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A Dry Spell: Water in 2024

Energy Research Paper

The Al-Attiyah Foundation

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Over 1.4 billion people, including 450 million children, inhabit regions grappling with high or extremely high-water vulnerability. This number is projected to increase in 2024, underscoring the urgency of optimising water use and identifying new and dependable water sources. Rapid industrialisation and urbanisation in some of the globe's fastest-growing economies have further strained already-stressed water resources. The electricity sector and smelting facilities and industries involved in chemical production and food processing contribute to this additional stress.

How is water scarcity challenging global security? What are some of the innovative solutions targeting sustainable and reliable water supply? What are the implications and opportunities for the GCC?

ENERGY RESEARCH PAPER

This research paper is part of a 12-month series published by the Al-Attiyah Foundation every year. Each in-depth research paper focuses on a current energy topic that is of interest to the Foundation's members and partners. The 12 technical papers are distributed to members, partners, and universities, as well as made available on the Foundation's website.

Introduction

- World Water Day, which was observed on 22 March, reminds us that water scarcity, Arctic ice melt, and rising sea levels pose urgent global challenges, potentially uncontrollable and irreversible. In the coming decade, this issue will profoundly impact global security, as 1.4 billion people are exposed to absolute water scarcity, increasing tensions between rival state and non-state actors[1]. In the longer term, disputes over Arctic water access will also drive the regional and global water security landscape. And the effects of melting ice on rising sea levels could displace millions leading to large-scale border neglect, uncontrolled migration, and public unrest.

Water Use and Efficiency by the Industrial and Energy Sector

- Water quality and accessibility challenges pose a significant risk for industry and can cause disruptions in supply chains. These risks could be reduced by implementing technologies that recycle and reuse wastewater, as well as making changes to materials intensity and industrial processes and equipment to enhance efficiency.
- Electricity generation, including thermal and nuclear power cooling, accounts for the majority of water withdrawals, much of which is later returned to the natural water system, in contrast to primary energy production (from fossil fuels and biofuels), which is the main source of water consumption. To achieve the UN's sustainable development goal (SDG) 7 (access to affordable, reliable, sustainable, and modern energy), there must be a substantial increase in the use of renewables, which will also contribute to achieving SDG 6 (access to clean water and sanitation), particularly in regions facing water scarcity. However, increased use of biomass and hydroelectricity pose challenges to water scarcity and are themselves affected by it.

Unconventional Water Resources

- In arid regions facing water-related sustainable development challenges, there is an emerging opportunity to narrow the water demand-supply gap by complementing conventional methods with unconventional resources. These resources span from Earth's seabed to its upper atmosphere and capturing them requires a diverse range of technological solutions and interventions such as fog-water harvesting, cloud seeding for rain enhancement, micro-catchment rainwater harvesting, offshore and onshore deepwater extraction, and even iceberg towing.

'Green' Desalination

- Desalination technologies face a significant challenge from the production of high salinity concentrates or brine. Improper discharge of this brine can impact the aquatic environment near the plant outfall. However, global long-term experience shows that when properly designed and operated, seawater desalination plant discharges are environmentally safe and do not significantly affect the marine habitat in the discharge area.

- Renewables could play an important role in water desalination. Technologies ideal for desalination encompass solar thermal, photovoltaics, wind, and geothermal energy. Concentrating solar power, which generates substantial heat, is particularly suited for thermal desalination. Additionally, combining electricity generation with water desalination can effectively address electricity storage challenges when generation exceeds demand.

Challenges and Opportunities for the GCC

- GCC countries show limited signs of becoming more frugal in their water consumption. Despite generous state subsidies that keep water prices low, demand has surged across the domestic industrial and agricultural sectors. Presently, the annual / capita water usage in GCC countries stands at 560 litres / day, significantly higher than the global average of 180 litres / day[ii].
- The GCC countries should intensify their efforts to manage the water-energy nexus to enhance water and energy security. Key reforms include tackling subsidies and pricing structures that hinder conservation, promoting the reuse of treated wastewater, and boosting investments in renewable energy. These actions would not only benefit the climate, jobs, and fiscal stability but also contribute to overall sustainability.

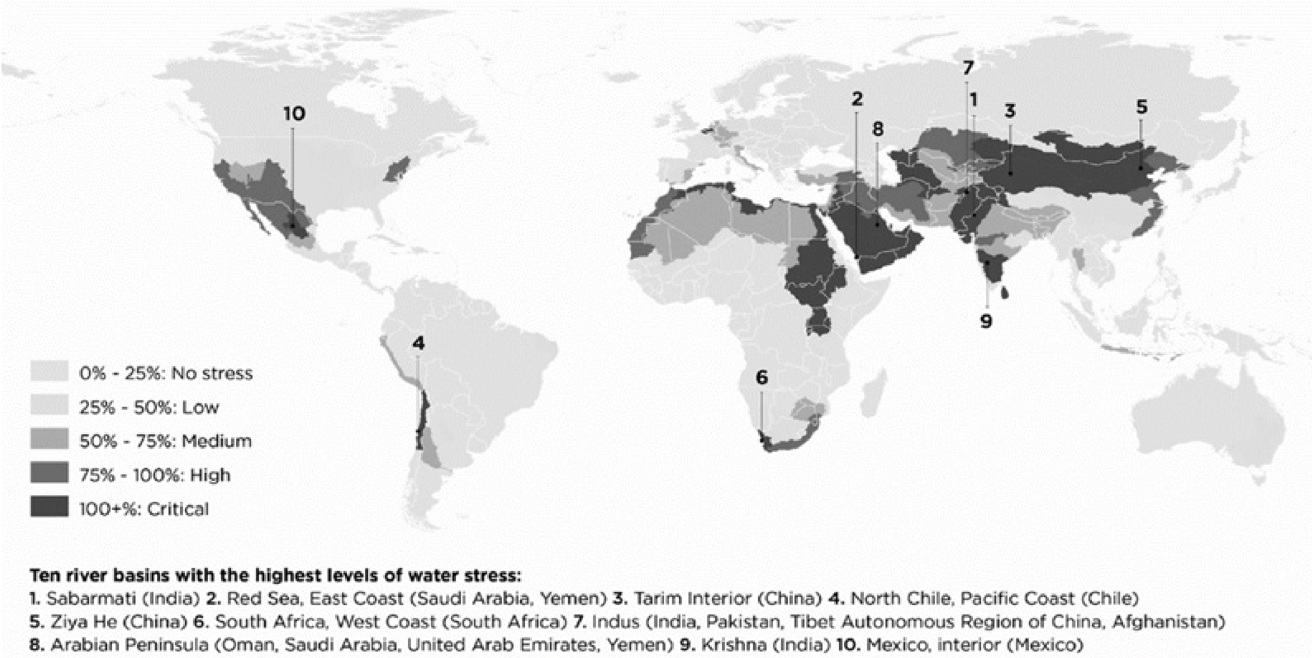
05 BACKGROUND

Water scarcity, Arctic ice melt, and rising sea levels, pose urgent global challenges that are uncontrollable and irreversible. In the coming decade, water scarcity will profoundly impact global security as 20% of the global population is exposed to absolute water scarcity, increasing tensions between rivalling state and non-state actors[iii]. In the longer term, disputes over Arctic water access will also drive the regional and global water security landscape. The effects of melting ice on rising sea levels could displace millions, leading to large-scale border neglect, uncontrolled migration, and public unrest.

