to sufficiently potable levels. Wastewater produced in these systems can have the potential to be reused in the environment, following treatment which also requires energy. As natural freshwater becomes scarcer, the region's water supply will become increasingly coupled to its energy needs.

Under climate change, several key trends in the Arabian Peninsula suggest the importance of addressing water and energy in an integrated and proactive way.

Firstly, climate change has already begun to affect rainfall and temperature patterns across the region, as established by the LNRCCP Regional Atmospheric Modelling sub-project. Secondly, regional socioeconomic growth trends indicate that the population in the region's hyper-arid environment is likely to continue to increase and will require additional energy-intensive desalination capacity to satisfy the increasing water demands. Thirdly, new energy and water technologies can increase production efficiency for both resources, if introduced within a water-energy integrated framework. Finally, a water-energy nexus strategic approach could help to inform future technology research, development, demonstration as well as deployment within several centres of excellence in the region.

The "water-energy nexus" is a framework that views water as part of an integrated water and energy system, rather than as an independent resource.

Water is used in all phases of the fuel cycle, from extraction of energy resources like natural gas and oil, to energy production and electricity generation. Energy is required to extract, convey, purify as well as deliver water to various types of end users in the economy. It is also used to treat municipal and industrial wastewater. Until recently, energy and water have been viewed as separate planning challenges. Any interactions between energy and water have typically been considered on a case-by-case basis. However, changing demographics, large-scale development initiatives and increased reliance on desalination have recently motivated attention on the connections between water and energy infrastructure.

Hence, the water-energy nexus is a particularly relevant framework to apply to explore climate change impacts on the Arabian Peninsula's water resources.

For the purposes of the analysis, the spatial focus was on the water-energy nexus situation in six countries: Kuwait, Saudi Arabia, Bahrain, Qatar, United Arab Emirates as well as Oman.

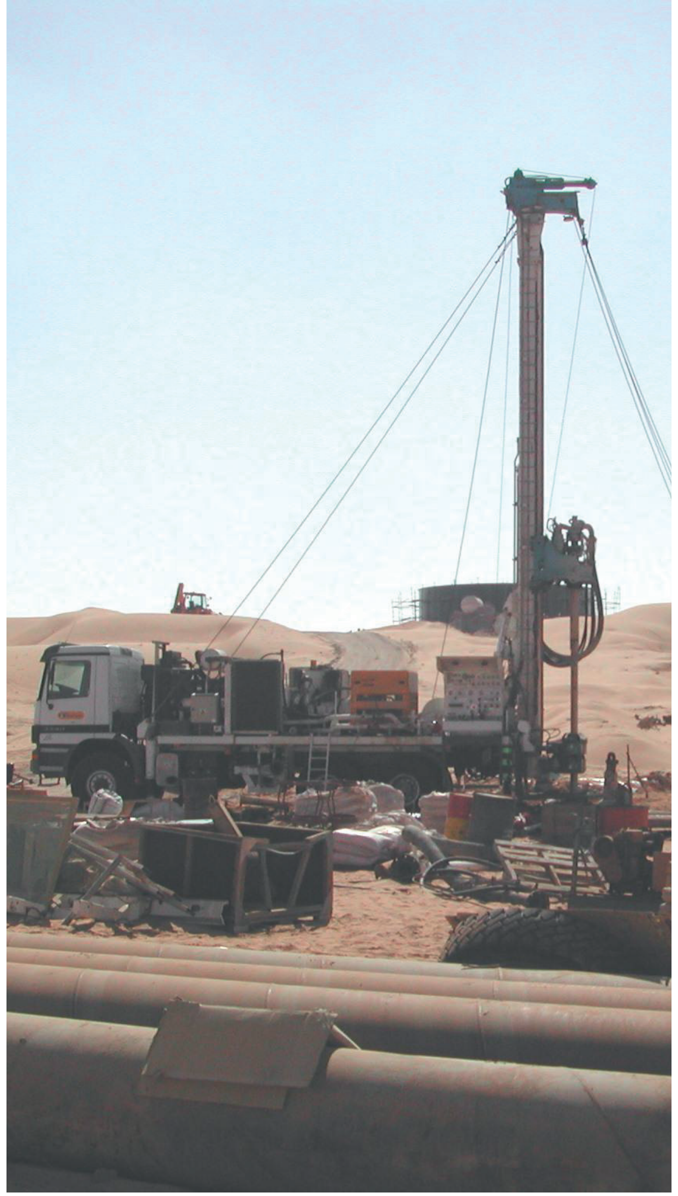
2. Approach

The overall goal of the sub-project is to better understand the water-energy nexus challenge in the Arabian Peninsula region in the face of climate change and socioeconomic development.

