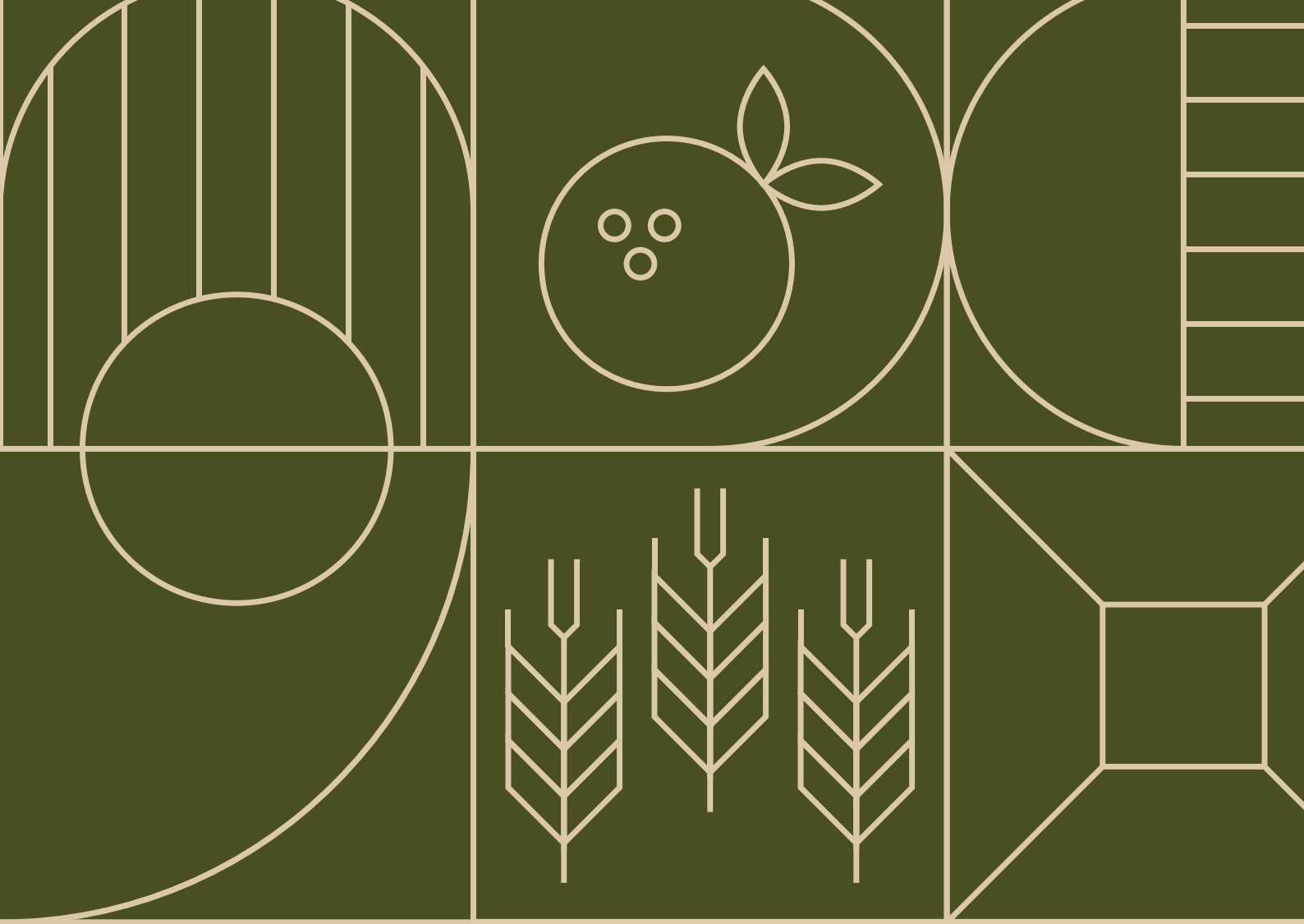

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POLICY PATHWAYS FOR FOOD AND WATER SECURITY IN THE MENA REGION

EDITED BY
MANNAT JASPAL and KRISTIAN P. ALEXANDER

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Introductory Essay

Mainstreaming Food and Water Security Amid the Strait of Hormuz Crisis

Mannat Jaspal and Kristian P. Alexander

In the recent years, food and water security have moved from the margins to the mainstream of policy discourse, sitting at the centre of strategic planning for governments worldwide. This shift is particularly pronounced in the Middle East and North Africa (MENA), one of the most water-scarce regions globally with water availability about 10 times lower than the global average.[1] The region accounts for just 1.4 percent of the world's renewable freshwater resources while hosting approximately 6.3 percent of the global population.[2]

As a result, countries—especially the Gulf Cooperation Council (GCC) with no permanent rivers—rely primarily on groundwater and desalination for drinking, industrial, and agricultural purposes.

The GCC region produces roughly 40 percent of the world's desalinated water, operating more than 400 desalination plants along their coasts.[3] The reliance on desalination for total water supply varies across member states: 61 percent in Qatar, 59 percent in Bahrain, 47 percent in Kuwait, 41 percent in United Arab Emirates, 23 percent in Oman, and 18 percent in Saudi Arabia.[4] Meanwhile, several states—including Syria, Jordan, and Palestine—rely on shared water systems, making transboundary governance and resource management crucial for broader social and economic development.

These geographical and structural constraints of limited freshwater availability and arid climatic conditions are being exacerbated by climate change. The MENA region is also the world's most vulnerable and disproportionally impacted by climate change,[5] experiencing accelerated warming, declining precipitation, rising seas, and increasingly frequent and severe droughts. Furthermore, the interlinkages between water and food security are equally critical and coming under increasing strain. Much of the region remains heavily dependent on food imports, exposing it to global market volatility and supply chain disruptions.

The Strait of Hormuz Crisis and Emerging Risks

The Strait of Hormuz crisis has once again exposed the fragility of critical resource systems in the region. In the context of the current escalating conflict involving the Unites States (US) and Israel, and Iran, attacks have extended beyond the energy assets to include critical water infrastructure, most notably the desalination plants. Iran has accused the US of attacking a desalination plant on Qeshm Island which affected the water supply for 30 villages in the country.[6] In retaliation, Iran attacked a water desalination plant near Muharraq in Bahrain—a country that relies on desalination for more than 90 percent of its drinking water requirements.[7]

Such incidents are not without precedent. In 2019 and 2022,[8] Yemen's Houthi launched a series of drone and missile attacks on Saudi Arabia's desalination facilities at Al-Shuqaiq, highlighting the vulnerability of civilian infrastructure in an asymmetric warfare. More recently, Iran has threatened to target desalination infrastructure used by the US and Israel in West Asia in response to any attacks on its own domestic fuel and energy infrastructure—signalling an alarming escalation in the weaponisation of water systems.[9] Besides military strikes, desalination plants are also vulnerable to contamination of seawater via oil spills and power outages owing to cyberattacks and fuel shortages.