Water scarcity casts a devastating shadow over large segments of the Middle East and African populations. Members today of traditional pastoral and agricultural cultures and societies, faced with this crisis, will be compelled to migrate to cities in waves of mass urbanisation. Even on a smaller scale, rapid, unplanned urbanisation has historically exacerbated poverty, significantly lowered living standards, and escalated crime rates. These consequences not only jeopardise national security for individual states but can pose a regional and global security threat. Contrary to the "realist" notion that state security hinges primarily on military and other hard might vis-à-vis other nations, the surge in illegal border crossings by water refugees will go beyond the control of state apparatus Desperate measures, including involvement in organised crime, may become the grim reality for those striving to survive amidst increasingly harsh conditions.

Topographic atlases are valuable starting points for anticipating future water conflicts. Key waterways such as the Euphrates, Tigris, Nile, Colorado, Murray-Darling, Mekong, and Brahmaputra, vital but shrinking water bodies such as Lake Chad and the Aral Sea, along with water reservoirs in Sub-Saharan Africa and the Gulf Cooperation Council (GCC) countries, are already central to regional and national security discussions.

Figure 1: Water Stresses by Major River Basinscountries, 11 March 2024[vi]



Access to these critical freshwater sources will become an even more pressing concern. Disputes are intensifying, and the spectre of violent clashes over water looms ever closer. In 2022, there were 228 water-related violent incidents and 117 incidents between January – June 2023[IV]. Over the last two years, there has been a surge in deliberate attacks on civilian water systems amid the ongoing war between Russia and Ukraine and across the Middle East in Gaza, the West Bank, Yemen, Syria, Iraq, and Israel. Unless decisive action is taken, there is little reason to believe that this number will decrease over the years ahead.

In other parts of the world, disputes over access to Arctic waters, the Northwest Passage, and Greenland's periphery are reshaping the regional and global security landscape. Unlike the predominantly equatorial water scarcity challenges, the Global North confronts a different dilemma: the accelerated melting of Arctic ice.

This paradoxically yields not only ample freshwater but also opens up new waterways for global trade and access to potentially vast oil & gas reserves. Geopolitical manoeuvring has already commenced among the stakeholders including Canada, the United States, Russia, Denmark (via its dependency of Greenland), Iceland, and Norway. China also considers itself a "near-Arctic" state. Each lays claim, to varying degrees, on parts of the soon-to-be ice-free Arctic. As the ice recedes, it unveils new arenas of influence, property rights disputes, and resource access struggles. The destabilising potential of these dynamics combines with other problems, such as the breakdown of West-Russia relations, even when the actors are ostensibly committed to international law and conventions.

Rising sea levels will compel millions of people to abandon their homes, resulting in widespread disregard for state borders, uncontrolled migration, and public unrest.

The Ganges-Brahmaputra Delta outside Bangladesh will experience sea level increases of 14 cm, 32 cm, and 88 cm by 2030, 2050, and 2100, respectively; and would lead to the submergence of 8%, 10%, and 16% of Bangladesh's total land area[V]. Given Bangladesh's already high population density, this situation will transform millions of Bangladeshi residents in coastal regions into climate refugees, exerting immense pressure not only on the country's vulnerable food security, but also impacting neighbouring nations and the broader region. If current warming trends persist, swathes of major cities like London, New York, Bangkok, Shanghai, Alexandria, and Karachi may eventually find themselves below sea level, potentially within our lifetime. The rising sea level will also contaminate both surface and underground freshwater sources, exacerbating the world's existing water scarcity.

Therefore, freshwater, whether scarce or abundant, must be recognised not only as a component of the climate challenge, but also as a critical global security concern and a matter of human survival. The irony lies in the fact that the very elemental necessity for life has now become potentially life-threatening.

WATER USE AND EFFICIENCY BY THE INDUSTRIAL AND ENERGY SECTOR

Effectively managing water reliability and supply security is essential in industry, despite its varying direct impact on GDP across different countries. Industries such as pharmaceuticals, which are less water-intensive, are strongly linked to GDP growth because of a higher value-add, in contrast to water-intensive sectors such as food, beverage, cotton, and textiles with lower levels of technological sophistication and value-add.

Water quality and accessibility challenges pose a significant risk for industry, which can cause disruptions in supply chains. These risks could be reduced by recycling and reusing wastewater, as well as making changes to materials intensity and industrial processes and equipment to enhance efficiency.

A recent survey conducted by Carbon Disclosure Project found that 1 in 5 companies worldwide are facing supply chain water risks that could have a major impact on their operations[VI].

Out of 3,163 surveyed companies, 623 with assets totalling US$77 billion were identified as being at risk due to water-related issues in their supply chains[VII]. The survey also indicated a growing trend in companies disclosing these risks as concerns about the global water crisis continue to grow[VIII]. There is increasing interest in investing in companies focussed on water-related challenges, for instance the Invesco Water Resources fund in the US[IX].

The mining & metals industry is the largest metal polluter overall. Yet, the technology sector, responsible for producing semiconductors, circuit boards, and batteries, also contributes to metal pollution, releasing substances like mercury, copper, iron, zinc, nickel, chromium, lead, tungsten, and lithium into wastewater and through E-waste leaching. These metals remain in lakes and rivers, posing a threat to ecosystems and human health as they can accumulate.

To achieve sustainable water management in industry, the relationship between water and industrial production must be decoupled by integrating methods that blend economic gains with environmental benefits.

The traditional linear flow of water model in industry, from extraction and usage to wastewater discharge, typically hinders reuse and recycling. However, there are numerous established technologies that can help reduce water usage (by lowering withdrawals and consumption) and promote reuse and recycling. Enhancing water efficiency involves making adjustments to materials, processes, and equipment. Technical solutions such as leak detection systems, water-free heat transfer systems, cooling towers, and heat exchangers that allow water recirculation in a closed system within the industry can lead to additional reuse. Significant savings in water consumption can be achieved through closed loop reuse, recycling with treatment, and reusing wash water.

The industrials sector can also benefit from treating wastewater as a sustainable source of energy, nutrients, and by-products, where harmful discharges are reduced and the need for freshwater is decreased.

Wastewater plays a crucial role in eco-industrial parks, where the concept of 'industrial symbiosis' allows it to flow through multiple industries, resulting in cost savings on treatment, particularly for small and medium-sized industries. These parks are a key part of the circular economy, emphasising inclusive and sustainable industrial development with a strong focus on water efficiency through repeated water use.

An example of global best practice in eco-industrial parks is the Kalundborg Industrial Symbiosis in Denmark, which saves 2 million m^3 / year of groundwater by using surface water[X].

The water requirements for generating fuels and electricity varies significantly based on resources, extraction and conversion processes, and energy output.

Electricity generation, including thermal and nuclear power cooling, accounts for the majority of water withdrawals, much of which is eventually returned to natural water systems, although it may be contaminated or at higher temperatures. This in contrast to primary energy production (from fossil fuels and biofuels), which is the main source of water consumption. To achieve the UN's sustainable development goal (SDG) 7 (access to affordable, reliable, sustainable, and modern energy), there must be a substantial increase in the use of renewables, which will also contribute to achieving SDG 6 (access to clean water and sanitation), particularly in regions facing water scarcity. However, biomass / biofuels and hydroelectricity involve substantial water withdrawals and some losses. They are also heavily exposed to water scarcity or unpredictability.