The major research questions underlying the methodological approach were twofold. First, what would be the future benefits (measured in water savings, energy savings, greenhouse gas emission reductions) associated with various scenarii that aim to promote efficiency and conserve natural resources under climate change? Second, what would be the costs associated with shifting to such scenarii and away from the current baseline development trajectories?

Addressing the goal and research questions required an analytical framework capable of accounting for water, energy and climate interactions in an integrated way.

On the water side, the Water Evaluation And Planning (WEAP) system was used; on the energy side, the Long Range Energy Alternatives and Planning (LEAP) system was used. WEAP and LEAP are integrated modelling tools that can track water and energy resources associated with extraction, production, and consumption, throughout the region's economy, including seawater desalination, groundwater pumping, and the transmission of water. Moreover, the models have been coupled (i.e. outputs of one model are used as the inputs to the other) to enable an analysis of the interplay between water management and energy management policies under changing future conditions. A planning period of 2010 through 2060 was considered in the analysis.



Regional atmospheric modelling

As part of the LNRCCP's regional atmospheric modelling sub-project, future climate changes were evaluated for the Arabian Peninsula region.

Some of the outputs of this research were incorporated into the analytical framework to capture the impact of climate change on the supply and demand for water and energy resources. Two greenhouse emission scenarios were modelled. One scenario assumed the IPCC's Representative Concentration Pathway 8.5 (RCP8.5), analogous to business-as-usual emissions; the other assumed RCP4.5, analogous to global greenhouse gas mitigation activities significantly limit the increase in greenhouse gas concentrations in the atmosphere. Under climate change, Average future temperature will increase on the order of 2° to 3°C higher over land areas across winter and summer months. (Yates, et. al. 2015).

The results of regional atmospheric modelling were incorporated into the analytical framework of the regional water-energy nexus study.

This was an important consideration as an already hot region will become even hotter, leading to additional energy for end uses like air conditioning and additional water for end uses like irrigation to account for higher evaporation rates. An algorithm was developed for, and incorporated into, the modelling framework that addresses the projected seasonal change in average temperatures. Other modelled climatic variables such as rainfall, humidity, wind, and extreme events were not incorporated in the analytical framework due to their negligible impact on water and energy.

Regional ocean modelling

As part of the LNRCCP's regional ocean modelling sub-project, future climate changes were evaluated for the Arabian Gulf, on which desalination activities depend.

The Arabian Gulf has historically been one of the most stressed marine environments on earth. It is a semi-enclosed, highly saline sea between latitudes 24°N and 30°N surrounded by a hyper-arid environment and limited freshwater inflow via the Tigris, Euphrates, and Karun rivers at the delta of the Shatt al Arab in Iraq. Under climate change alone, the Arabian Gulf will become even more highly stressed, with significant increases in temperature throughout coupled with zones of large salinity increases (Edson, et. al. 2015).

The results of LNRCCP sub-project #10 regarding average salinity impacts from climate change and desalination were incorporated into the analytical framework of the national water-energy nexus study.

This was considered necessary due to the relationship between feedstock salinity and the energy required for desalination (i.e. the higher the salinity, the more energy is needed to remove the salt). In shallow areas throughout the Southern Gulf, desalination activity represents a significant impact on average salinity. Depending on the brine discharge rate scenario, average salinity is projected to rise between 1.1 and 2.6 psu in the Southern Gulf. An algorithm was developed for, and incorporated into, the energy system model that addresses this change in Gulf salinity. The other modelled ocean variable - sea surface temperature – was not incorporated into the analytical framework due to its comparatively negligible impact on the energy needed for desalination.

