UNITED ARAB EMIRATES
MINISTRY OF CLIMATE CHANGE
& ENVIRONMENT

National Climate Change Adaptation Program

Adaptation of the UAE's Energy Sector to Climate Change

Risk Assessment & Options for Action

2019

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Executive Summary

As part of the National Climate Change Adaptation Program, this report presents the findings of the climate change risk assessment of the UAE's energy sector. The assessment was conducted by the Ministry of Climate Change and Environment (MOCCAE) according to a framework developed from global best practices. The UAE Sectoral Climate Risk Assessment Framework consists of five steps: 1) take stock of climate trends and relevant sectoral issues; 2) identify potential impacts of climate change on the sector; 3) evaluate the magnitude and likelihood of impacts to understand the risks; 4) assess and prioritize the risks; and 5) identify potential adaptation actions.

Climate change and energy

Climate change will result in higher temperatures across the UAE. Climate projections show a 2–3°C increase on average temperatures in the summer months of 2060–2079, although the changes may vary across the Emirates. Humidity is expected to increase along the coast, while rainfall patterns are projected to change, with the Northern Emirates expected to have more intense rainfall episodes. Sea level rise is expected to increase the threats of inundation along the coastline. Furthermore, the probability of extreme weather events is projected to increase in both frequency and magnitude.

Energy plays a key role in enabling economic progress and high quality of life. The UAE's energy sector is evolving from being hydrocarbon-based toward a more diversified mix to respond to growing energy demand, rapid urbanization, oil market volatility, and greater momentum for green growth. Current energy programs, specifically for electric utilities, mainly highlight mitigation. However, the growing impacts of climate change on the power systems sector make adaptation urgently imperative.

Assessing climate risks to the energy sector

Based on review of available and accessible scientific literature on the impacts of climate change on the energy sector, this report identifies the most relevant impacts, which are further assessed upon consideration of the local evidence to fit the UAE context. The impacts are translated into risks through the interaction of impacts and likelihood. In this context, risk is defined as the likelihood of impact occurrence. The shortlisted risks shown in the table below encompass the different stages of electricity cycle, namely generation, transmission, distribution, and end use. They also include heat (district cooling and solar thermal) and off-grid/mini-grid applications of renewables and diesel generators.

MOCCAE conducted an initial assessment of the shortlisted risks through a five-point scale ("very low," "low," "medium," "high," and "very high"). The preliminary results were then shared with stakeholders through interactive workshops, which involved representatives from the public, private, and civil society organizations, and were facilitated by subject matter experts. MOCCAE consolidated the stakeholder inputs and reflected their comments in the final assessment while further verifying the available evidence.

Based on the results above, three risks ("high") are identified as priority risks:

- Energy efficiency losses of power plants when the temperature exceeds standard design criteria;
- Reduced power output due to warmer cooling water; and
- Deterioration of power facilities, resulting in reduced reliability and increased maintenance cost.

For the "medium" risks, although they are not as critical as the "high" risks, a thorough investigation would be necessary to implement control measures to minimize the risks and prevent them from escalating into "high" risks. The "low" risks also require sporadic monitoring to determine changes in the situation that may affect the risk level.

Risk level	Impact
High	Energy efficiency losses of power plants when the temperature exceeds standard design criteria
	Reduced power output due to warmer cooling water
	Deterioration of power facilities, leading to reduced reliability and increased maintenance cost
Medium	Damage to coastal power infrastructure caused by sea level rise
	Damage and destabilization of energy production infrastructure due to storms and flooding
	Increased energy demand for cooling purposes due to global warming
	Increased energy demand for agriculture due to energy-intensive methods
	Increased incidents of power outages due to damage caused by high-impact storms and flooding
Low	Reduced solar power output caused by increased cloudiness and humidity
	Potential dispersion of radioactive material during extreme events

Options for action

Considering the UAE's current climate adaptation efforts, the below list of potential measures is proposed to address the three priority risks to the energy sector. To prioritize actions, current efforts may continue or expand, and new initiatives may be introduced. Some measures may require collaboration across authorities due to their inter-sectoral nature.

Type of measures	Energy efficiency losses of power plants	Reduced power output	Deterioration of power facilities
	Examples of potential adaptation measures		
Physical safeguards	• Improve or modify power plant designs to deal with extremely high temperature.	• Implement redundant and/ or hybrid cooling systems and retrofitting power plants.	• Expand modernization projects, including equipment upgrade to power facilities.
Risk	• Expand smart meter programs to allow end users to monitor their consumption.	• Develop logistical and backup plans during a sudden reduction in power output.	• Expand power generation risk engineering insurance to cover climate-induced maintenance and repair.
Knowledge	• Expand existing educational, informational, and behavioral campaigns about the implications of climate change on water and energy.		
Enablers	• Implement UAE-wide power plant design standards responsive to climate change. • Consider developing an electric utility climate change adaptation plan.		

Addressing the above risks will require interventions from both the supply and demand sides of the energy system. In general, design standards for power plants should not just account for historical climate data but also for anticipated climatic changes in the future to minimize efficiency losses and avoid power outages. In terms of demand-side management, expanding educational and informational campaigns will help influence consumer behavior and achieve energy savings. In the long term, policy interventions are necessary to address the gaps in terms of mainstreaming climate change adaptation in energy policies.

Introduction

As part of fulfilling its commitments under the Paris Agreement and in line with the UAE Vision 2021 and the UAE Green Agenda 2030, the UAE Government adopted the National Climate Change Plan 2050 (Climate Plan) in June 2017. The Plan aims to consolidate the country's climate action under a single framework that specifies strategic priorities, covering both mitigation and adaptation.

The Climate Plan structures action areas around three pillars: 1) greenhouse gas (GHG) emissions management; 2) climate change adaptation; and 3) private sector-driven innovative economic diversification. Under the adaptation pillar, the following outcomes are proposed:

- **By 2020:** Climate change risk and vulnerability assessments performed and immediate measures put in place.
- **By 2025:** Adaptation planning mainstreamed in development policy.
- **By 2030-2050:** Continuous monitoring and evaluation to ensure evidence-based adaptation measures.

As part of the implementation of the Climate Plan, the Ministry of Climate Change and Environment (MOCCAE) launched the National Climate Change Adaptation Program. The Program aims to carry out a systematic and participatory risk assessment as a basis for planning adaptation measures in four priority sectors: public health, energy, infrastructure, and the environment.

This report focuses on risk assessment for the energy sector. How energy contributes to climate change is already well understood, but how climate change affects energy systems still leaves considerable knowledge gaps. Considering the critical inputs of energy to all functions of the economy, addressing the impacts of climate change on energy systems is just as important as curbing the emissions of the energy industry itself.

Energy in the UAE comes from a variety of sources, both renewable and non-renewable. While natural gas is currently the main energy source, the contribution of nuclear, coal, solar, and hydroelectric sources is expected to increase in the near future. This report includes the various stages of the electricity cycle, namely generation, transmission, distribution, and end use. It also includes heat (district cooling and solar thermal) and off-grid/mini-grid applications of renewables and diesel generators. Oil and gas were excluded as this industry warrants a separate assessment given its size; such analyses may be covered in the future. The scope is further described below and illustrated in Figure 1:

- **Generation.** As the first stage of the process of delivering electricity to consumers, power generation involves generating electricity from renewable and non-renewable sources.
- **Transmission.** Generated electricity is then transmitted through high-voltage transmission lines over long distances from power plants to substations.
- **Distribution.** This is the final stage in electricity delivery to costumers and entails a network of substations, shorter distance power lines of low to medium voltage, distribution transformers, and customer electricity meters.
- **End use.** Electricity end use is the power directly consumed by the user to provide energy services, such as space cooling and lighting.