The crisis has had profound impacts on food security as well. The Gulf region imports between 80–90 percent of its food needs, and it is estimated that as much as 70 percent of it passes through the Strait of Hormuz.[10] Besides regional food availability coming under stress, global agricultural markets are also affected with rising energy prices and the concomitant increase in shipping and transportation costs.

At the same time, the Middle East supplies 30 percent of global fertilisers.[11] With the waterway under attack, the shipments have stalled. The price for Middle East granular urea jumped by 40 percent, trading at US$665 per metric ton on 20 March compared to US$485 only a few weeks earlier.[12] The situation could deteriorate when other countries impose protectionist policies in response—for instance, China is expected to withhold urea and phosphate exports until August 2026—a decision that could cause the regional crisis to spiral into global disruptions.[13]

Towards Resilience and Regional Cooperation

Despite these challenges, the countries of the Gulf region have made notable progress in overcoming some of the structural limitations. Investments in advanced desalination technologies, decentralised plants, renewable energy integration, controlled-environment agriculture, global food supply partnerships, and strategic food reserves have contributed to a more comprehensive framework for long-term resilience.

The United Arab Emirates stands out with its focus on innovation and international collaborations focusing on water management, sustainable agriculture, and climate adaptation. It will co-host the United Nations Water Conference with Senegal later this year, reflecting a commitment to accelerating action on sustainable water management and advancing collective solutions to both water and food security for the region and the world. This gathering will provide an opportunity for governments, international organisations, and research institutions to exchange ideas and advance solutions pertaining to these pressing challenges—now more critical than ever.

The timing of this volume is therefore particularly significant. While the essays were commissioned before the Hormuz crisis, their relevance has only intensified in the light of recent developments. Together, they highlight the specific experiences, innovations, and policy debates emerging from the region while offering in-depth perspectives on the multifaceted dimensions of water and food security. The contributions explore a wide range of themes, including technological solutions to water scarcity, national security implications, agricultural innovation in arid environments, geopolitical risks affecting food supply chains, the food-water-energy nexus, and country-led policy frameworks aimed at strengthening regional resilience.

It is our hope that this collection helps bridge the gap between academic analysis and policy application, offering valuable perspectives for decision-makers, development practitioners, and researchers alike. By bringing together diverse voices and perspectives from the region, this publication underscores the importance of interdisciplinary research, policy engagement, and international cooperation in addressing issues related to food and water security—one of the most defining security and existential challenges of our time.

Policy Pathways for Food and Water Security in the MENA Region reflects a shared commitment by the Observer Research Foundation Middle East (ORF ME) and Rabdan Security and Defence Institute (RSDI) to foster meaningful dialogue on issues that are shaping the future stability and prosperity of the region. Over the past year, ORF ME and RSDI have collaborated on two well-attended, policy-oriented panel discussions on water and food security, first in Dubai and subsequently in Abu Dhabi. These events brought together regional experts, government stakeholders, and international researchers to examine the strategic implications of resource scarcity, agricultural sustainability, technological innovation, and supply-chain resilience. The strong interest generated by these discussions demonstrated not only the urgency of the subject but also the value of sustained scholarly engagement on the subject.

We extend our gratitude to all the authors who contributed to this compendium for their timely and thoughtful analyses. ORF ME and RSDI will continue to collaborate with the authors and the wider community engaging on food and water security policy to further advance evidence-based policymaking and strengthen sustainable and inclusive resource management in the region.

Mannat Jaspal is Director and Fellow, Climate and Energy, ORF Middle East, United Arab Emirates.

Kristian P. Alexander is Senior Fellow and Lead Researcher, Rabdan Security and Defense Institute (RSDI), United Arab Emirates.

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Food and Water Security as an Element of National Security: Strategies for the Gulf

Maja Kent

In 2020, when the COVID-19 pandemic disrupted global supply chains and closed borders across the world, the movement of food and agricultural goods slowed down. Two years later, in 2022, the Russia-Ukraine war further challenged the supply of grain (mainly wheat and barley fodder)[1] and sunflower seed oil, to the Gulf. For Gulf states, which import more than 85 percent of food commodities,[2] these crises served as a test of food supply resilience and logistical preparedness.

Another challenge emerged in 2023, when the Bab el-Mandeb Strait, a vital maritime trade corridor linking Europe, the Middle East, and Asia, was affected by vessel attacks by Houthis just off the coast of Yemen.[3] The rerouting of vessels around the

Cape of Good Hope extended delivery times and raised transport costs while also putting at risk the Gulf's food supply route. These disruptions were a reminder to Gulf countries that food security is a matter of national security and can easily be interrupted by both regional conflicts and global events.

From Hyper-Arid Climate to High Food Security Index

The Arabian Peninsula's environment presents a challenge to agricultural self-sufficiency. With hyper-arid conditions, minimal rainfall, water scarcity, and less than 2 percent of land suitable for farming,[4] the Gulf's ecosystems naturally put a limit to traditional agriculture.

Although advanced systems that are designed to use less water, such as vertical farms and high-tech greenhouses, are rapidly expanding, they remain energy-intensive. Balancing technological progress, sustainability, and energy transition goals is still a shared challenge across the region and one that requires integrated planning.

Conflicts in neighbouring countries such as Syria, Yemen, and Iraq, compounded by environmental degradation and climate change,[5] could further trigger regional migration and instability with a spillover effect into the Gulf. To overcome this, countries have turned to diplomacy, innovation, and strategic planning.

For example, the Gulf Cooperation Council (GCC) has recognised that these environmental challenges are continuing to impact food and water security and, as such, need to be addressed as part of a wider security strategy. The Council published the Gulf Cooperation Council Vision for Regional Security in 2024 in which food and water security was named one of the grouping's cooperation objectives.[6]

Food Security Policies and Strategies in the Gulf

GCC governments have placed food and water security at the heart of their national agendas. This is reflected in their strong performance on the Global Food Security Index,[7] where all GCC members rank above the world average. The Index, which assesses availability, affordability, quality, and safety of food supplies, ranks the UAE highest at 23rd place, followed by Qatar at 30th and Oman at 35th.