Water system modelling

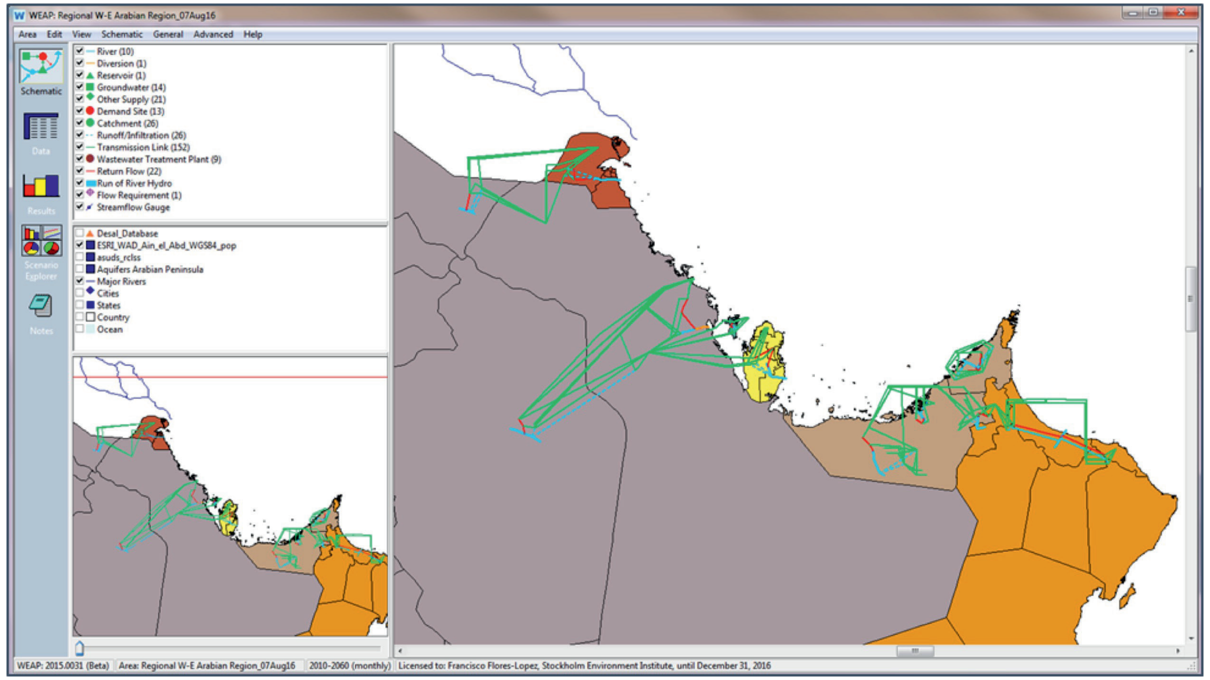
WEAP software was used to build a water system model for the Arabian Peninsula.

WEAP provides a sector-specific integrated approach to water resources planning by linking quantification of water availability and water allocation routines, hydrologic processes, system operations and end-use quantifications within a single analytical platform (Yates et al. 2005). The modelling software incorporates the multiple dimensions critical to water resource management, including surface water and ground water hydrology, water quality, water demands, population growth, reuse, system losses and consumption. WEAP represents water supply and demand centers in a spatial way because the focus is the flow of water from abstraction sites to consumption sites.

The water system model was built for the whole of the Arabian Peninsula.

The model captures system characteristics like agricultural areas, populations, water demand for human consumption and irrigated amenity areas, wastewater treatment plant capacities, desalinated water production capacities, irrigation demands, and groundwater availability/recharge. The model was developed using a monthly time step to examine water quantity availability in the region to balance supplies and demands in the country. An illustrative, schematic view of the model is shown in Figure 1. The schematic demonstrates the aggregated nature of the national representation of water supply (green lines) and demand (red dots) and their linkages.

Figure 1: Schematic representation of the regional water system model



Energy system modelling

LEAP software was used to build an energy system model for the Arabian Peninsula.

LEAP provides a sector-specific decision support system (DSS) within an integrated modelling framework that can be used to track energy consumption, production and resource extraction in different sectors of the economy. This can include the energy associated with providing water, such as pumping, desalination, treating, delivering, etc. The LEAP DSS can structure complex energy inputs for analysis in a transparent and intuitive way. It offers a wide range of flexibility, to produce specific results and enable tailored policy examinations.

Unlike WEAP, LEAP software does not represent energy supply and demand centers in a spatial way because the focus is on energy-related processes and activities rather than the flow of electrons.

At the supply level, this corresponds to transforming energy from one form into another (e.g. natural gas to electricity; crude oil to gasoline). At the demand level, this corresponds to accounting for energy consumed by sector (e.g. households), activity (e.g. space cooling), and technology (e.g. efficient air conditioners).

The energy system model focused on a subset of energy supply sources and energy demand sectors

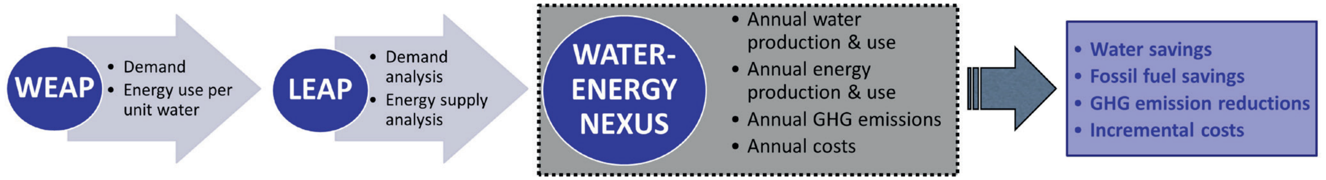
Specifically, the power/water supply, residential, services, and industrial sectors were considered, with a special emphasis on energy uses associated with water resource use. The model represents regional electric generating and desalination stations together with their associated fuel and energy transformation methods used to create electricity and freshwater. The model was developed using a monthly time step to examine energy supply and demand in the region. A final version of the regional energy system model, after receiving and incorporating all stakeholder feedback, will eventually be available for download at www.ccr-group.org/regional-water-energy-inspector-full.