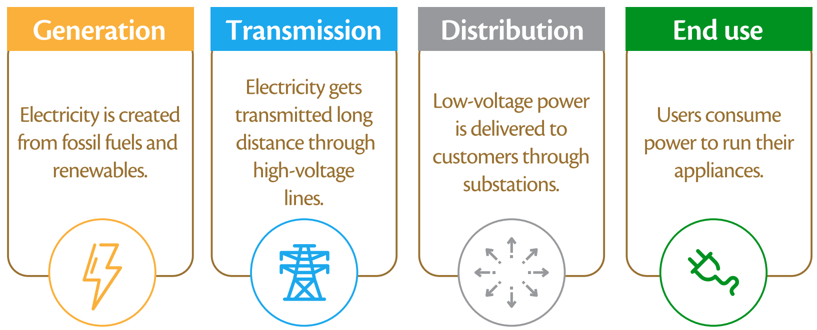


Figure 1. Stages of the energy system (modified from The Climate Reality Project)[1]

The report is divided into three chapters:

- **Chapter 1 sets the scene for understanding how climate change affects energy**. It also describes the observed and projected climate change in the UAE as well as global practices on climate resilience in the energy sector.
- **Chapter 2 focuses on the results of the risk assessment,** which was conducted based on available evidence, stakeholder consultation, and expert inputs, using a framework developed from global practices.
- **Chapter 3 presents adaptation measures** to help address the priority risks identified by the risk assessment. The measures include an extension of existing initiatives as well as new actions.

1. Climate Change and Energy

1.1. Climate change in the UAE

The Intergovernmental Panel on Climate Change (IPCC) has reported that the observed changes in the climate system are clear and have been unprecedented since the 1950s: increasing concentrations of carbon dioxide (CO_2), warming atmosphere and ocean, melting ice, and rising sea levels.[2] These global trends are projected to continue through this century and beyond, leading to a range of adverse local impacts.

Current trends and future projections of the UAE's climate are presented in Table 1. More information on past climate trends and future projections from various sources are compiled in the Annex. The Abu Dhabi Global Environmental Data Initiative (AGEDI) study projects that the UAE could be warmer in the future, with an expected temperature increase of 2–3°C, alongside increasing humidity. However, these changes will not be the same for all seven emirates as terrain, elevation, and weather patterns vary across the country. It should also be noted that there remain varying levels of uncertainty behind climate projections due to the complex interaction of climate, economic, social, and environmental factors, as well as the relative scarcity of climate modeling research for the region.

Table 1. Current trends and future projections of the UAE climate[3]

	TEMPERATURE	HUMIDITY	SEA LEVEL RISE	RAINFALL	EXTREME EVENTS
What is happening?	Temperature in summer months rises to about **48˚C** in coastal cities – even **50°C** in the desert regions.	Average humidity is **50-60%** in coastal areas; **45%** in inland areas. Extreme humidity reaches as high as **90%**.	Average sea level rise over the past decades in the Arabian Gulf is **0.18-0.23 cm** per year.	Annual rainfall is around **100 mm**.	**3 super cyclones** hit the Arabian Peninsula in 40 years. (1977-2018)
What could happen?	**2-3°C** average increase during the summer months by 2060-79	Humidity will increase about **10%** over the Arabian Gulf.	Coastal areas will experience **increasing mean high tides**.	More **intense rainfall**, particularly in Northern Emirates and Dubai.	More **frequent and severe** extreme events Growing risk of **high-impact storms**

In terms of precipitation, the AGEDI study reported that rainfall is projected to increase over much of the UAE. Increases of 50–100% from current amounts are projected for Dubai, Sharjah, and the Northern Emirates. Atmospheric modeling projects a 15–20% increase in rainfall over the Hajar Mountains by 2050. Despite the projected increases in rainfall, the number of wet days (with over 1 mm of rainfall) is projected to decrease. This implies that larger amounts of rainfall would occur during comparatively fewer rainfall events than currently observed. That said, while there might be some positive changes in terms of rainfall in some parts of the UAE, higher rates of evaporation may cancel out the increase in volume.

Sea level is also expected to rise in the UAE, increasing the threats of inundation along the coastline. Conducting climate modeling for sea level rise remains complex due to its broad suite of characteristics. Regarding extreme events, although current models cannot accurately predict their occurrence, current projections imply that they will become more frequent, their intensity more severe, and their trajectories or pathways less predictable.

1.2. Linkages between climate and energy

Energy is a valuable input in every sector of the economy as it is either directly or indirectly linked to all economic activities — from keeping buildings cool and desalinating seawater to powering appliances and so forth. There have been an increasing number of scientific studies — although only recently — documenting the impacts of climate change on energy.[4] As noted by the International Energy Agency (IEA), the energy sector must identify and evaluate how climate change impacts can disrupt supply, alter demand, and damage energy infrastructure.[5]

As defined by the IEA, resilience of the energy sector refers to the "capacity of the energy system or its components to cope with a hazardous event or trend, responding in ways that maintain their essential function, identity and structure while also maintaining the capacity for adaptation, learning and transformation."[6] Adaptation of an energy system to climate change refers to the "process of adjustment of all components of the energy system to actual or expected climate and its effects." Furthermore, adaptation in the context of the energy sector is characterized by the following components:[7]

- **Robustness:** the ability of an energy system to withstand disruptions (such as extreme weather) as well as gradual changes (e.g., sea level rise) and continue operating.
- **Resourcefulness:** the ability to effectively manage operations during disruptions.
- **Recovery:** the ability to restore operations to desired performance levels following a disruption.

Climate change can potentially cause damage to energy infrastructure, equipment, and facilities. It can also disrupt supply chains and operations, and even bring significant shifts in energy supply and demand.[8] In the power sector, direct impacts manifest when climate-related events damage energy supply installations, such as when electric substations and power plants experience flooding due to storm surge, leading to power outages. Other direct impacts include damage to power assets due to extreme heat events and warm temperatures.

On the other hand, indirect impacts include the effects on energy demand, such as an increased need for power for greater space cooling during extreme heat events. Social externalities, such as when power outages during heat waves heighten the exposure of the most vulnerable groups (i.e., children and elderlies), leading to increased morbidity and mortality, are also examples of indirect impacts. Compared to direct impacts, indirect impacts are more challenging — or even impossible — to quantify due to the complexity of assigning an economic value to intangible outcomes. Figure 2 encapsulates the differences between direct and indirect impacts of climate change on energy. Understanding these dynamics should guide the decision-making process of selecting appropriate resilience solutions.