Each country has tailored its approach towards food and water security based on its national priorities and circumstances. The Kingdom of Saudi Arabia (KSA), Sultanate of Oman, and the United Arab Emirates (UAE) are focusing more on achieving higher self-sufficiency through increased domestic food production. For its part, Qatar is relying on innovation, such as alternative proteins, to strengthen its food security. In addition, the UAE and the KSA are focusing their efforts on overseas land acquisition in case domestic production falls short.

Saudi Arabia has integrated food and water security into the Vision 2030 Strategy,[8] and its National Aquaculture Policies and Practices[9] and 2030 National Strategy for Agriculture[10] have helped strengthen food production and self-sufficiency in key products such as dairy and eggs. The agricultural sector's growing contribution to GDP, reaching US$30.4 billion in 2024,[11] demonstrates the effectiveness of Saudi Arabia's policy planning and implementation.

The UAE has adopted a comprehensive long-term approach through the 2051 National Food Security Strategy,[12] which promotes diversification of import sources, technology-driven local production, reduction of food waste, and enhanced resilience in supply chains, underpinned by specific targets. The UAE has also designated food as a priority within its new National Cluster Strategy,[13] connecting food systems to economic diversification. Meanwhile, Oman's Sustainable Agriculture and Rural Development Strategy (SARDS) 2040[14] and National Nutrition Strategy[15] were developed in partnership with the Food and Agriculture Organization (FAO) of the United Nations with the aim of promoting rural development and environmental sustainability.

For Qatar, once it became challenging to import food through Saudi Arabia several years ago, it turned to other countries for its food imports. The experience exposed Qatar's vulnerability as a result of relying on a single-entry point for its food imports and underscored the value of domestic production and supply diversification. Qatar's National Food Security Strategy 2030[16] thus continues to focus on resilience, sustainable consumption, and international partnerships. Similarly, Kuwait and Bahrain are advancing initiatives aligned with their own national visions. Kuwait Vision 2035[17] and Bahrain's first national food security strategy[a,18] contain plans to strengthen local agriculture, advance agritech, and develop long-term food reserves.

Water Security as a Strategic Priority

Water scarcity is another theme that is central to the region's long-term security planning. Groundwater resources such as the shared Umm er Radhuma–Dammam aquifer system covering 680,000 km^2 support the majority of agricultural production across Saudi Arabia, the UAE, and Oman. Because of its connection to food production, sustainable management of this resource is critical, and requires coordination between countries to prevent overextraction and improve resource quality.

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a The strategy was still being prepared at the time of writing this article.

To meet rising demand caused by population growth, GCC states have turned to technology to meet their water demands and have become global leaders in the desalination processes. In the UAE, the majority of drinking water comes from desalination[19] and in Saudi Arabia, desalinated water meets roughly 60 percent of urban needs.[20] Although states are investing in new and more efficient technology, climate change and environmental degradation of coastal ecosystems are still likely to increase energy usage. This is particularly challenging as the Gulf is looking to diversify its economy and transition away from fossil fuels while increasing food production.

The UAE's Water Security Strategy 2036[21] aims for sustainable access to water under both normal and emergency conditions, establishing storage capacity benchmarks and conservation programmes. Saudi Arabia's National Water Strategy 2030[22] envisions a sustainable and efficient water sector that safeguards natural resources while maintaining service quality. Meanwhile, Kuwait, Bahrain, and Qatar are expanding desalination and wastewater recycling—critical capacities given their near-total reliance on desalination.[23]

For their part, Jordan, Tunisia, and Israel have all developed wastewater policies that allow them to treat and reuse their water for agriculture and groundwater recharging. GCC countries still have a long way to go in wastewater reuse and it could be a significant resource for food production, thus further easing their reliance on energy-intensive desalination while preserving important natural capital.

Public-Private Partnerships and Agritech Investments

Given their constraints in natural resources, the Gulf countries have turned to innovation as a core element of their food and water security agenda. One of the results is the significant amounts of public and private sector investments in agritech. These efforts are important for enhancing self-sufficiency and are positioning the Gulf as a hub for agricultural innovation.

Across the GCC, more than US$3.8 billion has already been invested in food technologies,[24] with agritech expected to contribute US$30.5 billion to the Gulf economy. Large-scale projects such as Oman's Saham Agricultural City,[25] Saudi Arabia's Jeddah Food Cluster,[26] and the UAE's Food Tech Valley,[27] are designed to integrate research, production, and logistics, creating ecosystems that link innovation to national security goals. The International Center for Biosaline Agriculture (ICBA[28]) is a valuable example of how region-contextualised scientific research can help solve food security challenges by developing new techniques for growing crops in saline and arid conditions.

Adding another dimension to food security is overseas agricultural investments. Saudi Arabia's SALIC and the UAE's Al Dahra have acquired agricultural land and ownerships in agricultural companies across continents, ensuring reliable access to essential commodities

like grain and meat. As these portfolios expand, particularly into the Global South, their long-term benefits will increasingly depend on integrating geopolitical sensitivities, climate resilience, biodiversity stewardship,[29] and engagement with local communities, as part of their investment strategies.

Looking Ahead

1. Regional Cooperation: GCC countries face similar challenges when it comes to food and water security. They are all considered strong and stable economies and harnessing cooperation to tackle common problems is only expected. Shared initiatives can enhance food and water security through joint research, harmonised policies, and coordinated crisis management. The GCC Vision for Regional Security already recognises food and water security as essential to the region's collective stability. Furthermore, the GCC is showing greater interest in a harmonised GCC-wide Food Security Strategy, especially following COVID-19 where such regional cooperation[30] has proven to be beneficial to these countries in times of crisis.

A GCC-wide approach could also help manage future risks linked to climate change and trade disruptions. Coordinated efforts to diversify import sources, standardise emergency reserves, and develop regional food corridors could further strengthen resilience. Joint investments in renewable-powered desalination and climate-smart agriculture could reduce costs and accelerate sustainability goals.