Integrated water-energy system modelling

The development of an integrated water-energy system model for the region is the final component of the analytical approach.

This involved the coupling of the calibrated water and energy systems models via a software link, which was exclusively a one-way pass of energy used in water production, as determined within the water system model, which was then added to the energy demand component of the energy system model in LEAP. Since the volume of water used in energy production is negligible for the region, no information is passed from the energy system model back to the water system model, hence only the one-way pass of outputs from the water system model to the energy system model was needed. There were four (4) major steps involved in analyzing the water-energy nexus under climate change as illustrated in Figure 2.

Figure 2: Sequence of steps used to analyze the regional water-energy nexus under climate change



Step 1a: Calculate water supply/ demand Step 1b: Calculate energy use in water supply/demand Step 1c: Pass energy used by water activities to LEAP	Step 2a: Calculate energy supply & demand based on economic activity and pre- capita use. Step 2b: calculate desalination energy use based on technology (MSF, MED, and RO)	Step 3a: Finalize total energy supply/demand in LEAP (all water and energy activities) Step 3b: Finalize total water supply/demand in WEAP (all water activities)	Step 4: Using offline spreadsheet analysis, calculate impact of transitioning from the BAU scenario to each of the policy Scenarios based on water-energy nexus outputs

Cost modelling

Cost modelling focused on a few key metrics that could be reasonably estimated and used to compare among the policy scenarios.

A levelized cost approach was used to allow for comparison among the various technology alternatives. Levelized costs are defined as a constant annual cost that is equivalent on a present value basis to the actual annual costs. That is, if one calculates the present value of levelized costs over a certain period, its value would be equal to the present value of the actual costs of the same period. For electrical energy, levelized costs are often reported in $/MWh, which allows for a direct comparison of technologies in any year, something that would be more difficult to do with differing annual costs.

Water-related costs are limited to the costs of electricity and process heat to deliver water to consuming sectors.

That is, there is no inherent value ascribed to water in the modelling framework as it is considered a "free" natural resource with the only cost to consumers related to the energy needed to extract, desalinate, and deliver it. This energy is associated with groundwater pumping, wastewater treatment, wastewater reuse, improved water conservation/efficiency technologies, as well as the process heat needed for desalination using thermal technologies. Hence, all costs for water supply and demand are accounted for in the energy system model.

Energy-related costs correspond only to those costs associated with the energy used for water-related activities.

On the water side, this includes the costs of electricity for desalination, groundwater pumping, wastewater treatment, water reuse transmission, as well as the costs of process heat for desalination using thermal technologies (IEA, 2015; EIA, 2016). On the energy side, this includes costing to account for the impact of new demand-side electricity efficiency programmes and new supply-side renewable energy investments. All other costs such as those associated with fuel use (e.g. transport sector gasoline/diesel use, industrial sector natural gas use) or electricity/fuel use in other sectors (e.g. agriculture and fishing sector) are ignored as they were beyond the scope of this water-energy nexus study.

3. Policy scenario framework

The validated water-energy system coupled model was used to analyze the impact of potential policy scenario that could promote resilience of water and energy systems in the region in the face of climate change.

Establishing a plausible policy scenario framework is fundamental for using the coupled model to explore challenges and opportunities for transitioning to more climate-resilient development paths. This scenario framework consists of five (5) scenarios, as briefly described in the bullets below:

- Business-As-Usual scenario, without climate change: Assumes extension of past trends regarding per capita water and energy consumption, assuming no change in regional climate
- Business-As-Usual scenario, with climate change: Assumes extension of past trends regarding per capita water and energy consumption, assuming climate change unfolds in the region consistent with RCP8.5.
- High Efficiency and Conservation scenario: Assumes that the countries in the region will implement aggressive policies to reduce the consumption of water and electricity on the demand side (see Table 1). The overall aim of this policy scenario is to reduce per capita water and energy use across the region. A total of six (6) specific policies were assumed across water and energy activities that would be phased in through 2060, with the phase-in start year depending on the specific policy. The effect of climate change was incorporated into the scenario.