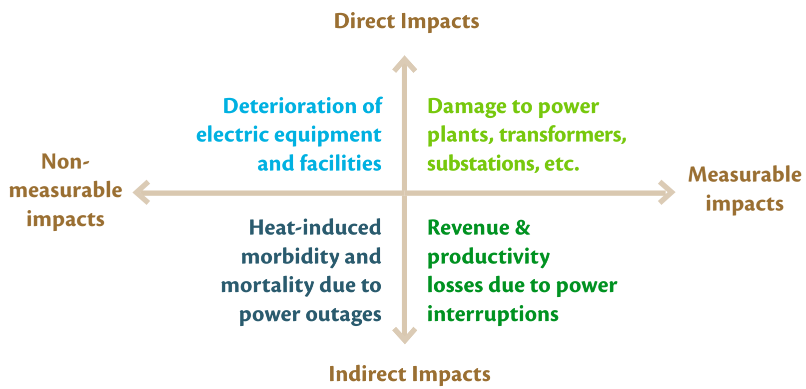


Figure 2. Examples of direct and indirect impacts of climate change on energy[9]

Since power systems may vary depending on the energy source, it is important to contextualize climate parameters *vis-à-vis* energy type and stage of delivering electricity to end users. Table 2 shows a more detailed breakdown of climate signals and which ones are most relevant to a specific energy source and stage of the power system. It shows that climate change affects all stages of power delivery in varying degrees and that some climate signals are more relevant to a particular source of energy than others.

Table 2. Indicative impacts of climate change on electricity[10]

	Climate parameters							
Energy source/stage	Air temp.	Water temp.	Water avail.	Wind speed	Sea level	Floods	Heat waves	Storms
Coal	Limited	Medium	Severe	–	–	Severe	Limited	–
Nuclear	Limited	Medium	Severe	–	Medium	Severe	Limited	–
Wind	–	–	–	Severe	Severe	Limited	–	Severe
Photovoltaic	Limited	–	–	Limited	–	Limited	Limited	Limited
CSP	–	–	Medium	Medium	–	Limited	Limited	Medium
Biomass/ Biofuel	Limited	Medium	Medium	–	Severe	Severe	Limited	–
T&D grids	Severe	–	–	Limited	Severe	Medium	Limited	Medium
End use	Medium	–	–	–	–	–	Severe	–

Notes: Impacts ratings are as follows:

Limited	Medium	Severe

– = no significant impact; T&D = transmission and distribution

1.3. Global practices on climate adaptation in the energy sector

Climate-related impacts have been occurring globally across the energy sector throughout the years as shown in Figure 3. In fact, power sector facilities and assets have experienced the most evident impacts of climate change as the effects are mostly tangible. Particularly, aging infrastructures are the most vulnerable as these assets are not designed to withstand extreme events. With the rise of more unprecedented climate-related natural disasters, the need for better understanding of climate risks and how to build resilience through adaptation has become a practical course of action for policymakers and private investors.

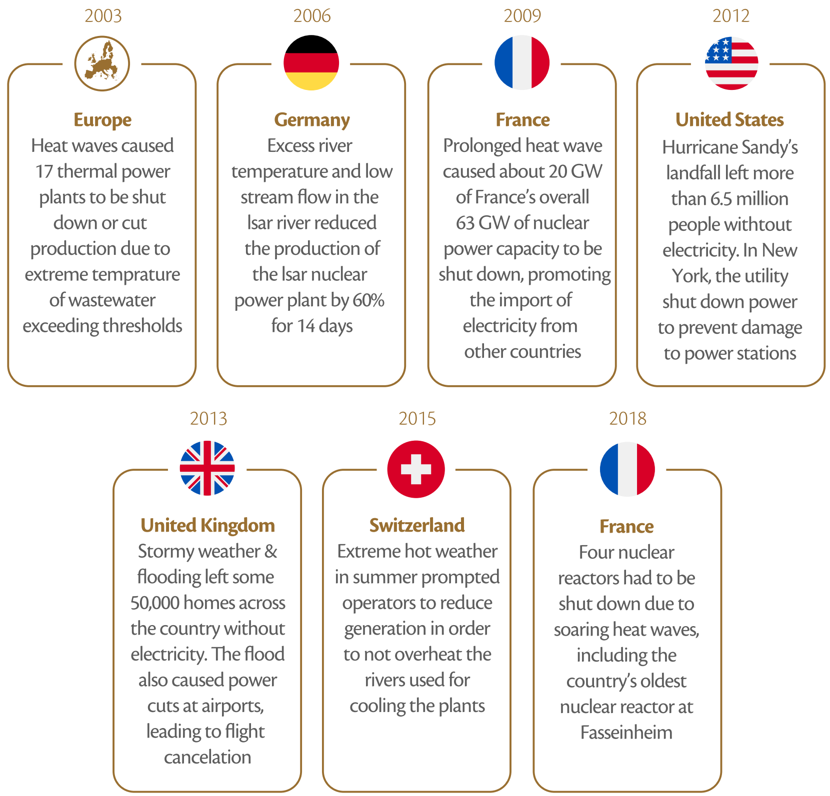


Figure 3. Global climate change impacts on the power system[11]

Generally, addressing climate change in the power sector is still viewed in the context of greenhouse gas (GHG) mitigation since the energy sector remains the largest contributor of carbon emissions in most countries, including the UAE. As such, most national energy strategies are focused on mitigation, while adaptation components are minimal or not explicitly highlighted. As noted by the European Union Energy Initiative Partnership Dialogue Facility (EUEI PDF), "[t]he energy sector is not yet a structural component of adaptation planning, even though energy can be an essential tool for resilience."[12]

Given the growing importance of adaptation to address climate impacts on energy as prompted by anecdotal evidences, some countries have been mainstreaming adaptation into their respective power supply and demand systems. Table 3 shows some initiatives on power sector resilience in Australia, Canada, and the United States, which have demonstrated considerable progress on risk assessments for the power sector. Also, in 2012, the Asian Development Bank (ADB) published a report specific to climate risk and adaptation in the electric power sector, compiling some of the best practices on power sector adaptation as depicted in Table 4.

Table 3. Examples of energy resilience initiatives in selected countries

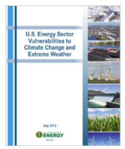
Country	Initiative
Australia 	**The Analysis of Institutional Adaptability to Redress Electricity Infrastructure Vulnerability due to Climate Change** (2013) examined the adaptive capacity of existing institutional arrangements in the National Electricity Market to climate change conditions. The recommendations were: • Address institutional fragmentation in power transmission and distribution. • Align both demand-side management (DSM) and business objectives of network service providers to avoid distorted investment deferments. • Introduce renewable energy targets for specific generation technologies ready to be commercialized with designated timelines • Improve electricity demand forecasts using a geographic information system (GIS).
Canada 	**The Adaptation Case Studies in the Energy Sector: Overcoming Barriers to Adaptation** (2016) documented a range of creative solutions to build resilience in energy systems. Some of the case studies for Canada include: • *Adapting to Reduced Equipment Thermal Ratings.* This initiative involves research and development of dynamic (real-time) thermal rating systems to prevent power outages during periods of high loads. • *New Climate Normal for Electricity Demand Forecasting.* A utility company put in place a system that uses combined weather and hydrological data to inform decision-making processes.
United States 	**The U.S. Energy Sector Vulnerabilities to Climate Change and Extreme Weather** (2013) proposed solutions to enhance power sector resilience through technologies, policies, information, and stakeholder engagement: • Technology: Support technologies on enhanced energy efficiency, reduced water intensity of thermoelectric power generation, etc. • Policy: Promote innovation policies and integration of power sector climate risks into development planning. • Information: Improve data on aggregate vulnerabilities of the energy sector to climate change as well as analysis of the costs and benefits of adaptation. • Engagement: Strengthen the dissemination of information on climate risks, vulnerabilities, and opportunities; ensure coordination among different levels of government.