2. National Strategies: As the Gulf moves into a new era shaped by climate change and new geopolitics, revisiting and updating national strategies becomes increasingly important. Many existing food and water policies are several years old and refreshing them to reflect current environmental realities and technological advances will ensure that they remain effective and forward-looking. Comprehensive and modernised water policies are needed to promote sustainable management of transnational aquifers, and regional cooperation in replenishing those essential groundwater resources through joint efforts.

Some states have already made substantial progress with data to show it,[b] while others are still developing frameworks that translate intent into concrete, measurable outcomes. Strengthening institutional capacity and aligning national efforts with scientific research will be beneficial. Locally driven science and research tailored to Gulf conditions can provide the evidence base needed to guide policy decisions and innovation.

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b Saudi Arabia, for example, has already achieved self-sufficiency in certain food commodities.

Although domestic production in this region is increasingly relying on technology to produce yields, agriculture still remains the biggest user of fresh water. For example, in the UAE, 73 percent of freshwater[31] is used for agriculture. Domestic production in this region comes at a cost, either by depleting critical natural resources such as soil and water or by increasing the demand for energy, as it is the case with the vertical farming systems.

Although the food-water nexus is acknowledged within some of the food security strategies, the GCC countries could benefit from further integrating their water, food, and energy policies.

3. Investment in innovation and new technologies: The Gulf's strong appetite for innovation will continue to play a pivotal role in shaping the next stage of its food and water security. By investing in knowledge, skills, and homegrown expertise, countries can ensure that technology serves long-term sustainability.

The Gulf's experience demonstrates that food and water security are not isolated development issues—they are integral to economic diversification, social well-being, and long-term national stability. The region has already made notable progress in turning challenges into opportunities for innovation. Continued investment in technological advancement and global partnerships will be essential to sustain this momentum. AI-powered technologies such as precision agriculture, Internet of Things (IoT), smart irrigation, vertical farming, and renewable-powered desalination can help balance environmental stewardship with desired productivity.

The path forward will likely build on the Gulf's proven ability to adapt. Over the recent decades, the region has transformed its deserts into global centres of business, technology and innovation. The same drive that powered this transformation is also being directed toward securing its most fundamental resources—food and water. The momentum created by hosting climate COP28 in 2023,[32] the yearly Abu Dhabi Food Security Summit,[33] and the upcoming United Nations Water Conference in 2026,[34] all offer an ideal opportunity to spearhead the food and water security agenda with sustainability at its core.

Maja Kent is Non-Resident Research Fellow, Centre for Climate Diplomacy (CCD), Anwar Gargash Diplomatic Academy (AGDA), UAE.

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Transboundary Water Management in the MENA: Politics and Prospects

Mohamed Abdelraouf

Water, whether surface or underground, is transboundary by nature; cooperation between riparian countries is an imperative. In an arid region like the Middle East and North Africa (MENA), the lack of freshwater resources and competition over transboundary water resources, in addition to political tensions and armed conflicts, could become a major source of instability in the region.

According to the United Nations,[1] MENA is one of the most water-scarce regions globally, with many countries approaching or exceeding water stress thresholds as shown in Table 1. Furthermore, mega-trends such as climate change, urbanisation, and changing lifestyles across the region increase the demand

for water. At the same time, these challenges can incentivise efforts to jointly manage the transboundary water resources in order to meet the growing water needs.

Table 1: Mean Annual Precipitation, Select MENA Countries

Country	Mean Annual Precipitation (mm/yr)
Bahrain	83
Egypt (Sinai Peninsula)	100
Iraq	216
Jordan	661
Kuwait	121
Lebanon	661
Oman	125
Palestine	402
Qatar	74
Saudi Arabia	59
Syria	252
UAE	78
Yemen	167

Source: Water Inventory[2]

Shared Underground Water Resources

Typically, disproportionate interest and attention is given to surface water, but the MENA region, and specifically the GCC countries, largely rely on shared groundwater resources. At the time of writing this article, no multilateral agreement exists to govern shared underground water resources in the region. For instance, in the West Asian region, the total renewable groundwater resources are estimated at 15.5 bcm.[2] Jordan, Palestine, Yemen and the six GCC countries rely on renewable groundwater sources. These are supplemented by extensive non-renewable groundwater reserves and, in particular in the case of the GCC, desalinated water sources.[4]

Sustainable Development Goal (SDG) 6

Sustainable Development Goal (SDG)-6—'Ensure availability and sustainable management of water and sanitation for all'—is off-track to being met in the MENA region by the 2030 deadline. Progress on key targets is insufficient, with the region facing the highest levels of water stress in the world and a host of mounting challenges such as climate change impacts, unsustainable water use, infrastructure gaps, financial constraints, and poor governance. According to the UN 2023 SDG Report,[5] without intensified efforts, investments, and good governance, the MENA region may not fully meet SDG 6 by 2030.

Water Cooperation and Hydropolitics

Transboundary water management interacts with energy and food security through a complex interplay of resource allocation, infrastructure, and ecological factors as well as political dynamics. The need for water for irrigation (food security) and for hydropower (energy security) often creates competition among riparian states. Coordinated management is necessary to balance these competing demands, ensuring the sustainable management and use of shared water resources.[6]

Water resources in the MENA region are unevenly distributed and under immense pressure. Approximately two-thirds of the Arab world's surface water supplies are transboundary, making regional cooperation not a luxury, but a necessity for human and economic development. This is especially true in the MENA region which experiences high water stress due to extensive aridity and a reliance on shared water sources: over 60 percent of the freshwater flows across national boundaries.

Ineffective transboundary governance exacerbates water scarcity issues, causing agricultural vulnerability for downstream countries and the inability to meet domestic food production needs due to water scarcity that forces many MENA countries to rely heavily on global food imports. Effective management is crucial for balancing energy and food security demands across the region's shared basins.

Long-standing regional political instability has hindered effective cooperation over shared water resources as security considerations are prioritised. Peace is therefore, in most cases, a precondition for cooperation between countries in any field, especially for sharing an essential resource. The inverse is also true: depleted, polluted and degraded transboundary water supplies themselves have the potential to cause social unrest, triggering conflicts within and between countries.

Hydropolitics—or the strategic use and control of water as a political tool—is a key feature of the region's geopolitical landscape. Upstream countries often exploit their geographic location to gain influence, while downstream countries have historically used economic or military force to protect their interests. The desire for water dominance can lead to either cooperation or conflict, depending on the strategies employed and the shifting balance of power.