- Natural Resource Protection scenario: Assumes that the countries in the region will implement aggressive supply-side policies to conserve its natural resources, specifically groundwater and energy (see Table 1). The overall aim of this policy scenario is to protect fossil groundwater resources from any further depletion and to reduce the use of fossil fuels. A total of six (6) specific policies were assumed for resource planning across water and energy that would be phased in through 2060, with the phase-in start year depending on the specific policy. The effect of climate change was incorporated into the scenario.
- Integrated Policy scenario: Assumes that the countries in the region will implement all 6 demand-side and all 6 supply-side policies collectively (see Table 1). The overall aim of this policy scenario is to optimize efficiency and natural resource protection in the region. The scenario assumes a future in the region where there is a broad consensus among national policymakers that the implementation of all the policies and measures embedded in the High Efficiency and Natural Resource Protection Scenarios are essential. The effect of climate change was incorporated into the scenario.

Table 1: Specific policies analyzed within the water-energy nexus scenarios

Sector	Demand-side policies	Supply-side policies
Water policies	1. Indoor water use efficiency and conservation programme 2. Introduction of outdoor garden and amenity caps 3. Improved irrigation efficiency 4. Water loss reduction programme	1. Fossil groundwater phase-out 2. Increased use of treated sewage effluent 3. Sustainable desalination
Electricity policies	5. Demand side electric efficiency and conservation programme 6. Peak load management of space cooling load	5. Carbon dioxide cap 6. Renewable portfolio standard 7. Clean coal capacity cap

The essential findings of the study focus on several key metrics, water demand electricity demand, greenhouse gas emissions, and incremental costs.

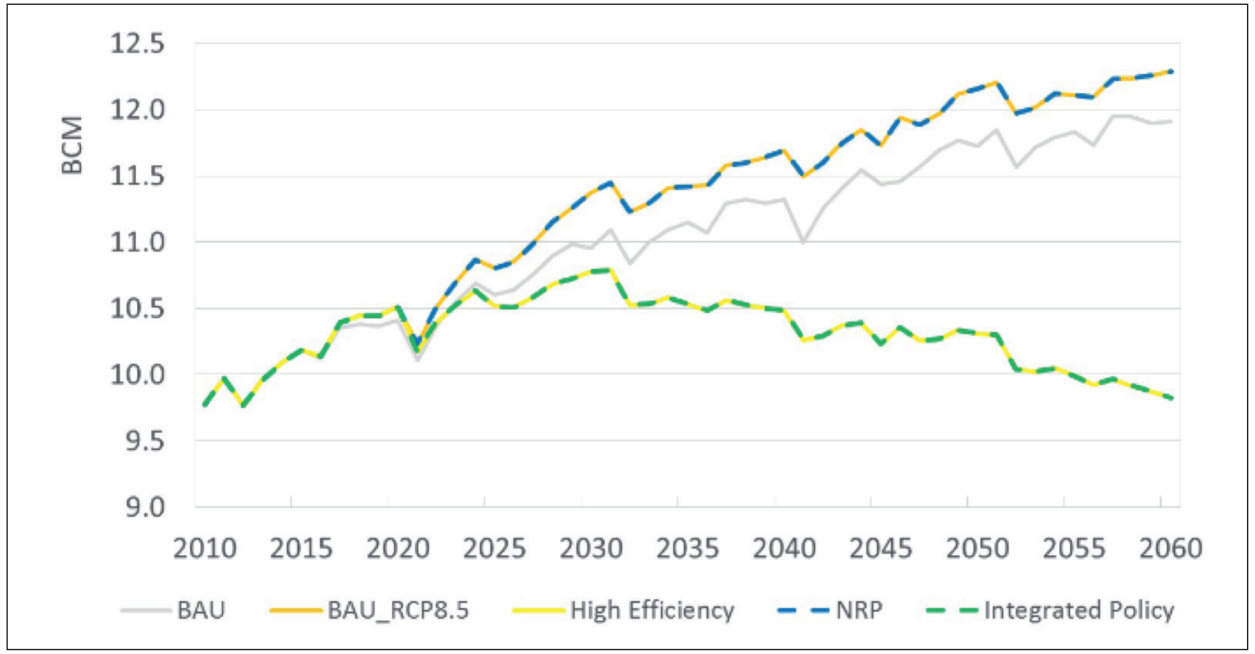
Brief descriptions of the key outcomes are outlined below.

Water demand

A comparison of water demand across the two BAU scenarios and the three policy scenarios appears in Figure 3.