Table 4. Compilation of best practices on energy sector adaptation[13]

	Direct and indirect impacts	Social/institutional
Thermal	•Enlarge or retrofit cooling systems (where water is expected to be very scarce). •Design waterproofed facilities (where increased flooding is expected).	•Avoid high-risk locations. •Impose more stringent design standards that account for climate extremes.
Nuclear	•Consider redundant cooling systems. •Assure robust protection from floods or other extreme events that can damage backup and cooling systems.	•Develop more stringent safety regulations against extreme events, including flooding.
Solar	For photovoltaics (PVs): •Consider designs that improve passive airflow beneath mounting structures. •Specify heat-resistant cells, modules, and components. •Consider distributed systems to improve grid stability and microinverters (for each panel).	For PVs: •Select locations where expected changes in cloud cover, airborne grit, snowfall, and turbidity are relatively low.
	For concentrated solar power (CSPs): •Consider more robust structures, tracking motors, and mounting. •Consider air or waterless cooling in water-restricted areas.	For CSPs: •Avoid locations with high, gusting winds or expectations of increased cyclones/ extreme events.
Wind	•Design turbines and structures that are better able to handle higher wind speeds and gusts to capture greater wind energy with taller towers. •Design new systems that are better able to capture the energy of increased wind speeds.	•Improve the reliability of expected output with better weather predictions.
T&D	•Specify redundancy in control systems, multiple T&D routes, relocation, and/or underground distribution. •Adopt higher design standards for distribution poles. •Use more effective cooling systems.	•Adopt new mandatory design codes for lines, transformers, and control systems to cope with climate change.
End use	•Increase generation and capacity to meet higher demand. •Improve the efficiency of power supply (generation, T&D system improvements). •Improve end use efficiency for buildings, facilities, and energy-intensive appliances and machinery.	•Apply mandatory minimum energy performance standards for buildings, manufacturing facilities, and appliances.

Similarly, the World Bank has documented case studies[14] on energy adaptation, noting that climate change adds a new source of uncertainties for the electricity sector and that efforts within the energy sector to address risks are still limited and patchy despite evident risks and potential opportunities. In summary, the report highlights the following lessons for energy stakeholders in the context of risk assessment and adaptation: 1) strengthen collaboration between the power sector and meteorological agency in developing high-quality and tailored climate data; 2) create a business environment favorable for climate change adaptation through incentives for power utilities to go beyond "business-as-usual" risk management; and 3) build the economic case for adaptation, by quantifying the costs and benefits to motivate utilities to act.

2. Assessing Climate Risks to the Energy Sector

2.1. Sectoral risk assessment framework

The UAE Sectoral Climate Risk Assessment Framework (Assessment Framework) consists of a five-step approach as illustrated in Figure 4. The succeeding discussions in this section are based on the application of the five steps. The process of risk assessment combines a literature review, a stakeholder consultation, and expert inputs (see the Assessment Framework document for more details).

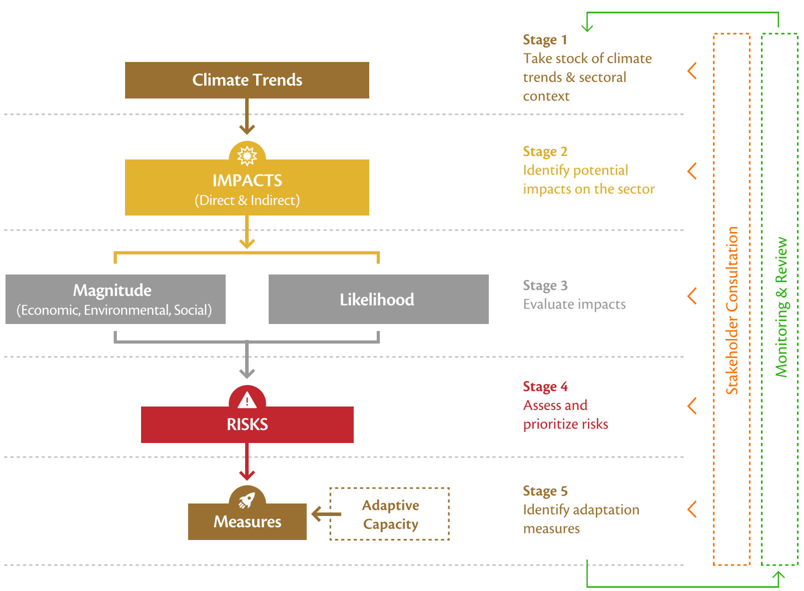


Figure 4. UAE sectoral risk assessment framework

2.2. UAE energy sector

Stage 1 of the risk assessment framework aims to provide a contextualization of the UAE's energy sector and the prevailing challenges and opportunities. Since the discovery of oil in the 1950s, the energy industry has enabled the UAE's rapid economic transformation and high standard of living. As a major oil producer, the UAE plays a central role in the global market for hydrocarbons, fostering international cooperation efforts with trade partners.

State of the energy sector

Despite having a fossil fuel-dominated power sector, the UAE has been tapping the potential of clean energy as a strategic decision to meet the country's growing energy demand, reduce reliance on fossil fuels, protect the environment and social well-being, and maximize economic opportunities brought by green industries. The country has channeled its oil revenues toward clean energy to promote a symbiotic relationship between renewables and hydrocarbons. This implies that having more renewable energy will provide the country with more available hydrocarbons to be utilized for higher-value industries and help meet global energy demand.[15]

In the UAE and the wider Gulf region, understanding electric utility planning must consider the interlinkages between energy and water as power plants are also used in seawater desalination to meet the increasing water demand in the country. Since heat generated from electricity production is used to desalinate seawater, increasing water demand will require more energy for desalination.

It is predicted that water demand in the UAE will increase to 44% by 2025 and that energy demand will double by 2020, according to the United Nations Environment Programme (UNEP).[16] There is also a move toward reverse osmosis instead of cogeneration, and this will enable a higher utilization of renewable energy generation. While the power sector is still largely fueled by gas-fired thermoelectric power plants, efforts to diversify energy sources, i.e., to also utilize solar PV and CSP, waste-to-energy, and nuclear energy, are underway.

Energy policy framework

Considering the wide range of economic, social, and environmental benefits of clean energy, there is strong leadership in the UAE to increase the share of clean energy in the total energy mix in the long term. Specifically, the UAE has set a target for power generation from clean energy to 24% by 2021 in support of the Paris Agreement. In line with this target, the Ministry of Energy and Industry developed in 2017 the UAE Energy Plan for 2050 to increase the contribution of clean energy (including nuclear) in the total energy capacity to 50% by 2050. Key targets of the UAE's energy sector include:

- Achieve the 24% clean energy target (generation).
- Achieve the 50% clean energy target (capacity).
- Reduce carbon emissions resulting from the power generating process by 70%.
- Improve energy efficiency to 40% by 2050.
- Achieve clean energy targets: 44% renewable energy, 38% gas, 12% clean fossil, and 6% nuclear energy.