In 2022, solar photovoltaic (PV) technology accounted for over 40% of global investments in electricity generation, three times the investments in fossil fuel-based electricity projects[XI]. Solar PV has a low water requirement for manufacturing and panel cleaning and when used as floating systems over bodies of water, it can even help reduce water loss via evaporation. On the other hand, concentrated solar power (CSP) demands significant amounts of cooling water, posing challenges in hot and arid climates where it is most effective[XII].

Alternatives like dry cooling can be less efficient and more costly, but hybrid wet / dry cooling methods could reduce water consumption by 50% with minimal impact on efficiency.

Decarbonising the energy system will rely significantly on the accessibility of critical minerals. For instance, solar PV requires about six times more of these minerals per megawatt of installed capacity compared to natural gas projects[XIII]. Mining and processing these critical minerals often requires increased water usage and pose high levels of eco-toxicity.

Wind power has limited interaction with freshwater. Currently, the main water connection is with saltwater, as many wind farms are located offshore.

Water-based electricity such as hydropower currently accounts for 16% to global generation[XIV]. With proper design and maintenance, hydropower projects can operate for more than 100 years. Pumped-storage hydropower offers benefits such as energy balancing, stability, storage capacity, and grid services like network frequency control and reserves. It will gain further importance for balancing variable renewables, particularly over longer timescales (weeks to seasonal).

Biofuels have similar to significantly higher water intensity compared to fossil fuels. For instance, irrigated soybeans and biodiesel can range from 103 – 106 litres of water / tonne of oil equivalent (toe), while conventional oil falls within the range of 102 – 104 litres of water / toe[XV]. Water quality is a key consideration, as runoff from biofuel cultivation may contain fertilisers and pesticides.

Nuclear power uses approximately the same amount of water per unit of energy as coal and natural gas projects. The common practice of once-through cooling can lead to increased discharge water temperatures and environmental harm. Concerns over safety, costs, and waste disposal typically overshadow water concerns in the nuclear power industry. Small Modular Reactors (SMRs) are attracting interest as they are easily transportable, particularly to remote areas, and feature a self-contained design using cooling water in a continuous loop. Some SMR designs do not utilise water for cooling, opting for different coolants. However, placing SMRs underground raises worries regarding potential groundwater contamination.

Carbon capture and storage (CCS) is an innovative technology that captures CO2 from fossil fuel-based electricity and industrial projects. These systems are often highly energy and water intensive. They not only demand more water for cooling but also require additional water as a crucial component of the carbon capture process, potentially boosting a project's water withdrawal and consumption by up to 90% / megawatt-hour[XVI].

In arid regions facing water-related sustainable development challenges, there is an emerging opportunity to narrow the water demand-supply gap by complementing conventional methods with unconventional resources. These resources span from Earth's seabed to its upper atmosphere and capturing them requires a diverse range of technological solutions and interventions such as fog-water harvesting, cloud seeding for rain enhancement, micro-catchment rainwater harvesting, offshore deep groundwater extraction, and even iceberg towing.

'Ensuring universal access to water and sanitation', a key objective of the United Nations' (UN) Sustainable Development Goal (SDG) 6 faces significant challenges due to escalating water scarcity[XVII]. Unfortunately, UN water experts have warned most countries are off track to achieve SDG 6 by the 2030 deadline[XVIII]. In response, a new water paradigm is taking shape, particularly in water-scarce regions and river basins, which recognises the untapped potential of unconventional water resources. These resources present emerging opportunities to address water shortages in areas where reliable access to water remains elusive and conventional sources are limited. They may generate small quantities of water, sufficient for isolated communities or temporary locations or settlements, or they may yield water in larger amounts, suitable for agriculture, industrial or urban areas.

Fog water, found within dense fog, is recognised as a viable source of drinkable water in arid regions where conventional water access is unreliable, and rainfall is scarce. However, specific conditions must be met: frequent fog events, high fog concentration, persistent winds (such as trade winds blowing consistently from one direction at speeds of 4 – 10 metres / second or 14 – 36 km / hour), and sufficient space and altitude for fog interception[XIX]. Fog water collection offers a passive, practical, and low-maintenance solution to supply fresh drinking water to communities that experience frequent fog occurrences.

Fog collection systems typically consist of polypropylene mesh nets, often Raschel nets. However, in windy regions where Raschel nets are too delicate, alternative fabrics and configurations are used, for instance, three-dimensional spacer fabric serves as a replacement for Raschel nets that may tear in harsh environments. The specific installation of fog collectors depends on factors such as fog thickness, duration, frequency, local climate, topography, water demand, and the community's financial and human capacity to operate and maintain the system.

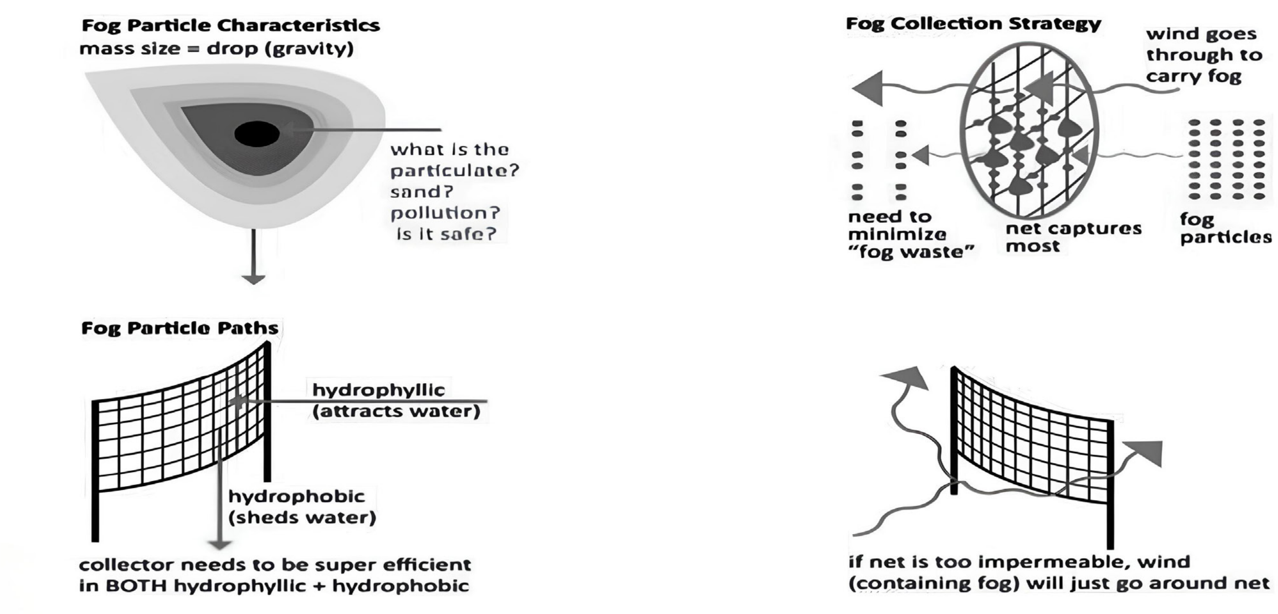
Dry mountainous and coastal regions offer ideal conditions for implementing fog water collection systems. Numerous fog water projects have been initiated in Middle East and North African (MENA) countries, including Morocco, Egypt, Ethiopia, Israel, Saudi Arabia, and Oman, as well as neighbouring nations like Azerbaijan and Pakistan. Notably, the largest fog collection project is situated in the Aït Baamrane region of Southwest Morocco; despite an arid ecosystem with an annual rainfall of just 112 millimetres, the region experiences frequent fog events, averaging 143 days / year[XX].