The overall increasing trend in water demand for the BAU scenarios is driven primarily by the assumptions of regional population growth. Comparing the BAU_RCP8.5 scenario relative to the BAU scenario, climate change results in an increase of annual water demand by about 3%. By 2060, and relative to the BAU_RCP8.5 scenario, the High Efficiency scenario reduces water use by 20%. Since the Natural Resource Protection scenario includes only supply side measures, water use remains unchanged relative to the BAU_RCP8.5 scenario. Combining both demand and supply side measures of the Integrated Policy scenario results in a 20% reduction in water use relative to the RCP_8.5 scenario in 2060.

Figure 3: Total annual electricity use for each of the five scenarios

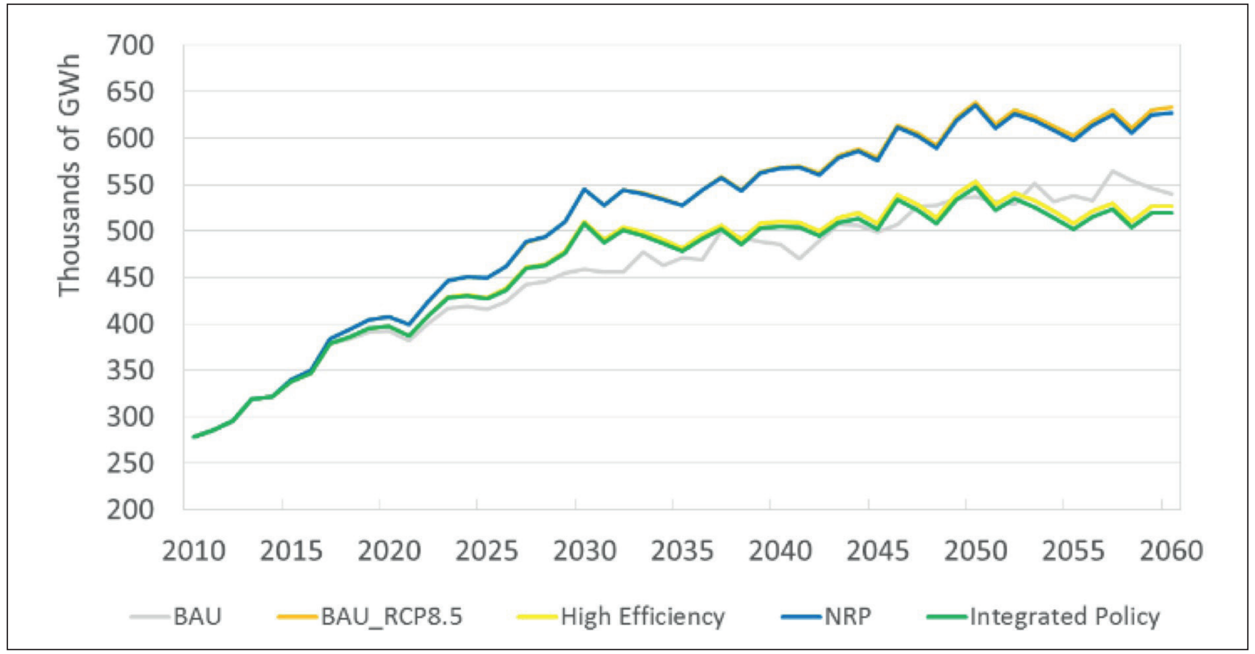


Electricity demand

A comparison of electricity demand across the two BAU scenarios and the three policy scenarios appears in Figure 4.

The overall increasing trend in electricity demand for the BAU scenarios is driven primarily by the assumptions of regional population growth. Comparing the BAU_RCP8.5 scenario relative to the BAU scenario, climate change results in an increase of annual electricity demand by about 15%. This increase in electricity demand is driven by the higher heat index, leading to an increased demand for seasonal cooling; while the increase in water demand is due to increased evaporative losses due to warming. By 2060, and relative to the BAU_RCP8.5 scenario, the High Efficiency scenario reduces electricity use by 15%, achieved primarily through reductions in per-capita electricity use achieved by the policies. Since the Natural Resource Protection scenario includes only supply side measures, electricity use is reduced by a modest 1%. The small reduction in energy use is attributable to changes in the municipal water supply sources such as the shift away from MSF and MED to RO technologies, which is less energy intensive. Combining both demand and supply side measures of the Integrated Policy scenario results in a 16% reduction in electricity use relative to the RCP_8.5 scenario in 2060.