The Abu Dhabi Department of Energy (DOE), the Dubai Electricity and Water Authority (DEWA), the Sharjah Electricity and Water Authority (SEWA), and the Federal Electricity and Water Authority (FEWA) are responsible for the generation, transmission, and distribution of electricity in different parts of the UAE. These public authorities are exclusive purchasers, transmitters, and distributors of electricity in each of their areas of operation. The private sector can participate in power generation and sell electricity to the authorities, although the majority of generation falls under these four entities.[17]

The Emirates National Grid (ENG) project was launched in 2001 to connect all seven emirates in a single unified power grid. The first connection between Abu Dhabi and Dubai was completed in 2006, while the connection of four entities was completed in 2008. The UAE is also connected to the GCC grid, which allows electricity to be traded to neighboring countries at a maximum of 1,200 MW.[18]

At the emirate level, various initiatives on renewable energy targets and demand-side management are planned in response to increasing energy demand (see Table 5). For example, the Dubai Clean Energy Strategy 2050 aims to transform the city into a global hub for clean energy and green technology by targeting to produce 75% of its energy requirements from clean sources by 2050. Dubai has also established renewable energy facilities, such as the Mohammed bin Rashid Al Maktoum Solar Park, the largest single-site solar park in the world. In January 2019, Abu Dhabi also started to operate the Noor Abu Dhabi, the world's largest independent solar power plant, with a generation capacity of 1,177 MW. Under the Masdar Initiative established in 2005, Abu Dhabi built the Masdar City Solar Power 10 MW photovoltaic plant as one of the country's first renewable energy projects and is registered for carbon credits under the United Nations Clean Development Mechanism (CDM).[19]

Table 5. Selected emirate-level energy policies, targets, and initiatives

Emirate-level targets	Key agency	Examples of energy initiatives
Abu Dhabi (7% renewable energy capacity by 2020)	Department of Energy (DOE)	• 100 MW Masdar solar CSP plant (350 MW PV solar park under tender) • 5,600 MW nuclear plant, including 1,400 MW Barakah nuclear plant (all four units to be operational by 2020–2024) • 1,177 MW solar power plant • 30 MW onshore wind farm in Sir Bani Yas Island • 100 MW water-to-energy plant
Dubai (7% clean energy by 25% ,2020 by 2030, and %75 by 2050, as per Dubai Clean Energy Strategy 2050)	Dubai Electricity and Water Authority (DEWA)	• Mohammed bin Rashid Al Maktoum Solar Park (total planned capacity of 1,000 MW by 2020, and 5,000 MW by 2030) • 2,400 MW Hassyan clean coal power station (Phases 1 and 2 by 2023); 1,200 MW (Phase 3) • Shams Dubai (rooftop PV targets for all buildings by 2030) • 250 MW pumped-storage hydroelectric power station at Hatta Dam by 2022
Sharjah	Sharjah Electricity and Water Authority (SEWA)	• Dependent on imports from national grid (700 MW to 1200 MW)[20] • Targets electricity self-sufficiency by 2021 by improving generation by 1.5 GW • Waste-to-energy production, generating enough power to supply 28,000 homes and increasing the rate of diversion of waste from landfills from 20% to %70
Northern Emirates (Ajman, Ras Al Khaimah, Fujairah, Umm Al Quwain)	Federal Electricity and Water Authority (FEWA)	• 200 MW solar power plant by 2025 • 1.8 GW coal-fired plant being planned based on an independent producer model • 2 MW waste to energy conversion facility is operational, and Ras Al Khaimah and another similar facility are under development in Fujairah

Going forward, the key challenge for the power sector is how to ensure long-term energy security while reducing the relative share of fossil fuel-based power generation. Energy diversification initiatives are critical in support of sustaining strong economic growth while achieving energy security through greener alternative sources. They will also enable the UAE to fulfill its international commitments in climate negotiations and serve as a role model in the region and to other hydrocarbon-based economies on how to effectively decarbonize the energy sector.

2.3. Evaluation and prioritization of climate risks

Climate impacts on energy

Climate change puts the reliability of the power system at risk as extreme events may push the operational capacity of power facilities and equipment beyond thresholds. Understanding such risks is vital to strengthening resilience. This section aims to assess climate-related risks to the energy sector. To evaluate and prioritize risks, a list of impacts has been first developed based on readily accessible international and local literature, in accordance with Stage 2 of the Assessment Framework. Table 6 identifies and characterizes climate impacts relevant to the UAE's energy sector.

Based on the long list in Table 6, a final list of nationally-relevant direct and indirect impacts is developed as shown in Table 7. These risks are exacerbated by both climate and non-climate pressures. It is imperative to note that the severity of impacts of climate change on the energy sector may differ across the UAE due to the geographical, climatic, and socioeconomic differences of the seven Emirates.

Table 6. Impacts of climate change on the energy sector[a]

Climate events/signals	Direct and indirect impacts
Rising temperature complemented by increasing humidity	•Efficiency losses of power plants when the temperature exceeds standard design criteria for power infrastructure •Reduced power output (e.g., nuclear, gas, or coal) due to the potential higher cooling temperature of seawater and/or due to lack of available seawater during extreme red tide events and extreme salinity episodesb •Increased cost of maintenance and repair due to increased deterioration of power equipment, especially aging facilities with design standards not built to meet rising temperature and extreme events •Reduced power output due to damage to power plants and infrastructure within the coastline (e.g., pipelines) •Need for greater space cooling due to the increased power demand of residential and small commercial/industrial end users •Increased power demand by non-residential end users (e.g., agriculture) because of an increase in demand for energy-intensive methods of providing irrigation •Increased episodes of partial or complete power outages due to damage to power plants and infrastructure •Reduced solar power output due to a reduction in generation caused by increased ambient temperature and humidity
Rising sea level	•Damage to power plants and infrastructure within the coastline (e.g., pipelines) during sea level rise events and extreme salinity episodes •Damage to power generation, transmission, and distribution infrastructure, including destabilization of power grids
Extreme weather and climatic events (storm, flooding, sandstorm, and fog)	•Increased cost of maintenance and repair due to increased deterioration of power infrastructure and equipment, especially aging facilities •Increased incidents of partial or complete power outages due to damage to power plants and infrastructure •Reduced solar power output due to a reduction in generation caused by cloudiness, dust, aerosol deposition, and fog •Potential dispersion of radioactive material during floods or high-impact storms
Extreme drought	•Increased power demand by non-residential end users (e.g., agriculture) •Lack of freshwater resources for hydroelectric power plants to produce/generate power due to decreased water availability

(a) The selection of preliminary risks involved a review of chapters from the most recent IPCC assessment reports. MOCCAE examined the contents and arguments related to the energy sector and selected the most evident impacts. It also used reports from organizations of global authority to verify the evidences and check for consistencies. The risks were then localized through a review of local evidence, such as scientific and policy studies conducted in the country. Through a consultation workshop, stakeholders provided inputs and the risks were further revised, incorporating their feedback.
(b) Note that extreme red tide will not lead to high seawater cooling temperature.

Table 7. Summarized list of climate risks to the UAE's energy sector[c]

Direct impacts
1. Damage to power plants and infrastructure within the coastline due to sea level rise and extreme salinity episodes
2. Damage to power generation, transmission, and distribution infrastructure, including destabilization of power grids due to extreme events
Indirect impacts
3. Efficiency losses of power plants when the temperature exceeds standard design criteria
4. Reduced solar power output due to a reduction in generation caused by increased ambient temperature, cloudiness, dust, aerosol deposition, humidity, and fog events
5. Reduced power output due to the potential higher cooling temperature of seawater caused by the lack of available seawater during extreme red tide events and extreme salinity episodes
6. Potential dispersion of radioactive material during extreme events
7. Increased energy demand for cooling purposes due to global warming
8. Increased power demand by non-residential end users due to an increase in demand for energy-intensive methods of providing irrigation and/or drinking water
9. Increased cost of maintenance and repair due to increased deterioration of power infrastructure and equipment, especially aging facilities
10. Increased incidents of partial or complete power outages due to damage to power plants and infrastructure caused by extreme events

Evaluating the magnitude and likelihood of impacts

Table 8 presents the magnitude and likelihood of the occurrence of the direct and indirect climate change impacts in the above final list. According to Stage 3 of the risk assessment framework, the magnitude of impacts was examined from three dimensions: economic, social, and environmental, whereas the likelihood was assessed based on the estimated chance that the impact may occur in the future. The combined assessment of magnitude and likelihood results in the determination of the risk level of the impacts.