In specific conditions, cloud seeding can enhance rainfall in a targeted area, by dispersing specialised glaciogenic or hygroscopic substances into clouds or their vicinity. These substances activate water droplets or ice crystals on heterogeneous nuclei through water vapor condensation-freezing processes[XXI]. As a result, artificial and natural water droplets and ice crystals collide and coalesce, forming large hydrometeors (such as raindrops, graupel, hailstones, and snowflakes) that fall as precipitation. Remarkably, only about 10% of the total cloud water content is typically released as precipitation, highlighting the significant potential for rain enhancement technologies to improve precipitation formation[XXII].

Artificial cloud seeding involves spraying specific aerosol particles into a cloud environment. These particles compete with naturally occurring ones for water vapour. Among the aerosol particles used are ice-forming substances like silver iodide that have a lattice structure similar to natural ice crystals. Alternatively, chemical compounds such as salt-based hygroscopic particles with various additives, dry ice pellets, or liquid nitrogen can also be employed.

While the scientific understanding of weather modification is advancing, cloud seeding still faces barriers relating to incomplete grasp of cloud dynamics and related microphysics. Although cloud seeding provides essential precipitation, "atmospheric rivers" can lead to floods, mudslides, and landslides.

Figure 2: Fog-Water Harvesting



Unfortunately, there isn't an effective technique for controlling these atmospheric rivers. Nevertheless, progress has been made in modelling, analysis, and observation capabilities, enhancing our scientific knowledge of individual cloud processes and their interactions.

Global examples of cloud seeding reveal that it can enhance precipitation from virtually zero to more than 20% of the annual average, depending on factors such as available cloud resources, reagent types, delivery methods, cloud water content, and base temperature[XXIII].

In arid and semi-arid regions where rainfall is scarce, a substantial portion of the rainwater is lost through surface runoff and evaporation, which at times is exacerbated by inadequate vegetative cover and shallow crusted soils. Consequently, there is a compelling need for strategies that optimise the utilisation of small amounts of rainfall and runoff water that micro-catchment rainwater harvesting systems provide under such challenging conditions.

For agricultural purposes, various micro-catchment techniques have been employed. Contour bunds, constructed from earth, stone, or discarded materials, are strategically placed along the contours of sloping fields or hillsides, which trap rainwater, promoting greater infiltration. Additionally, semicircular, trapezoidal, or 'V'-shaped bunds are arranged in a staggered pattern, allowing water to accumulate behind them. When the 'hoop' area fills with water, any excess is diverted around the bund edges.

The meskattype system is another form of water harvesting involving micro-catchments. Unlike alternating catchment and cultivated areas, this system divides the field into two distinct zones: the catchment area directly above the cropped region. To enhance runoff, the catchment area is often devoid of vegetation. Meanwhile, the cultivated area is encircled by a 'U'-shaped bund, effectively retaining the runoff.

Figure 3: Cloud Seeding for Rain Enhancement

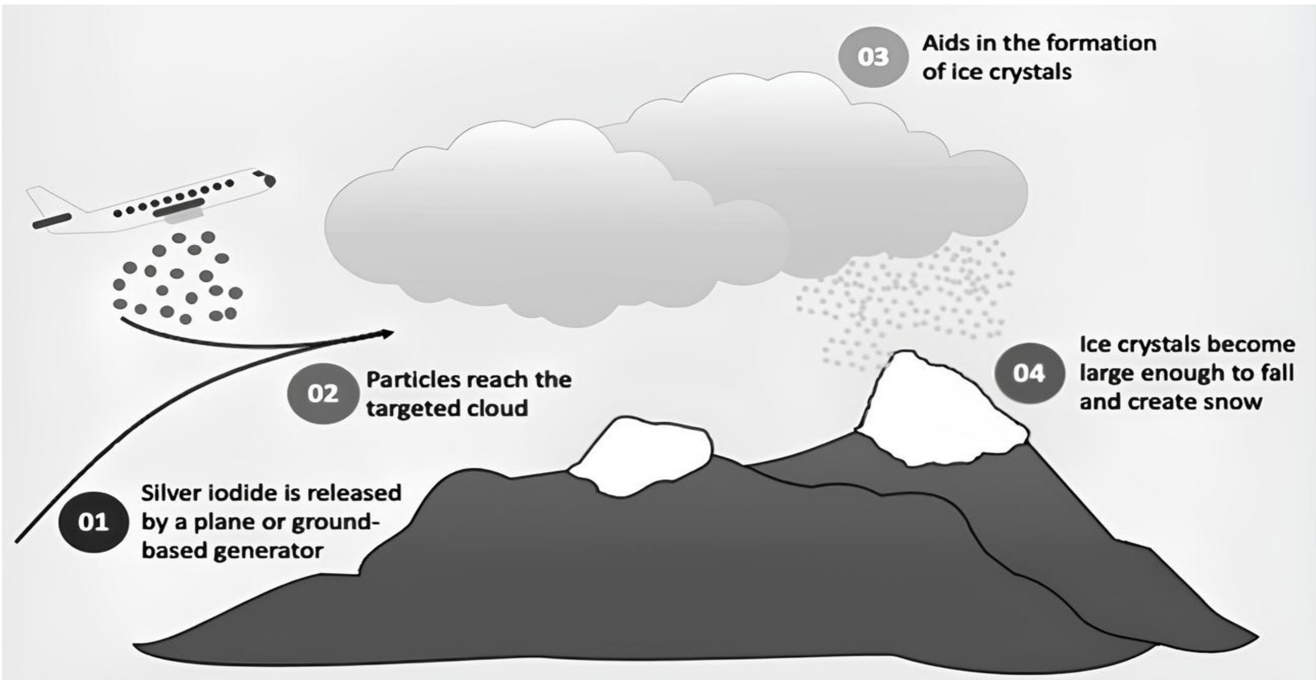
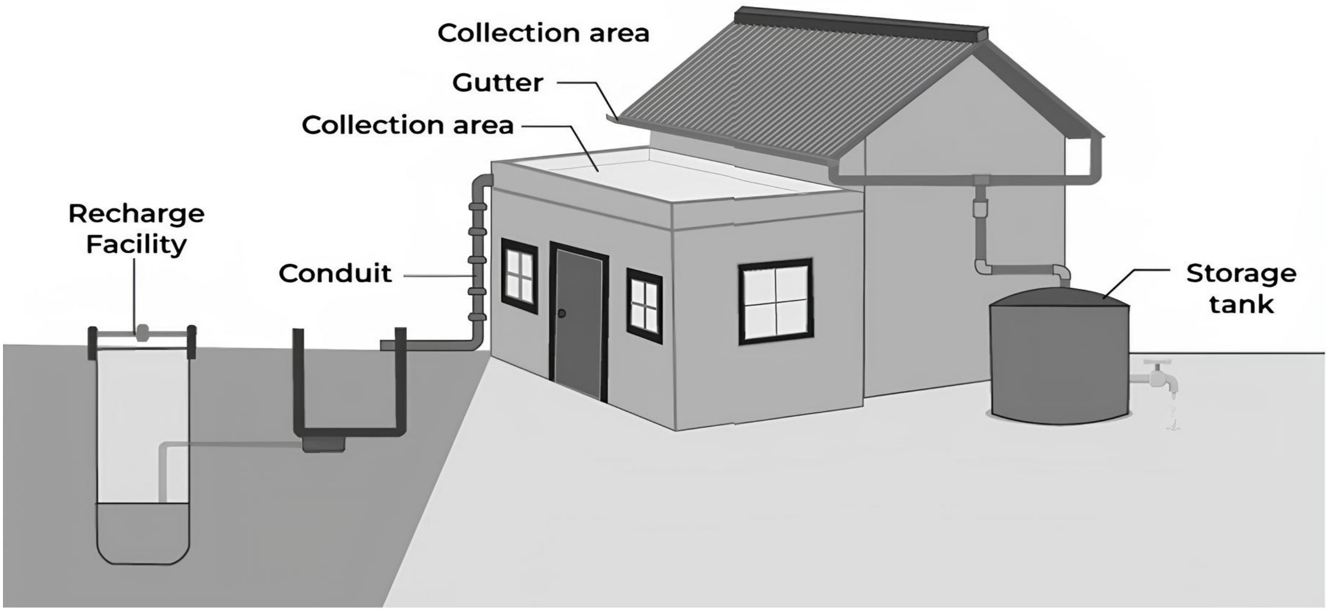