Figure 4: Total annual electricity use for each of the five scenarios

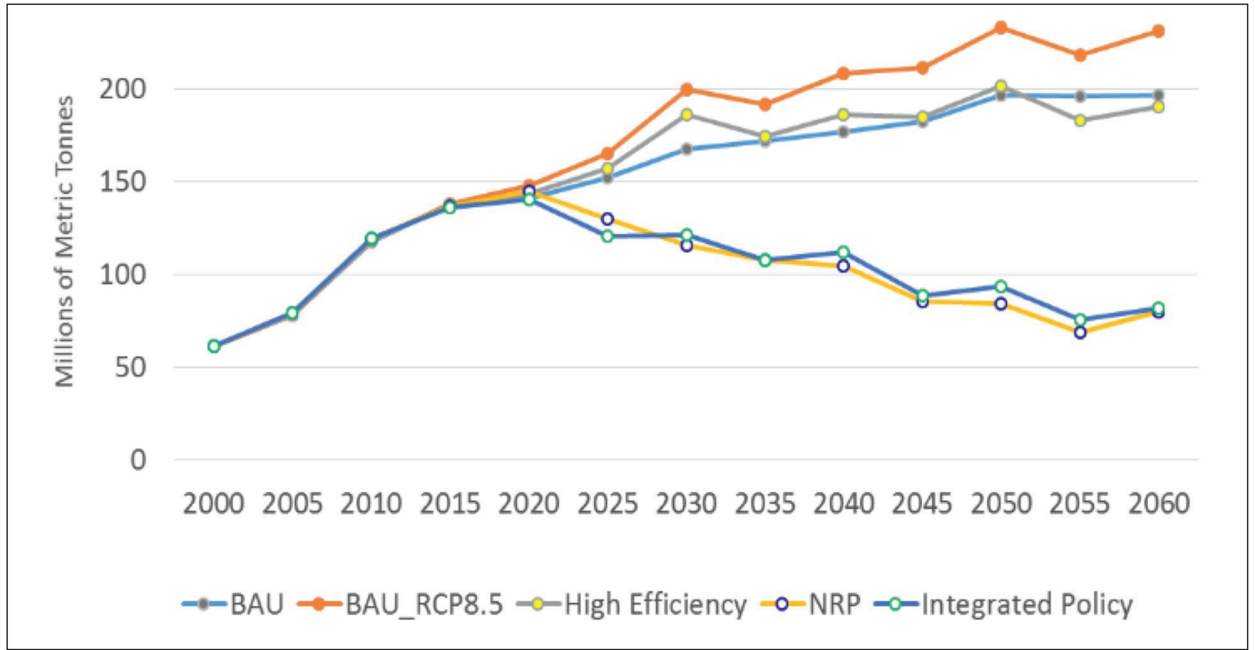


Greenhouse gas emissions

Figure 5 shows the total annual carbon dioxide equivalent from 2000 through 2060 across the two BAU scenarios and the three policy scenarios.

The BAU_RCP8.5 scenario leads to more than 15% greater GHG emissions when compared with the BAU scenario, as natural gas continues to dominate energy production and resource use increases due to warmer conditions that require more water and energy. For the High Efficiency scenario, efficiency improvements and conservation targets reduce emissions, but regional population growth means that both energy use has grown overall, with emissions only being reduced by about 15% relative to the BAU_RCP8.5 scenario. The Natural Resource Projection and Integrated Policy scenarios result in sharp reduction in GHG emissions – leading in 2060 to levels consistent with 2005 levels. Interestingly, the total emissions of the Integrated Policy scenario are slightly higher than the Natural Resource Protection, primarily because natural gas remains a larger share of overall production as energy demand stays lower and is not replaced by new solar capacity.

Figure 5: Annual CO2e emissions for all scenarios



Incremental costs and overall summary

A summary of the results is presented in Table 2.

This Table synthesizes the essential cost findings of the study, and are accompanied by a summary of the results described above. Brief descriptions of the key outcomes are provided in the bullets that follow:

- In a future in which past policies continue without any additional efforts to improve the efficiency of water/energy use and introduce renewable energy, climatic changes would lead to a cumulative increase over the 2010-2060 period of 1 billion tonnes of CO2e, 13 billion cubic meters of water, and 470 TWh of electricity.

Table 2: Costs and benefits associated with the implementation of the policy scenarios.

Cumulative benefits (2020-2060)

Summary of Scenario Action	Alternative Scenario	Starting Scenario	Water savings (BCM)	Energy savings (TWh)	CO2e reductions (million tonnes)	Total Incremental cost (billion 2015$)	Avoided CO2e emissions from policies ($ per tonne)
From climate change, only	BAU-RCP8.5	BAU	-13	-470	-1,000	47	NA
From introduction of improved efficiency & conservation measures	High Efficiency & Conservation	BAU-RCP8.5	49	1,600	900	-21	-$24.0
From introduction of renewable energy and reductions in groundwater withdrawals	Natural Resource Protection	BAU-RCP8.5	0	4,200	4,200	57	$13.8
From introduction of all sustainable development measures	Integrated Policy	BAU-RCP8.5	49	4,400	4,000	12	$3.0