The Nile Basin Case (the Grand Ethiopian Renaissance Dam)

There is a long-standing dispute between Egypt, Ethiopia, and Sudan regarding the utilisation of Nile waters, representing one of the most complex and potentially destabilising transboundary water issues in the region. The core of the conflict lies in the clash between Ethiopia's developmental aspirations and Egypt's and Sudan's historical water rights.

Despite numerous rounds of negotiations, mediated by entities such as the African Union, a comprehensive, legally binding agreement remains elusive. Ethiopia has proceeded with the unilateral filling and operation of the dam's reservoir, leading to continued diplomatic tensions and accusations from Egypt and Sudan of violating international law.[7] On paper, there is enough water in the Nile basin for all countries and all uses. It is a matter of political will, however, to reach a shared vision and strategy on how best to utilise the available water resources.

The Tigris–Euphrates Case

Tigris–Euphrates tensions emerge from a significant and ongoing transboundary water conflict in the Middle East, primarily between upstream riparian Turkey and the downstream nations of Syria and Iraq. The core of the dispute revolves around Turkey's large-scale water development projects on the rivers' headwaters, specifically the Southeastern Anatolia Project (GAP). Unpredictable water flows from rivers like the Nile and Tigris-Euphrates negatively impact agriculture by decreasing crop yields due to floods and droughts, which in turn raises food prices.

Despite numerous bilateral and multilateral negotiations since the mid-20th century, a legally binding comprehensive agreement for the equitable sharing of the rivers' waters has not been reached. The lack of a formalised cooperative framework, exacerbated by political instability, civil conflict in Syria and Iraq, and climate change, has left the conflict unresolved.

GCC-Shared Groundwater Resources

The primary natural conventional water resource in the GCC is groundwater, with limited supply, along with the deep, non-renewable fossil aquifers that constitute the bulk of the resource. The region shares several major aquifer systems, including the Saq, Tabuk, Wajid, Minjur-Dhruma, Wasia-Biyadh, Um Er Radhuma, and Dammam.

Despite these shared groundwater resources, there is no agreement that governs their utilisation and management, making the region highly vulnerable to potential conflicts over climate change impacts, water depletion, and/or pollution. Groundwater depletion in the GCC countries severely impacts long-term food production and livelihood resilience by directly causing water scarcity, increased extraction costs, reduced crop yields, soil degradation, and increased dependence on vulnerable food imports.

While the political landscape in the MENA region often complicates transboundary water management, there are many avenues for cooperation, discussed in turn in the following paragraphs.

Water Diplomacy

International water law offers some guidance for the common management of shared water resources. However, it will not solve all shared water resources issues alone. A full resolution calls for water diplomacy to fill the gaps by offering means for all riparian countries to benefit from their shared water resources.

Water diplomacy is an important tool for preventing conflict and promoting cooperation as it can promote cooperation, stability, and peace through the management of shared water resources, conflict prevention and resolution, sustainable water management, and improved regional integration.

Nexus approach

Adopting the water-energy-food-climate nexus approach enables countries to address interconnected challenges holistically. For example, the projects supported by the Food and Agriculture Organization (FAO) aim to help countries in the region develop water strategies that are resilient to climate change.

Improved water governance

There are no basin-wide agreements on shared water resources in the MENA region. Existing bilateral agreements only govern surface water resources and centre mainly on water allocation. It is of utmost importance to have comprehensive bilateral or multilateral agreements that focus on sustainably managing these water resources (surface and underground) for the benefit of all riparian countries.

Integrated Water Resource Management

Water cooperation in MENA would also help in implementing IWRM practices on a basin-wide scale. Cooperation in water management demands that all countries and stakeholders in the MENA region share a common understanding of the needs, priorities, and options to take concrete steps towards solutions.

Flexible agreements to address climate change

New water-sharing agreements must account for the impacts of climate change, such as reduced rainfall and increased water scarcity. International funding can encourage countries to cooperate toward more equitable and robust agreements that address both water and climate crises.

Regional Organisations

None of the regional organisations currently working in the field of water has proved to be effective in dealing with tensions over shared water resources between MENA region countries and their neighbours. However, regional organisations such as UN-ESCWA, GCC, and the Arab League, can play a role in improving regional water resources given their political and technical expertise.

A Potential Role for the UAE

GCC countries, either as a bloc or individually, could consider supporting regional water cooperation through their foreign policies by:

- Acting as a mediator for water diplomacy activities among other countries of the region;
- Hosting annual meetings for riparian countries regarding the region's key transboundary water resources;
- Helping in establishing and/or hosting joint technical secretariats for shared water resources management.

There is no doubt that in a water-scarce region like MENA, cooperation around shared resources is essential for promoting peaceful cooperation more broadly. There is plenty of scope for cooperation on aspects related to shared water resources, such as data and monitoring, joint water research, and joint infrastructure water projects. More sustainable management of common water resources can also help achieve stability in the region, indirectly reducing migration and radicalisation.

These strategies can help realise SDG 6 in the MENA, as well as support peace and stability in the region.

Conclusion

Water issues in the MENA should serve as an incentive for countries in the region to cooperate over water resource utilisation. In addition, mega-trends such as climate change, urbanisation, and changing lifestyles can also act as an impetus for efforts to jointly manage shared water resources to meet the growing water needs amidst increasing scarcity.

The transboundary water dynamics in the MENA represent a complex interplay of politics, hydrology, and development. While the potential for conflict remains, particularly in river basins, the increasing pressures of climate change and population growth also provide powerful incentives for cooperation. By prioritising water diplomacy, embracing integrated resource management, and establishing climate-resilient agreements, the region can transform water from a source of geopolitical contention into a catalyst for stability and shared prosperity.

Mohamed Abdelraouf is Program Director, Sustainability Research, Gulf Research Center, Kingdom of Saudi Arabia.

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Public Health Implications of Gulf Water Contamination: Risks, Monitoring, and Response

Fatin Samara and Maya Wael Ahmed Mohamed Tarrad

Safeguarding health in the Arabian Gulf and the Gulf of Oman is centred on understanding what is in the water, where it moves, and how people are exposed to harmful contamination. As populations grow and coastal industries expand, the Gulf's semi-enclosed waters are under increasing pressure from industrial discharges, wastewater effluents, and desalination by-products. These exposure risks are highly differentiated across populations and pathways.