Figure 4: Micro-catchment Rainwater Harvesting System



In Tunisia, olive trees thrive within these systems[XXIV], while a similar approach called 'Khushkaba' is employed in Baluchistan, Pakistan for cultivating field crops[XXV].

Moreover, offshore freshwater resources can be categorised into two distinct types: submarine groundwater discharge and offshore aquifers. The east coast of the United States, including locations like New Jersey and Martha's Vineyard in Massachusetts, have been a focal point for comprehensive drilling and testing between the 1970s and 2010. During this period, freshwater aquifers were established when sea levels were significantly lower over the past million years due to extensive ice sheets covering the continents[XXVI].

Offshore freshwater exists at marine depths of < 600 metres and distances from shore of < 100 km beneath a fine-grained confining unit. The volume of offshore freshwater varies between ~0.8 – 9.0 km^3 / km of coastline[XXVII]. Current estimates indicate that up to 5×10^5 km^3 of fresh to brackish water (with salinity < 1 part per thousand (ppt)) are stored in shallow, permeable sandstone and limestone reservoirs at depths below ~500 metres[XXIX].

Recent advancements in marine magnetotellurics and controlled source electromagnetic methods allow for imaging offshore freshwater, which could be applied across the MENA region to characterise offshore freshwater and reduce drilling exploration expenses. Offshore freshwater, with an electrical resistivity of ~100 Ohm-m, is a poor conductor of electricity, which facilitates its detection and distinction from saline water. By utilising horizontal wells, it becomes feasible to achieve substantial daily production rates (19,200 m^3) of offshore freshwater over a 30-year period, provided that the freshwater is confined by a relatively tight unit[XXX]. Ongoing developments in horizontal drilling technology are also contributing to cost reductions.

Figure 5: Cross Sections Illustration of Selected Meteoric Groundwater Reserves (the curved lines are contours of salinity in parts per thousand and the vertical lines are offshore well locations)

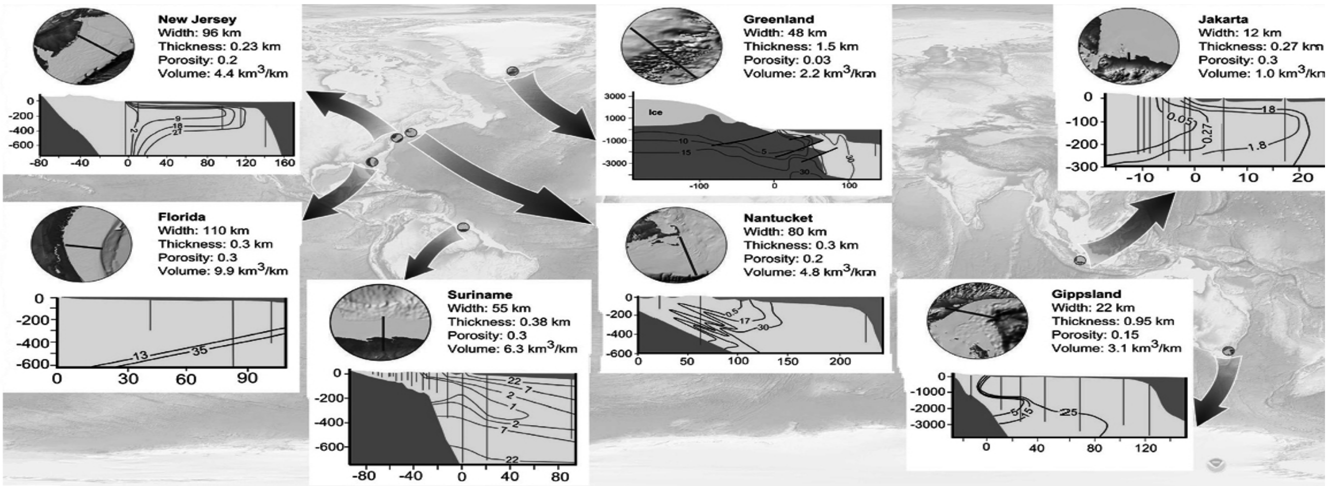
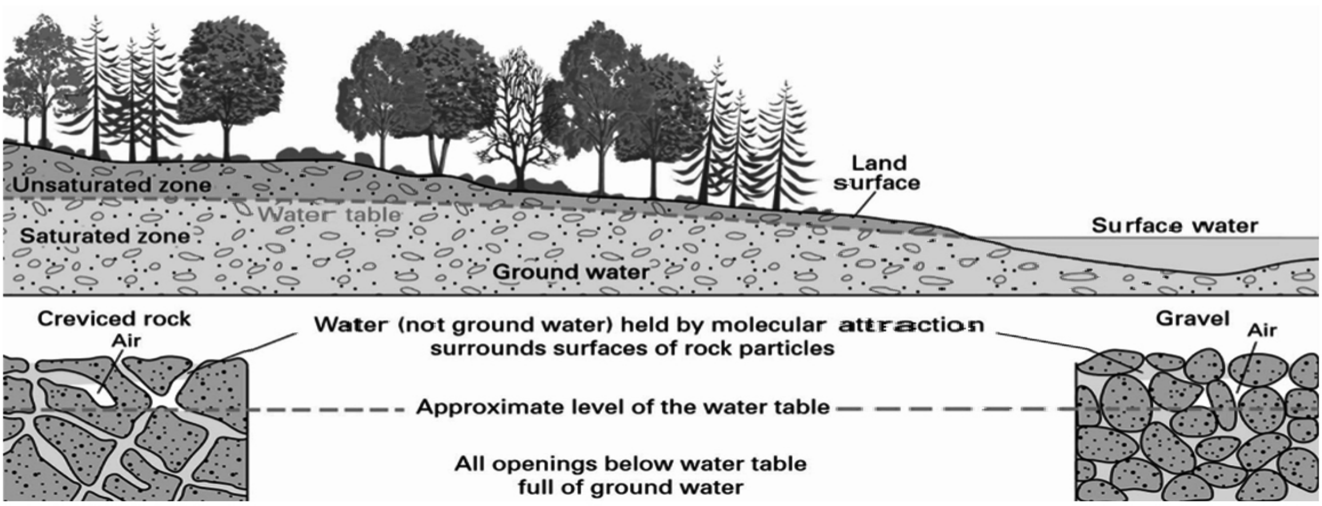


Figure 6: Onshore Groundwater in Geological Formations



Unlike offshore sources, onshore freshwater primarily originates from groundwater within confined aquifers and fossil aquifers. Fossil aquifers can be situated between low-permeable confining layers or even exist in unconfined formations deep below the surface. Notable examples include the Ogallala Aquifer in the United States and the Nubian Sandstone Aquifer System in northern Africa. These aquifer systems experienced significant recharge rates over the past 2 million years when the climate was generally cooler and wetter in those regions. However, due to their relatively low recharge volumes today, any extraction from these aquifers can be equated to resource mining.