- Introducing a set of targeted efficiency and conservation measures across the water and energy sectors in the region would, over the 2010-2060 period, lead to cumulative benefits of 900 million tonnes of CO2e avoided, 49 billion cubic meters of water saved, and 1,600 TWh of electricity saved. These benefits would come at a negative cost, meaning that the costs of achieving the benefits (i.e. new technologies), would be $21 billion lower than the value of the benefits (i.e. lower electricity bills, lower water bills). That is, each tonne of CO2e avoided would be achieved while saving $24.0 in the process.
- Introducing a set of targeted measures to protect groundwater resources for future generations and limiting the use of fossil energy resources (oil and natural gas) would, over the 2010-2060 period, lead to cumulative benefits of 4,200 million tonnes of CO2e avoided and 4,200 TWh of electricity saved. These benefits would come at a cost of $57 billion, equivalent to $13.8 for each tonne of CO2e avoided.
- Combining targeted efficiency/conservation and natural resource protection measures across the water and energy sectors in the region would, over the 2010-2060 period, lead to cumulative benefits of 4,000 million tonnes of CO2e avoided, 49 billion cubic meters of water saved, and 4,400 TWh of electricity saved. These benefits would come at a cost of $12 billion, equivalent to $3.0 for each tonne of CO2e avoided.

The results of the study confirm that green growth objectives that will increase the resilience of the water-energy nexus in the region under climate change can be achieved cost-effectively.

- Assessing national green growth scenarios in the context of climate change in a hyper-arid environment where energy-intensive desalinated water makes up a significant share of water supply requires a focus on both water and energy. The water-energy nexus approach offers an analytical framework that considers water and energy as an integrated system where alternative policy scenarios can be readily evaluated.
- Pursuing an economic diversification agenda employing a green growth framework can lead to significant environmental benefits. These benefits can be achieved at net economic savings in the case of a scenario emphasizing energy/water efficiency investments (-$10.2 for each tonne of CO2e avoided), and at modest economic cost in the case of a scenario emphasizing renewable energy investments ($13.2 for each tonne of CO2e avoided). Taking advantage of the synergies across efficiency and renewable green growth strategies achieves maximum benefits at very low cost ($3.4 for each tonne of CO2e avoided).


Google Image

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About

AGEDI

Under the guidance and patronage of His Highness Sheikh Khalifa bin Zayed Al Nahyan, President of the United Arab Emirates, the Abu Dhabi Global Environmental Data Initiative (AGEDI) was formed in 2002 to address responses to the critical need for readily accessible, accurate environmental data and information for all those who need it.

With the Arab region as a priority area of focus, AGEDI facilitates access to quality environmental data that equips policy-makers with actionable, timely information to inform and guide critical decisions. AGEDI is supported by Environment Agency – Abu Dhabi (EAD) on a local level, and by the United Nations Environment Programme (UNEP), regionally and internationally.

For more information, visit www.agedi.org.

The Environment Agency-Abu Dhabi

The Environment Agency – Abu Dhabi (EAD) was established in 1996 to preserve Abu Dhabi's natural heritage, protect our future, and raise awareness about environmental issues. EAD is Abu Dhabi's environmental regulator and advises the government on environmental policy. It works to create sustainable communities, and protect and conserve wildlife and natural resources. EAD also works to ensure integrated and sustainable water resource management, to ensure clean air and minimize climate change and its impacts.

For more information, visit www.ead.ae.

CCR Group

Climate Change Research Group (CCR Group) is a sustainable development research and consultancy firm focused on the intersection of energy, climate and development. Our network of specialists works with international development organizations, national and local governments, as well as non-governmental institutions to formulate policy frameworks, technical assessments and capacity building programmes.

Since CCR Group's founding in 2009, we have lead projects across Africa, the Middle East, Eastern Europe, Asia and the Americas. Because each client faces a unique set of challenges based on local context, we have experience developing strategies for multiple issues areas within sustainable development. Thematic issue areas and services for CCR Group include: Climate Change Adaptation Strategies; Greenhouse Mitigation Analysis; Climate Change & Disaster Risk Management; Climate Change, Agriculture & Food Security; Climate Change & Water Security; Climate Change & Public Health; Power Supply & Renewable Integration Modelling; Air Pollutant & Greenhouse Gas Emission Scenarios Modelling; and Capacity Strengthening Programmes.

For more information, visit www.ccr-group.org.

All reports and resources are available for download at www.agedi.org and on our Climate Change Inspectors Online Portal, http://www.ccr-group.org/cc-inspectors.

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