Coastal labour communities and marine-dependent populations, such as fisherfolk, experience elevated risks due to direct and prolonged contact with contaminated seawater, sediments, and bioaccumulated pollutants in seafood, as documented in recent

occupational and coastal exposure studies by Halder et al.[1] Urban residents, meanwhile, are exposed primarily through indirect pathways such as drinking water, air, and food, usually at lower levels but over long periods. Children and pregnant women are particularly vulnerable because of higher intake relative to body weight and greater sensitivity to neurodevelopmental and endocrine-disrupting contaminants.[2] Occupational groups, including desalination workers, face elevated risks from repeated exposure to process waters, aerosols, and by-products, underscoring the importance of targeted monitoring of desalination systems and effluents.[3]

Protecting communities across the region requires an integrated, evidence-based monitoring framework that connects environmental science to public health. The rest of this article outlines the key contamination risks, the need for harmonised monitoring, and the pathways to build resilient water and health systems in the Gulf.

Water Quality in the Gulf Region

The Arabian Gulf faces various environmental stressors. It is shallow, warm, and semi-enclosed with limited circulation, which can allow contaminants to persist longer than in open seas. Rapid urbanisation, industrial growth, and dependence on desalination have intensified pollution pressures. While desalination is essential for water security, it can return concentrated brine, trace metals, and chemical residues to the sea, affecting salinity and ecological balance. Similarly, wastewater reuse and aquifer recharge projects, though vital for sustainability, can introduce microbial and chemical contaminants if not properly managed.

Climate change complicates these dynamics. Rising sea temperatures and evaporation rates exacerbate salinity, while dust storms increase the atmospheric deposition of metals and organics.[4] Across the wider Gulf, similar pressures are evident. In Kuwait Bay, continuous wastewater discharge has degraded recreational water quality and increased public health risks.[5] These findings highlight that pollution challenges are not confined to one country but are shared across interconnected Gulf waters. Recent studies in the UAE have documented how these combined stressors alter microbial communities and nutrient cycles. A study published in 2025 in *Frontiers in Marine Science* found that urbanisation and climatic variation significantly affected microbial and chemical water quality in Khalid Khor, Sharjah.[6] Such findings highlight how environmental and anthropogenic factors intersect, shaping health risks in the region.

The Human Health Connection

Water contamination in the Gulf translates into tangible public health concerns. Chemical pollutants such as mercury, lead, and cadmium bioaccumulate through seafood consumption, impairing neurological and renal functions. Studies of stranded marine mammals in the UAE have found high levels of heavy metals and persistent organic pollutants in their

tissues, indicating broader ecosystem contamination.[7] Emerging contaminants, including per- and polyfluoroalkyl substances (PFAS), a large class of persistent, human-made "forever chemicals",[a] along with pharmaceutical residues and microplastics, are now being detected in coastal waters and sediments, raising questions about long-term exposure and its endocrine-disrupting effects. Microbial contamination is also an important concern. Discharges from treated wastewater can introduce pathogens and antibiotic-resistant bacteria into marine environments, which may increase health risks for coastal labour communities, particularly where access to adequate storage and hygiene infrastructure is limited.

Indeed, faecal contamination of groundwater and surface water was previously documented in Sharjah's Al Wasit Nature Reserve, illustrating how microbial pathways can extend inland.[8] Additionally, the modern desert dust storms carry anthropogenic particle loads that deposit onto Gulf coastal waters and desalination intakes, reinforcing the need for integrated air–sea monitoring and rapid public-health response.[9] During the storm in the UAE in mid-April 2024, floodwaters around Sharjah, UAE contained tire-derived chemicals,[b] underscoring the need to integrate stormwater and drinking-water monitoring into Gulf public health response.[10,11]

A 'One Health' approach that integrates environmental, animal, and human health data is therefore essential to trace these linkages and manage risk comprehensively. In the GCC region, existing water limitations and climate conditions shape agricultural productivity, and environmental contamination can further influence food security alongside food safety. Declines in water quality can affect fisheries and aquaculture, which are important regional protein sources, while contaminated irrigation water and soils may reduce crop yields. In a region that imports approximately 85 percent of its food, these pressures can increase reliance on external supply chains and sensitivity to global food price changes and disruptions.[12] Contaminated coastal waters can reduce local fish stocks through increased salinity, temperature stress, and chemical pollution, leading to fish mortality and loss of biodiversity. These altered conditions also threaten aquaculture viability by impairing the growth and survival of cultured species. The buildup of contaminants in marine organisms can affect the safety and quality of seafood exports, with possible trade and economic impacts. At the same time, concerns about seafood safety may reduce consumer confidence and demand, affecting coastal livelihoods and regional food systems.[13]

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a 'Forever chemicals' is a common term for per- and polyfluoroalkyl substances (PFAS), a group of synthetic chemicals widely used since the 1950s for their non-stick, water-repellent, and grease-resistant properties. They are called "forever chemicals" because their strong carbon–fluorine bonds prevent them from breaking down easily in the environment.

b These are complex, often toxic, substances released into the environment through tire and road wear particles, comprising rubber additives, antioxidants, and vulcanisation agents.

The Importance of Baseline Data

Effective monitoring begins with robust baseline datasets. Yet, across the Gulf, data are often fragmented among ministries, municipalities, and research institutions. Without harmonised methods and multi-year records, it becomes difficult to discern whether observed changes represent genuine deterioration or natural variability. Building regional baselines for chemical, microbial, and ecological indicators would allow authorities to detect shifts early and coordinate responses.

These baseline data should include the following:

Chemical profiles: metals, nutrients, hydrocarbons, and organic pollutants measured seasonally across representative coastal and offshore sites.
Microbial indicators: coliform counts, antibiotic resistance genes, and pathogen diversity tracked over time.
Biomonitoring data: sentinel species such as oysters, fish, and seagrass to capture bioaccumulation and ecological stress.