Treatment of oil-field produced water is another promising option in major oil-producing states, including in the MENA region. Oil-field waters are typically highly saline, more than seawater, and contain oil traces as well as heavy metals and other contaminants. Petroleum Development Oman, which produces about 1 million m^3 of produced water daily (ten times the volume of its oil output), uses reed beds to clean up its water, before processing the remainder in evaporation ponds[XXXI]. Otherwise, water can be cleaned up and re-used in hydraulic fracturing operations.

Researchers are increasingly focusing on unconventional water resources, including the concept of towing icebergs, as a response to the growing water scarcity crisis. While this practice is still in its early stages, it has garnered attention. ~75% of the world's freshwater is locked in ice, with 90% of that icy volume situated in the Antarctic[XXXII]. The vast Antarctic ice sheet contains a staggering 27 million km^3 of water. Annually, around 2,000 km^3 of this frozen resource break off as icebergs.

Given the abundance of transportable icebergs, which come in various sizes and shapes, the possibility of selecting and towing them over long distances becomes feasible through the use of remote sensing techniques.

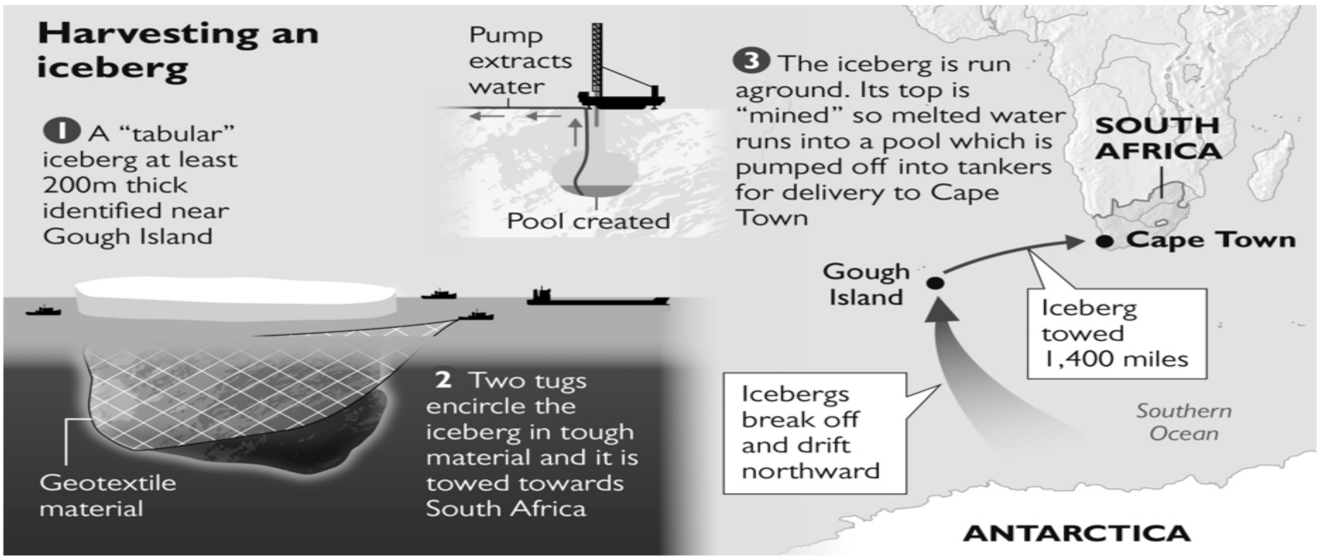
Beyond serving as a water supply, icebergs hold untapped energy potential.

By transporting icebergs to lower latitudes, a significant amount of energy can be harnessed from the thermal gradient.
Additionally, in conventional stations powered by fossil fuels, ice can effectively reduce the condensing temperature.

Assessing the fate of niche unconventional water resources, such as towed icebergs and ballast water, poses various challenges due to limited practical experience. Developing future scenarios and projections utilising these resources is equally complex. While resources like fog water and rainwater harvested in micro-catchments yield small volumes compared to conventional sources, they play a crucial role in supporting local communities facing water shortages.

Unconventional resources have the potential to narrow the water demand – supply gap. However, quantifying their impact across different scales remains a valid question, hindered by the scarcity of consolidated information and data. Additionally, despite demonstrated benefits, most unconventional water resources remain underexplored due to various barriers.

Figure 7: Example of Iceberg Towing in South Africa



Desalination technologies face a significant challenge from the production of high salinity concentrates or brine. Improper discharge of this brine can impact the aquatic environment near the plant outfall. However, global long-term experience shows that when properly designed and operated, seawater desalination plant discharges are environmentally safe and do not significantly affect the marine habitat in the discharge area.

There are ~16,000 operational desalination plants globally, producing a daily output of 95 million m^3 (~35 billion m^3 / year) of clean water[xxxiii]. This can be compared to total global freshwater use of about 4 trillion cubic metres per year, i.e. desalination accounts for about 1% of the total. Around 50% of the global desalination capacity is concentrated in the MENA region, and the region will continue drive global growth[xxxiv]. However, other regions are also expanding rapidly, notably China, the United States, and parts of Latin America.

Part of this growth is driven by advancements in membrane technology and material science. Recent breakthroughs include pressure-exchanger based energy recovery systems, more efficient reverse osmosis (RO) membrane elements, nanostructured RO membranes, innovative membrane vessel configurations, and high-recovery RO systems. These technological strides are expected to significantly reduce the energy requirements for desalination and play a pivotal role in driving down the cost of desalinated water, which are projected to significantly decline by 2030[xxxv].

Desalination technologies face a significant challenge related to the production of high salinity concentrate or brine. If improperly discharged, this brine could potentially impact the aquatic environment near the plant outfall. However, global experiences indicate that when properly designed and operated, discharges from seawater desalination plants are environmentally safe and do not significantly affect the marine habitat in the vicinity of the discharge[XXXVI].

Seawater desalination results in brine production estimates of 142 million m³ / day, which is ~50% greater than the volume of desalinated water produced daily[XXXVII]. Brine production from desalination plants using brackish water is 6 – 10x smaller than the volume of desalinated water[XXXVIII].

These advances aim to achieve several goals: reducing energy consumption by 20% – 35%, lowering capital costs by 20% – 30%, enhancing process reliability and flexibility, and significantly decreasing the volume of brine discharge[XXXIX]. To generate additional value, research is underway to extract rare metals from desalination brine using innovative technologies such as nanoparticle-enhanced membranes, biomimetic membranes, and forward osmosis[XL].

Renewables are playing an important role in water desalination. Technologies suitable for desalination encompass solar thermal, photovoltaics, wind, and geothermal energy. Concentrating solar power, which generates substantial heat, is particularly suited for thermal desalination. Additionally, combining electricity generation with water desalination can effectively address electricity storage challenges when generation exceeds demand.