(c) Risks will vary depending on the location, age, design, and adaptive capacity of energy facilities. Rising sea level will affect areas near the coast, but those areas that are well equipped with resources and capacity to counter the impacts of sea level rise will be less affected. Thus, while the above risks are representative of the UAE, site-specific assessments are advised in the future to fully account for local impacts.

Table 8. Evaluation of magnitude and likelihood of impacts

Impact	Magnitude			Likelihood	Risk level
	Econ	Env	Soc		
1. Damage to coastal power infrastructure caused by sea level rise	Very large	Moderate	Very large	Likely	Medium
2. Damage and destabilization of energy production infrastructure due to storms and flooding	Very large	Moderate	Large	Very likely	Medium
3. Energy efficiency losses of power plants when the temperature exceeds standard design criteria	Very large	Small	Very large	Almost certain	High
4. Reduced solar power output caused by increased cloudiness and humidity	Moderate	Small	Small	Likely	Low
5. Reduced power output due to warmer cooling water	Very large	Moderate	Large	Almost certain	High
6. Potential dispersion of radioactive material during extreme events	Very large	Very large	Very large	Unlikely	Low
7. Increased energy demand for cooling purposes due to global warming	Very large	Large	Moderate	Very likely	Medium
8. Increased energy demand from agricultural production due to energy-intensive methods	Very large	Moderate	Moderate	Likely	Medium
9. Deterioration of power facilities leading to reduced reliability and increased maintenance cost	Very large	Small	Very large	Almost certain	High
10. Increased incidents of power outages due to damage caused by high-impact storms and flooding	Large	Small	Large	Very likely	Medium

In line with Stage 4 of the risk assessment framework, the climate impacts with "very high" and "high" risk levels have been identified as priority risks that the UAE need to address most urgently. Three priority risks are identified as "high": a) energy efficiency losses of power plants when the temperature exceeds standard design criteria; b) reduced power output due to warmer cooling water; and c) deterioration of power facilities leading to reduced reliability and increased maintenance cost.

- **Energy efficiency losses of power plants when the temperature exceeds standard design criteria.** The economic and social impacts of efficiency losses are considered "very large" due to the increasing energy demand in the UAE (which puts more pressure on power plants) and the expected increase in the temperature (2–3°C by 2060–2079). In the UAE, energy demand increases by 10% per year and predicted to double by 2020.[21] Without further action on energy efficiency and conservation, higher temperatures will increase electricity costs and create a need for additional generation capacity.[22] Nonetheless, some entities in the UAE are well prepared to address this risk as power generation units are designed to operate up to an ambient air temperature of 50°C, and gas turbines are equipped with advanced cooling systems to reduce the impact of high ambient air temperature.

- **Reduced power output due to warmer cooling water.** Although actual projections for sea surface temperatures are not explicit, it is certain that the overall temperature in the UAE will rise, and this will have impacts not only on terrestrial but also coastal and marine areas, which are the sources of water for cooling for many of the power plants. This explains why the likelihood for this risk is "almost certain." According to researchers, an increase of cooling seawater temperature of 15°C results in a 2% loss of efficiency and about a 6% power loss for a power plant. A 1.5°C increase in seawater temperature due to climate change, which could be seen in the Arabian Gulf by 2040s, would lead to a power loss of around 0.5%.[23][24]

- **Deterioration of power facilities leading to reduced reliability and increased maintenance cost.** The likelihood of this impact is almost certain as power sector stakeholders confirmed that in recent years, climate change-induced events, such as higher temperatures and extreme weather, have been observed to have affected the performance of power facilities. A study on a solar desalination plant in Abu Dhabi established the strong seasonal effect of dust deposition on plant performance, especially during the summer months due to sandstorms. It can cause a monthly drop in glass tube transmittance of 10–18%, which can result in a large reduction in energy production.[25]

Other impacts fall under "medium" risks, which may be relatively acceptable in the short term, but a thorough investigation is necessary to implement control measures to minimize the risks so that the "medium" risk level will not turn into "high." The impacts with "low" risks require sporadic monitoring to determine changes in the situation which may affect the risk level. Figure 5 demonstrates a more visual way of communicating the results of the assessment by plotting all impacts in a color-coded, 5-by-5 risk matrix.

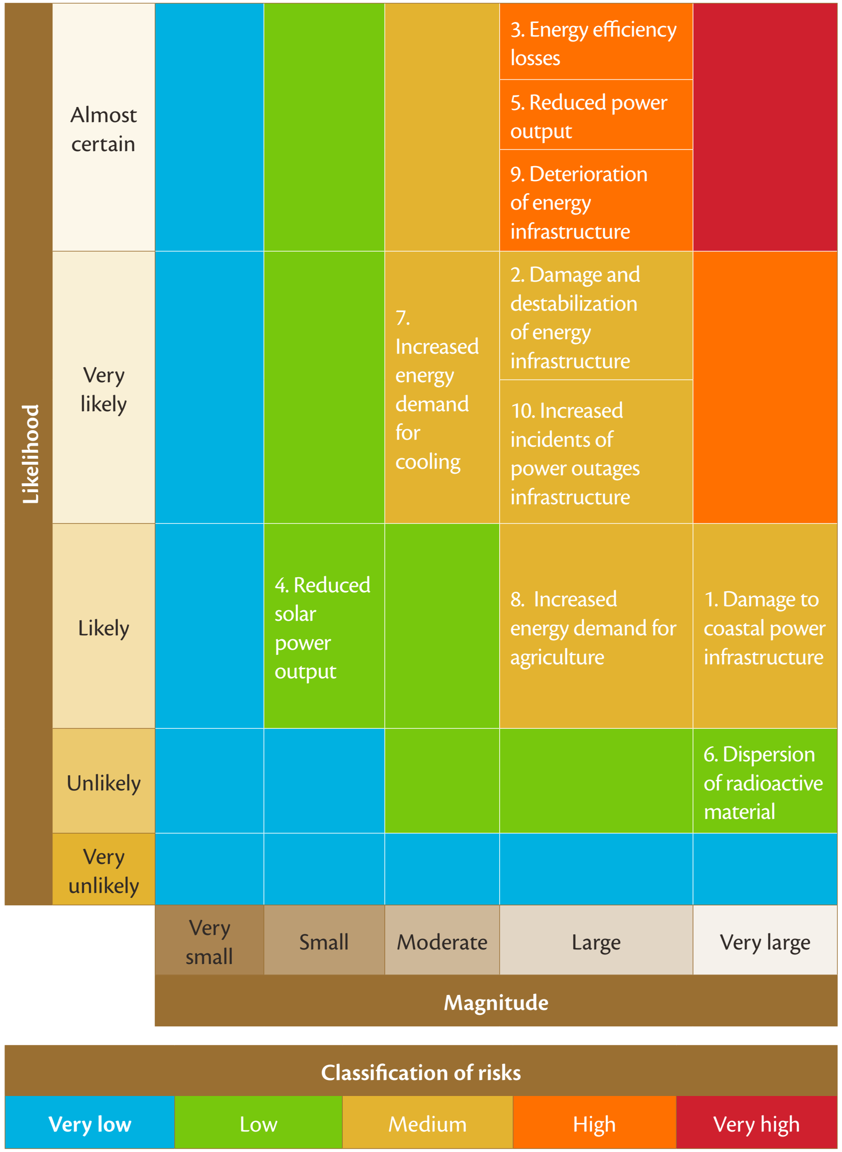


Figure 5. Risk matrix for the energy sector

3. Options for Action

3.1. Initiatives on climate adaptation in the energy sector

This chapter applies Stage 5 of the risk assessment framework, elaborating potential actions to address the priority risks identified in the previous chapter. In providing recommendations, it is important to acknowledge existing initiatives relevant to climate change adaptation in the energy sector. This will help identify gaps and explore the opportunities for addressing them.