Previous research by P. S. et al. has demonstrated that remote sensing of oyster habitats in the northern UAE can serve as an early indicator of ecological change.[14] Such integrative approaches exemplify how technology can support baseline development. Shared baselines, published transparently, enable authorities to map hotspots, evaluate interventions, and align national efforts under a common framework. Recent analyses of large-scale desalination in Gulf Cooperation Council states indicate that weak brine-management policies in some areas, particularly Qatar and Bahrain, have intensified salinity and chemical stress in coastal waters, highlighting the urgent need for region-wide regulation.[15]

Strengthening Monitoring Systems

In the GCC, contamination monitoring and response are implemented through a coordinated multi-agency framework. National emergency management authorities (for example, the National Emergency Crisis and Disasters Management Authority - NCEMA in the UAE) provide overall coordination for major incidents, while environmental, health, and municipal authorities carry out complementary roles in pollution control, public health protection, and local enforcement, in line with established mandates. Regional coordination is supported through existing cooperation platforms and can be further strengthened through shared data protocols, interoperable monitoring systems, and joint preparedness exercises.[16]

To support this governance structure and move from periodic sampling toward more timely environmental intelligence, the Arabian Gulf and the Gulf of Oman would benefit from a unified monitoring network integrating four complementary components:

1. Routine chemical testing of metals, organic pollutants, and nutrients in coastal and desalination intake waters.
2. Microbial surveillance for pathogens and antimicrobial resistance genes, leveraging genomic sequencing.
3. Biomonitoring of sentinel species and seafood to assess pollutant accumulation across the food chain.
4. Remote sensing and in-situ sensors to detect algal blooms and contamination plumes, with data feeding AI-based early warning systems.

Such an integrated approach aligns with established international frameworks, such as the EU Water Framework Directive, and can be adapted to the Gulf's environmental conditions. The Regional Organization for the Protection of the Marine Environment (ROPME) has initiated efforts to promote regional data sharing, providing a foundation on which broader coordination and information integration can continue to build.[17]

Linking Monitoring to Health Outcomes

Environmental data, on its own, cannot accurately reflect health risks without context. To understand exposure pathways, water quality measurements must be linked to human behaviour and health outcomes. This requires integrating environmental, dietary, and medical data within a unified analytical framework. Research should connect contaminant levels in water and seafood with biomarker studies, hospital surveillance records, and broader population health indicators.

The UAE's Water Security Strategy 2036 acknowledges this connection by emphasising health-based standards for desalinated and recycled water.[18] Expanding similar frameworks across the Gulf would promote consistent risk assessments and enable more targeted health advisories. These initiatives are informed by global guidelines such as the World Health Organization's Guidelines for Drinking-water Quality.[19] For instance, comparing hospital data on gastrointestinal illnesses with environmental contamination trends could uncover unreported outbreaks or chronic exposure patterns. Likewise, analysing seafood consumption alongside evidence of bioaccumulation helps support scientifically grounded dietary recommendations.

Funding and Capacity Building

None of these advances are possible without sustained investment. Monitoring programmes across the Gulf often rely on short-term grants, limiting continuity and comparability. Establishing a regional water quality and health fund co-supported by governments, industry, and international partners would secure long-term capacity.

Priority investments should include the following:

- Upgrading laboratories and ensuring inter-laboratory proficiency testing.
- Expanding training in environmental chemistry, epidemiology, and data science.
- Maintaining sensor networks and field logistics.
- Developing open-data platforms that integrate chemical, microbial, and health metrics.

Steady funding signals political commitment and builds resilience. It also enables cumulative datasets that move policymaking from assumptions to evidence.

Collaboration, Transparency, and Policy Integration

The Gulf's waters are shared, not divided. Pollution in one area inevitably affects another. This demands cooperative monitoring and open data sharing. A regional State of the Gulf Waters annual report, modelled on the European Environment Agency's water-quality assessments, could strengthen transparency and accountability.[20] Partnerships between national laboratories, universities, and regional organisations such as ROPME would help harmonise protocols and improve inter-laboratory calibration.[21]

Desalination is a pillar of water security in the GCC and accounts for approximately 46 percent of global desalination capacity, reflecting the region's long-standing investment in desalination to meet water demand under arid conditions.[22,23] Recent reviews by D'Agostino et al. show that although desalination research in the region has expanded rapidly, much of the operational data and infrastructure remain with private operators, highlighting the need for closer collaboration between industry, regulators, and researchers to support effective environmental safeguards.[22] In addition to domestic use, desalinated water increasingly supports food-system resilience through irrigation, food processing, and controlled-environment agriculture such as hydroponics, strengthening the regional water–energy–food nexus.[23]

While regional mechanisms support cooperation, monitoring and response across the GCC are mostly carried out through national programmes that use different indicators, sampling frequencies, and data systems. This can delay the detection of transboundary contamination or harmful algal blooms, creating blind spots for desalination intakes in shared waters and complicating coordinated assessments of fisheries and seafood safety. Existing platforms provide a strong basis for cooperation and could be further enhanced through improved data interoperability and aligned monitoring outputs.[22,23,24]

Transparency also enhances public engagement. Making water quality information accessible encourages industries and citizens to support preventive measures. When communities understand the health implications of pollution, they can act as partners in protecting water sources.

Towards a Health-Centred Water Policy

True water security depends not only on availability but also on safety. Placing health at the centre of water policy shifts the focus toward well-being, resilience, and preparedness. Developing risk-based standards that reflect the unique conditions of Gulf ecosystems can safeguard vulnerable communities while supporting sustainable development. Integrating One Health data with AI-driven early-warning systems could further enhance the region's ability to anticipate and respond to contamination incidents.

The Gulf has the expertise and innovation capacity to lead in this field. Its experience in desalination, smart infrastructure, and data analytics can be channelled into comprehensive environmental-health governance.

Conclusion

Protecting the Gulf waters is about protecting people. By strengthening integrated monitoring, establishing shared baselines, and linking environmental data with public health, the region can detect risks early and respond effectively. Collaboration, transparency, and sustained investment will determine whether the next generation inherits a Gulf defined by resilience or risk. Science-driven, cooperative policy action offers the surest pathway to safeguard both water and health.

Fatin Samara is Professor of Environmental Sciences, American University of Sharjah, UAE; Deputy Director, EWSERC; and Adjunct Faculty, American University, Washington DC.

Maya Wael Ahmed Mohamed Tarrad is a Chemistry Graduate from the American University of Sharjah, UAE.

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Hydrogen and Water in the Gulf Energy Transition: Competing or Complementary Needs?

Lourdes F. Vega

The Gulf Cooperation Council (GCC) countries are positioning themselves as global leaders in hydrogen,[1] with multi-billion-dollar projects aiming at exporting hydrogen-based fuels. From Saudi Arabia[2] to the UAE,[3] the region is investing billions of US dollars to become a leading exporter of clean hydrogen.[4]

At the same time, however, the region faces acute water scarcity, raising fears that hydrogen production from water electrolysis will compete with already stretched water resources.[5] The question, therefore, is whether large-scale green hydrogen production will compete with local water needs, or both can become complementary pillars of sustainable growth.