Desalination consumes a significant amount of energy. Seawater desalination via MSF (Multi-Stage Flash) typically requires 81 kWh – 120 kWh of thermal energy and 1.5 kWh – 4 kWh of electricity / m³ of water[XLI]. On the other hand, utility-scale RO desalination only needs about 3.5 kWh – 5 kWh of electricity / m³[XLII].

Globally, the production of 95 million m³ of desalinated water / day involves an annual energy consumption of ~75 TWh, which accounts for 0.5% of the global electricity demand[XLIII].

Figure 8: Energy Consumption by Desalination Technologies

	Multi-Stage Flash	Multiple-Effect Distillation	Sea Water Reverse Osmosis	Electrodialysis Desalination
Operational Temperature	90°C – 110°C	70°C	Ambient	Ambient
Electricity Demand	1.5 – 4 kWh / m³	1.5 – 2.5 kWh / m³	3.5 – 5 kWh / m³	1.5 – 4 feed water with 1,500 – 3,500 ppm solids
Thermal Energy Demand	81 – 120 kWh / m³	81 kWh / m³	-	-

The cost of desalination has been steadily decreasing, reaching as low as US$ 0.5 / m^3[XLIV]. However, market prices for desalinated water typically fall between US$ 0.5 – US$ 2 / m^3[XLV]. This can be compared to typical US prices for industrial water of about US$ 0.3 / m^3, which includes distribution costs.

Currently, desalination is affordable for middle-income regions but remains challenging for the poorest countries. The viability of renewable desalination hinges on the cost of renewable energy, as energy consumption significantly impacts desalination costs[XLVI].

While renewable desalination is still more expensive than conventional fossil fuel-based desalination, the rapidly decreasing costs of renewables will continue to improve the cost parity of renewable desalination. In remote areas where energy transmission and distribution costs outweigh distributed generation costs, renewable desalination plants are already proving to be a viable alternative[XLVII]. Reverse osmosis desalination plants can also be operated in a flexible mode, being turned off when electricity demand is higher than can be met by the available renewable output. This uses desalinated water effectively as a kind of electricity storage.

Figure 9: Renewable Water Desalination Energy and Cost Profile

	Solar Stills	Solar Multiple-Effect Distillation	Solar Membrane Distillation	Concentrating Solar Power / Multiple-Effect Distillation	Solar Photovoltaic / Reverse Osmosis	Solar Photovoltaic / Electrodialysis Desalination	Wind / Reverse Osmosis
Energy Input	Solar Passive	1.5 kWh / m_3 + 100 kJ / kg	< 1 kWh / m_3 + < 200 kJ / kg	1.5 – 2 kWh / m_3 + 60 – 70 kJ / kg	0.5 – 1.5 kWh / m_3 + 4 – 5 kJ / kg	3 – 4 kWh / m_3	0.5 – 5 kWh / m_3 + 100 kJ / kg
Average Current Capacity	0.1 m^3 / day	1 – 100 m^3 / day	0.1 – 10 m^3 / day	> 5,000 m^3 / day	< 100 m^3 / day	< 100 m^3 / day	50 – 2,000 m^3 / day
Production Cost	US$ 1.3 – 6.5 / m^3	US$ 2.6 – 6.6 / m^3	US$ 10.4 – 19.5 / m^3	US$ 2.3 – 2.9 / m^3	US$ 6.5 – 15.6 / m^3	US$ 10.4 – 11.7 / m^3	US$ 3.9 – 9.1 / m^3

GCC countries show limited signs of becoming more frugal in their water consumption. Despite generous state subsidies that keep water prices low, demand has surged across the domestic industrial and agricultural sectors. Presently, the annual / capita water usage in GCC countries stands at 560 litres / day, significantly higher than the global average of 180 litres / day[XLVIII].

Saudi Arabia ranks as the third largest / capita water consumer globally, trailing only the United States and Canada[XLIX]. The region's nations exhibit a penchant for water-intensive megaprojects. For instance, international football pitches require a staggering 10,000 litres / day of desalinated water each[L].

To address the energy requirements of desalination, a promising solution involves linking desalination plants to renewables. NEOM, a smart city initiative in Saudi Arabia has embraced this approach.

In June 2022, NEOM announced a collaboration with French energy company Veolia and Japanese trading company Itochu to develop a reverse osmosis desalination facility powered entirely by renewable energy[LI]. Expected to be operational by 2025, this plant will produce 500,000 m^3 of water / day, supplying 30% of NEOM's projected water demand[LII]. Additionally, other solar-powered desalination projects exist in the region, including the Al Khafji Desalination Solar Facility in Saudi Arabia and similar initiatives in the UAE and Oman.

As MENA countries increasingly turn to desalination as a solution for their water needs, there are indications that desalination diplomacy could emerge as a crucial political tool. GCC countries, being pioneers in this sector, have a unique first-mover advantage, by leveraging their expertise, technology, and even water exports to other neighbouring countries.

For instance, the annual MENA Desalination Projects Forum has become a significant platform for regional and international stakeholders to showcase the latest advancements in desalination technology[LIII].

Desalination also mitigates some of the primary drivers of water conflict. By relying on seawater instead of river water, it reduces tensions that often arise between upstream and downstream riparian countries[LIV]. A notable example is the ongoing dispute between Egypt and Ethiopia over the latter's construction of a new dam[LV].

Recognising the potential for desalination to foster peace, the Middle East Desalination Research Centre was established in Muscat in 1996 as part of the post-Gulf War Middle East peace process[LVI]. The centre aims to address critical regional and transboundary environmental challenges by facilitating cross-border sharing of scientific and technological expertise; and has rightly been hailed as a pivotal achievement[LVII].

However, desalination could also emerge as a focal point for political conflict, generating its own geopolitical dynamics. For instance, GCC countries grapple with their dependence on the same water body (the Arabian Gulf and in case of Saudi Arabia the Red Sea) for their drinking water requirements. Notably, the GCC's waters have evolved into a water security issue. These waters, dotted with offshore oil rigs and frequented by the world's largest oil tankers, pose the risk of an oil spill or other accident that could disrupt water supply across multiple Gulf countries[LVIII].

Furthermore, security analysts highlight the potential danger of attacks targeting a nation's desalination infrastructure, particularly due to their coastal locations. A historical precedent lies in the First Gulf War in 1991, as the Iraqi Army withdrew from Kuwait, former Iraqi dictator Saddam Hussein destroyed Kuwait's desalination plant and released oil into the Gulf, resulting in a significant oil slick and disrupting desalination facilities in the broader region[LIX]. Hence, concerns persist that a future cross-Gulf conflict, most likely involving Iran, might once again witness water infrastructure becoming a target.

The GCC countries should intensify their efforts to manage the water-energy nexus to enhance water and energy security. Key reforms include tackling subsidies and pricing structures that hinder conservation, promoting the reuse of treated wastewater, and boosting investments in renewable energy. These actions would not only benefit the climate, jobs, and fiscal stability but also contribute to overall sustainability.

Most of the freshwater in the GCC region is obtained from desalination plants or deep aquifer wells. However, this supply-driven approach is both carbon and energy intensive. As demand for freshwater and energy increases, it puts pressure on both resources, leading to excessive and inefficient use.