Measures for climate change adaptation can be generally classified into four types:[d]

- **Physical safeguards** refer to engineered structures, technological systems, and services, as well as ecosystem-based infrastructure, that support adaptation objectives.
- **Risk management** covers the regulations, incentives, and financial mechanisms, as well as early warning systems and emergency plans, that directly address climate risks.
- **Knowledge** encompasses climate data and research, risk assessment, and awareness campaigns and communication.
- **Enablers** are foundational policies not directly targeting adaptation but providing an enabling condition for improving resilience.

Tables 9–11 show examples of climate actions that are relevant to addressing the priority risks identified in the previous chapter according to the abovementioned adaptation measures categories. The list is not exhaustive and only intends to provide illustrative examples.[e] The measures include both options directed to address the risk itself and those that could compensate or offset the risk and help build resilience. MOCCAE developed the proposed measures based on the results of the risk assessment and existing initiatives.

(d) This typology of adaptation measures is consistent with IPCC categories (structural/physical, social, and institutional adaptation) and the World Health Organization adaptation measure taxonomy (risk management, information, foundations).

(e) Most of the recommendations focus on either continuing current efforts or addressing the challenges through new initiatives in line with international best practices. Some measures may require collaboration across authorities due to the inter-sectoral nature of adaptation initiatives. Note that the associated costs of the proposed measures are not considered as it is beyond the scope of this report and separate analyses are required.

Table 9. Potential adaptation measures for "high" risk (a)

Type of measures	Energy efficiency losses of power plants	
	Existing measures	Additional measures
Physical safeguards	•Redundant and passive cooling systems •Substation modernization using IEC 61850 Edition 2 (DEWA)[f] •Concentrated solar power in residential areas (e.g., Hatta villas)	•Improve or modify power plant designs to deal with an extremely high temperature •Install output efficiency monitoring systems to properly account for losses during spikes •Expand smart grids and smart transformers across all emirates
Risk management	•DEWA's Smart Power Plants system •Risk insurance schemes for power generation	•Explore more innovative insurance schemes for power plants •Adopt DEWA's advanced risk mitigation strategy in other emirates.
Knowledge	•Green Dubai initiativeg •DEWA's Let's Make this Summer Green and Peak Load campaigns •Sharjah's Peak Hour Campaign •Online Monitoring for Improvement of Power Plant Performance (for nuclear plants)	•Expand existing awareness-raising activities about the effects of climate change on power output efficiency and overall electricity supply. •Expand smart meter programs to allow end users to monitor their consumption and potential impact on the electricity grids, which can hopefully help modify consumer behavior.
Enablers	•Dubai Clean Energy Strategy 2050 and DSM 2030 •UAE's Nuclear Liability Law •Electricity Law (Dubai, Abu Dhabi) •Incident Reporting Regulations 2008 •Dubai's Green Building Regulations	•Implement UAE-wide power plant design standards that are responsive to climate change. •Encourage organizational adoption of ISO 50001, a global energy management system standard. •Institutionalize load forecasting using climate information and expand collaboration of utilities with meteorological services. •Develop logistical and backup plans during a sudden reduction in power output.

(f) According to the International Electrotechnical Commission, IEC 61850 is an "international standard defining communication protocols for intelligent electronic devices at electrical substations. It is a part of the International Electrotechnical Commission's Technical Committee 57 reference architecture for electric power systems." This is part of DEWA's campaign for substation automation.

(g) Green Dubai is DEWA's initiative that provides incentives to customers to make sustainable choices in three areas: 1) smartphone application on high water usage alert; 2) electric vehicle charger; and 3) installation of photovoltaic solar panels on rooftops.

Table 10. Potential adaptation measures for "high" risk (b)

Type of measures	Energy efficiency losses of power plants	
	Existing measures	Additional measures
Physical safeguards	•Redundant cooling systems for nuclear power plants •Emirates National Grid project •Concentrated solar power projects	•Implement redundant and/or hybrid cooling systems for lower water requirements in power plants. •Consider retrofitting power plants to potentially accommodate high salt-tolerant cooling systems. •Explore the potential of fog harvesting
Risk management	•Risk insurance schemes for power generation	•Explore more innovative insurance schemes for power plants.
Knowledge	(Same as in Table 9)	
Enablers	•Power tariff incentive schemes for end users •Abu Dhabi's Estidama Initiative[h] •DEWA's Integrated Management System Policy •UAE's Nuclear Liability Law •Electricity Law (Abu Dhabi, Dubai, FEWA) • Incident Reporting Regulations 2008	•Ensure presence and availability of power plant emergency repair and restoration teams. •Require higher standards in the design of new power facilities or in refurbishing existing power infrastructure. •Promote a power infrastructure enhancement program. •Consider developing an electric utility climate change adaptation plan. •Review and modify maintenance and operating plans, incorporating climate factors.

(h) "Estidama" is the Arabic word for sustainability. The Estidama Initiative by the Department of Urban Planning and Municipalities in Abu Dhabi aims to improve the efficiency performance of new buildings and promote ratings on sustainability in the design, planning, and construction phases of new urban developments.

Table 11. Potential adaptation measures for "high" risk (c)

Type of measures	Energy efficiency losses of power plants	
	Existing measures	Additional measures
Physical safeguards	•Substation modernization using IEC 61850 Edition 2 (DEWA)	•Expand modernization projects, including equipment upgrade in power facilities similar to DEWA's modernization initiative for substations •Reinforce existing power structures to ensure stability during extreme events
Risk management	•Risk insurance schemes for power generation	•Expand power generation risk engineering insurance to cover climate-induced maintenance and repair •Promote sector-wide adoption of ISO 50001
Knowledge	(Same as in Table 9)	
Enablers	•Power tariff incentive schemes for end users •Abu Dhabi's Estidama Initiative •DEWA's Integrated Management System Policy •UAE's Nuclear Liability Law •Electricity Law (Abu Dhabi, Dubai, FEWA) •Incident Reporting Regulations 2008	•Ensure presence and availability of power plant emergency repair and restoration teams. •Require higher standards in the design of new power facilities or in refurbishing existing power infrastructure. •Promote a power infrastructure enhancement program •Consider developing an electric utility climate change adaptation plan •Review and modify maintenance and operating plans, incorporating climate factors

It is evident that the UAE is already implementing a portfolio of resilience solutions, although the aspects related to adaptation are not explicitly emphasized. It is therefore critical to understand the synergy or co-benefits of mitigation and adaptation efforts in all climate actions to help raise public awareness and catalyze better-informed actions. For example, while there are initiatives to minimize efficiency losses, such as the application of enhanced cooling systems or the adoption of smart technologies, adaptation is not the core component of these efforts. As such, it is important that adaptation to observed and expected impacts of climate change become the integral driver in scaling up existing efforts and implementing new ones.