As the GCC countries deplete their groundwater reserves, reliance on desalination becomes inevitable. Between 2014 – 2020, the annual production of desalinated water in the GCC grew by 19% / year, and this trend is expected to continue[LX]. Consequently, the need for energy will also significantly rise.

Without further efficiency improvements, the energy required to desalinate seawater will double due to increased freshwater demand. For instance, Saudi Arabia's water consumption has surged fifteenfold since 1980[LXI]. The country currently uses a third of its oil production to meet domestic water and energy needs[LXII]. Hence, freshwater production poses risks to GCC hydrocarbon exports and budget revenues. By 2050, some GCC members may even lack sufficient natural gas to desalinate water for municipal use alone.

The Arabian Gulf and Red Sea are naturally saltier than the world's oceans due to higher evaporation rates and reduced freshwater inflows[LXIII]. Problematically, the effluent from new desalination plants creates a vicious cycle: the more concentrated the salt in waste near intake sources, the greater the energy needed to remove that salt when processing new seawater for desalination.

GCC countries have the opportunity to take decisive actions. They can decouple freshwater production from fossil fuel consumption, scale up renewables to reduce emissions, restore marine habitats, manage risks related to the water-energy nexus, diversify water sources, and accelerate the transition toward greener, more resilient, and inclusive development.

Moreover, both greywater reuse and wastewater treatment require significantly less energy per cubic metre of water compared to desalination. Even within desalination, innovative approaches like expanding the use of reverse osmosis can decrease energy intensity, cut costs, and minimise the carbon footprint of water production.

Additionally, GCC nations can strategically reserve aquifers for national security and leverage trade to enhance food security. For instance, it takes 1,500 m3 of groundwater to produce one ton of grain[LXIV]. By importing grain, these countries can redirect water to more productive purposes. Policies that limit access or phase out subsidies can also incentivise grain farmers to shift toward cultivating less water-intensive and higher-value crops.

The water and energy infrastructure's negative ecological externality must be integrated into water infrastructure economics. Currently, the desalination industry discharges waste effluent without bearing any cost, endangering marine resources. However, the GCC has the opportunity to adopt brine abatement as a shared policy and a prerequisite for new plant tenders. By internalising negative effects, the GCC can drive technological innovations and enhance production.

Traditionally, wastewater has been considered a liability with associated costs. Looking ahead, the region could prioritise increasing treatment, recycling, and reuse of this often overlooked but crucial resource. Countries can reclaim and repurpose over 90% of wastewater for purposes like irrigation, industry, or domestic use (as seen in Israel, Tunisia, and Morocco)[LXV]. Most municipal wastewater in the GCC is now re-used for landscape irrigation, although it could be upgraded to higher-value industrial, district cooling or even potable uses.

To tackle diverse threats to their shared resources, GCC countries might collectively establish standards and measures to mitigate the rising salinity of the Gulf. This collaborative process can draw inspiration from parallel initiatives focused on other saltwater bodies, such as the Mediterranean Action Plan[LXVI] or HELCOM[LXVII] in the Baltic, while fitting into the existing GCC framework.

CONCLUSION

Water scarcity is a pressing concern globally, and especially across the Middle East due to its arid climate and rapid population growth. Many countries in the region are among the most water-stressed globally, grappling with limited freshwater resources and high demand. The eastern Mediterranean region, extending into Lebanon, Jordan, Palestine, and Syria, is expected to become even drier with the advance of climate change. Conversely, parts of the Gulf may receive higher precipitation overall than the historically very low levels, but it will be episodic and unpredictable, creating challenges of flooding and effective capture and use of water from intense but occasional downpours.

Water resources are increasingly scarce, particularly for the millions who lack access to clean and safe water. The water-related challenges faced by the UAE and Saudi Arabia, Iraq, Yemen, and Egypt are unique in each case, raising different questions of affluence and resource-intensive use, conflict and insecurity, cross-boundary water flows, the exhaustion of groundwater, changing patterns of rainfall because of climate change. and lack of access to finance and technology.

Despite having some of the world's largest oil and gas reserves, and some of the best solar resources, the MENA region's harsh climate and environment will continue to impact the quality of life for rural and impoverished communities. Lack of water exacerbates food insecurity, as farmers struggle to secure reliable water sources and suitable agricultural land. Additionally, governments heavily rely on importing food from water-rich countries outside the region. Unfortunately, much of the available land for food production is becoming unusable due to desertification.

Water scarcity in the Middle East results from a combination of natural factors and human activities. Limited rainfall and high temperatures play a significant role, as do practices like overexploitation of groundwater and inefficient irrigation.

Groundwater, a critical water source in the region, is depleting rapidly due to excessive use. Additionally, climate change exacerbates the issue by causing more frequent and severe droughts.

Desertification, a widespread environmental challenge, stems from unsustainable agricultural practices and overgrazing. Irrigation for agriculture consumes two-thirds of the water in this region. Frequent droughts further contribute to landscape changes, impacting the already scarce water resources of these countries.

Water scarcity in the Middle East prompts various responses from countries in the region. These include implementing water conservation measures, promoting water-efficient technologies, minimising distribution system losses, and exploring alternative water sources like treated wastewater and rainwater harvesting. Additionally, some nations experiment with cloud-seeding technology to enhance local precipitation.

However, these efforts face constraints due to political and economic factors. Not all countries possess the means to implement these solutions, making it challenging to achieve sustainable water use and ensure equitable access for all. The uneven distribution of water resources, coupled with population growth, has also led to water-related conflicts among regional countries.

In summary, addressing water scarcity in the Middle East necessitates a comprehensive approach, which involves not only technological solutions but also social and political interventions to promote fair access to water resources. Furthermore, it requires tackling interconnected issues related to water, energy, and food security.

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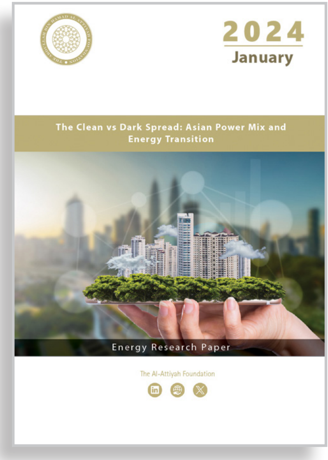

January – 2024

The Clean vs Dark Spread: Asian Power Mix and Energy Transition

Recent fuel price volatility and the increasing prominence of renewables have altered the traditional dynamics between coal, hydropower, and gas generation in Asia.

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December – 2023

Fair COP or COP Out? Key Outcomes from COP28 and the Long-Term Effect on Fossil Fuel Demand

The 28th UN climate conference, COP28, held in Dubai in November-December 2023, was the largest and one of the most complicated of the series.

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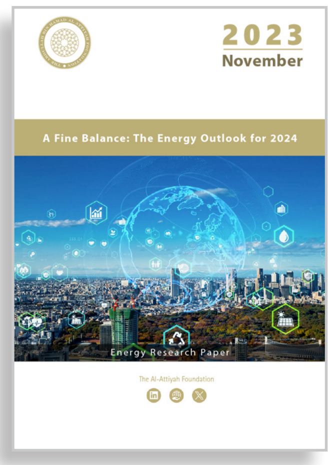

November – 2023

A Fine Balance: The Energy Outlook for 2024

Energy has witnessed four very volatile years since the start of the decade. Global markets are still striving to find a sustainable balance between supply and demand, while a decelerating macroeconomic framework and geopolitical events add headwinds to slowing demand growth.

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