It is important to note that the potential adaptation measures are based on international best practices and tailored to the UAE context. In scaling them up, the proposed measures should clearly account for impacts of climate change throughout the life cycle of power delivery to ensure resilience. More robust design requirements are necessary to cope with climate pressures. Furthermore, improving the reliability of control systems through enhanced automation also improves the adaptive capacity of the power sector to cope with climate impacts. Operational and maintenance practices should also respond to the evolving demands of climate change in electric utility investments.

3.2. Opportunities and way forward

Making the power sector resilient to the impacts of climate change will require short- and long-term measures to reduce risks and transform such risks into opportunities. Considering the findings from the risk assessment and examination of current initiatives, there are opportunity areas for scaling up actions as well as new innovative approaches. Key opportunities include:

- **Support investments in climate-smart technologies and facilities.** Upon the conduct of site-specific risk assessments of weather and climate-related causes of actual and anticipated utility operational impacts, adaptation actions may include the use of artificial intelligence, using drones to pre-assess potential on-site utility damages at the event of a forecasted storm.[26] This example can help power utility companies to put in place measures to minimize the impending impacts of a storm or cyclone. Expanding underground lines to avoid exposure to extreme heat and storm damage is also critical. As such, developing submersible equipment that can withstand extended flooding is another example of climate-smart technology for the energy sector.[27] Other examples include strengthening transmission and distribution lines by adding structural reinforcement to existing lines such as steel poles, and elevating existing and new equipment, building floodwalls to prevent exposure of substations, transformers, pumps, etc.

- **Regularly review the design criteria for energy utilities and develop climate-focused management strategies for the energy sector.** While current power facilities in the UAE are built to endure the harsh climate in the country, projections show that observed climatic events may become more extreme in the future. As such, it is important to revisit the design specifications of power infrastructure, facilities, and equipment on a regular basis. Design configuration for new assets should incorporate extreme climate events. Further, the electricity load management should focus on measures that would reduce incidents of power outages. This also involves improving the ability to have backup power in times of climatic emergencies through decentralization of some parts of the system.

- **Improve knowledge on location-specific risk assessment.** This will entail conducting a comprehensive inventory of power infrastructure and facilities and paying special attention to those located in high-risk areas. Continuous improvements in climate modeling will help lessen the uncertainty of climate projections and address gaps in the vulnerability of the power sector to climate change. Considering the expected rise in energy demand and investments in the next decades, sufficient resources must be allocated to ensure adequate assessment, accounting, and management of climate risks to energy systems.

- **Promote knowledge sharing and training on power sector adaptation.** Staff exposure to climate change adaptation at the federal and emirate levels is still minimal because most of the training programs and workshops focus on mitigation. Instituting a department dedicated to climate change adaptation with assigned adaptation focal points within the authorities is advised.

- **Communicate to stakeholders the benefits of integrating climate variables in the planning and management of climate-proofing the power system.** Stakeholder engagement for adaptation should emphasize how climate proofing represents a good business practice for the benefit of consumers and utilities. Also related to stakeholder management is the improvement of inter-sectoral collaboration on risk assessment and adaptation by working with other sectors beyond the energy system, such as linkages with the water and food production systems. It is important to note that identifying specific actors involved in different responses, assigning roles and responsibilities to promote local ownership, and considering current management responses to climate variations being done by other sectors can influence energy outcomes.

- **Mainstream climate risk assessment and adaptation in energy planning.** At the federal and emirate levels, climate change issues are not yet fully integrated into the energy systems via institutional mandates, strategic goals, key performance indicators, annual work plans, and budgets. Among energy entities, awareness and understanding of climate change are associated with mitigation; this necessitates a more explicit reorientation or integration of climate adaptation in activities related to this area.

- **Develop a long-term strategy to climate-proof the power system.** Consider the development of a federal energy adaptation plan in the future or develop national guidelines for utilities to create their own local energy adaptation plans. In the energy sector, for instance, a national energy adaptation vision that will address long-term energy impacts of climate change is highly recommended to highlight a more proactive approach to climate-proofing the power sector and emphasizing preventive adaptation measures.

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Annex:
Summary of Climate Change Projections

	Global	Regional (Arabian Gulf)	National (UAE)
Temperature	**2046–2065** [A] • RCP 2.6: 0.4–1.6°C • RCP 4.5: 0.9–2.0°C • RCP 6.0: 0.8–1.8°C • RCP 8.5: 1.4–2.6°C **2081–2100** [A] • RCP 2.6: 0.3–1.7°C • RCP 4.5: 1.1–2.6°C • RCP 6.0: 1.4–3.1°C • RCP 8.5: 2.6–4.8°C	**By the late 21st century:** 3–4°C [B] **RCP 4.5** [C] 2050: 1.2 1.9° C 2100: 1.5–2.3° C **RCP 8.5** [C] 2050: 1.7–2.6 °C 2100: 3.2–4.8 °C	**2060–2079: 2–3°C** [D] **2050: 2.1–2.8°C** **2100: 4.1–5.3°C** [E]
Humidity	By 2100, the combination of high temperature and humidity is expected to compromise human activities, including growing food and working outdoors (high confidence). [F]	Heat waves due to high humidity in the Gulf could increase, leading to higher exposure to heat-related diseases. [G]	Humidity changes are greater in the summer months, about 10% greater over the Arabian Gulf, with higher humidity across most of the UAE. [D]
Sea level rise	**2046–2065** [A] • RCP 2.6: 0.17–0.32 m • RCP 4.5: 0.19–0.33 m • RCP 6.0: 0.18–0.32 m • RCP 8.5: 0.22–0.38 m **2081–2100** [A] • RCP 2.6: 0.26–0.55 m • RCP 4.5: 0.32–0.63 m • RCP 6.0: 0.33–0.63 m • RCP 8.5: 0.45–0.82 m	**Predicted sea level rise scenarios for the Southern Arabian Gulf by 2099:** • Low scenario: 0.21 m [H] • Medium scenario: 0.59 m [A] • High scenario: 0.81 m [I] • Extreme scenario: 2.0 m [J]	**According to different sources, all coastal cities in the UAE will experience progressively increasing inundation:** • Sea levels increasing by 20–30 cm in the coastal shallows of the UAE. [K] • Sea level rise may advance landward flooding at a rate of 23–58 m per year and result in flooding 2.26–3.81 km from the shoreline by 2100. [L] • In the worst-case sea level rise scenario, inundation may extend to 25–30 km in Abu Dhabi by 2100. [M]
Rainfall	Changes in precipitation will not be uniform. [F] It is likely that the frequency or proportion of heavy rainfalls in total precipitation will increase. [N]	By the end of the 21st century, there is a reduction of the average monthly precipitation reaching 8–10 mm in the coastal areas of the Arab Domain. Some areas, however, show increasing precipitation trends. [C]	Rainfall in the UAE will likely increase, especially in the summer (50–100% in the Northern Emirates and Dubai, and 25% in surrounding regions). [D]
Extreme events	Models project substantial warming in temperature extremes by the end of the 21st century. It is likely that the frequency or proportion of heavy rainfalls in total precipitation will increase. [K]	Being in the domain of the monsoon system, the southern part of the Arabian Peninsula is expected to receive more precipitation in the form of extreme events, such as when Cyclone Gonu hit Oman in 2007. [N]	An increasing risk for "grey swan" (high-impact) cyclones to hit the UAE is predicted. Albeit a low likelihood, this will have a high impact. [O]

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