Hydrogen's Promise and the Gulf's Water Paradox

GCC countries are leading the global hydrogen transition, with national strategies positioning the region as a clean hydrogen exporter to Asia and Europe. Hydrogen investments aim to transform the energy landscape and diversify hydrocarbon-based economies. However, hydrogen production is water- and electricity-intensive, potentially competing with municipal and agricultural needs. This poses a dilemma, as water is the Gulf's most limited resource. Can the region expand clean energy ambitions without intensifying water stress?

Yet, at the same time, this narrative of competition for water is only half the story. Water and hydrogen can become complementary pillars of the Gulf's energy transition. Integrated policies, technological innovation, shared infrastructure planning, and regional collaboration, can turn the hydrogen boom into a catalyst for sustainable resource management, enabling integrated water–energy solutions.

Green hydrogen from electrolysis requires around nine litres of high-purity water per kilogram. Large-scale hubs, such as NEOM in Saudi Arabia or projects in Abu Dhabi, Dubai, and Oman, envision around 10 million tons of green hydrogen per year,[6] translating to hundreds of millions of cubic meters of water demand. This would be a cause of concern for a region that is among the most water-scarce in the world. Gulf states rely on desalination for up to 80 percent of municipal water supply, and desalination faces cost, energy, and environmental challenges. Diverting scarce water to hydrogen without planning would appear to be counterintuitive, or even irresponsible.

A False Dichotomy: Why Competition Is Not Inevitable

Framing hydrogen and water as competitors oversimplifies the picture. A number of factors demonstrate that the relationship between these two resources does not need to be one of conflict, and they are discussed in turn in the following paragraphs.

1. The scale of demand relative to desalination capacity. Even if the Gulf produces 10 million tons of green hydrogen annually, the associated water demand would be about 90 million cubic meters per year. By comparison, Saudi Arabia alone desalinates over 2.5 billion cubic meters annually.[7] In percentage, hydrogen would add approximately 3-5 percent to total desalination demand. While not negligible, this is far from catastrophic.

2. Synergies in energy and water infrastructure. Green hydrogen production requires both water and renewable electricity. Coupling renewable-powered desalination plants with electrolysis facilities allows integrated infrastructure for water purification and hydrogen generation. This co-location reduces costs, improves efficiency, and strengthens resilience. Furthermore, desalinated water costs around 0.8 EUR/m3, adding only 0.007 EUR/kg to the

production cost of hydrogen.[8] Water desalination plants for hydrogen could also supply freshwater for human consumption and/or irrigation, creating multiple benefits to the local area.

3. Innovation in water sources and use. Hydrogen does not rely solely on desalinated seawater. Alternative feedstocks include saline water,[9] brackish groundwater,[10] wastewater,[11] or industrial effluents.[12] Advances in electrolysis are also reducing water and energy intensity and enabling tolerance of lower-quality water inputs. Rather than competing with water, hydrogen can push investment into technologies that broaden the water portfolio.

4. Hydrogen as a driver of sustainable desalination. The Gulf's hydrogen ambitions are accelerating renewable-powered desalination, creating incentives for greener water and low-carbon, high-efficiency desalination technologies. The long-term effect could be cleaner, cheaper, and sustainable water systems that benefit society.

The Opportunity for Complementarity

Hydrogen and water can reinforce each other's sustainability agendas, particularly in the Gulf, where water and energy security are deeply interconnected.[13] The Gulf region's abundant renewable resources, engineering expertise, and financing capacity, uniquely position it to pioneer a water–hydrogen nexus with global relevance.[14] The following examples illustrate this complementarity:

1. Coupling renewable desalination with hydrogen. The Gulf's high solar irradiance[15] and coastal geography make it ideal for renewable-powered desalination. Integrated facilities where renewable electricity drives both desalination and electrolysis can achieve economies of scale, cut costs, improve operational stability, and reduce emissions compared to standalone facilities.

2. Circular approaches to water use. Hydrogen facilities can be designed for circular water systems, treating, and reusing wastewater within the plant. Industrial symbiosis—using effluents from one process as inputs for another—can minimise freshwater demand. Combining hydrogen hubs with carbon capture, ammonia production, or industrial parks creates opportunities for resource cascading.

3. Supporting food security. Shared resources will free up desalinated water for agriculture, supporting food-security strategies across the GCC. This is especially relevant for countries like the UAE, Saudi Arabia, and Oman, which are currently expanding domestic food production through hydroponics and high-tech agriculture, increasing freshwater and electricity demand.

Furthermore, green hydrogen-derived fertilisers, such as green ammonia, can boost crop yields while aligning food production with low-carbon sustainability goals, strengthening the energy-water-food security objectives.

4. Driving technological innovation. Hydrogen is already attracting substantial R&D funding. Aligning hydrogen strategies with water-security goals can drive innovation toward advanced desalination membranes, brine valorisation, and water-efficient electrolysis, generating benefits beyond hydrogen for agriculture, industry, and urban water supply.

The Gulf region is already leading this technology-driven integration. In Saudi Arabia, a 100-percent renewable-powered selective desalination plant,[16] is designed to produce up to 500,000 m³/day while enabling advanced water reuse and value recovery from brine, linking circular water management to hydrogen production. In Oman, renewable-powered desalination and water purification systems are integrated with green hydrogen production facilities.[17] The second solar-powered desalination plant[18] is under construction, demonstrating integrated solutions for water and energy in arid climates.

5. Exporting sustainability, not just fuel. Global buyers of hydrogen (i.e., Europe, Japan, and Korea) are increasingly focused on the carbon footprint of imports. Demonstrating that hydrogen from the Gulf countries produced with sustainable water practices can strengthen the region's competitiveness. Positioning hydrogen as "water-neutral" or "water-positive" adds value in global markets where Environmental, Society and Governance (ESG) criteria matter.

The Risks of Inaction: When Complementarity Fails

Synergy is not guaranteed. Without careful planning, hydrogen development could worsen water challenges or miss its goals. Key risks stand out:

- If hydrogen water demand is met with desalination powered by fossil fuels, the carbon savings of hydrogen are compromised.
- Diverting desalination capacity to hydrogen exports while neglecting domestic water affordability would increase the water stress and create public opposition.
- Building hydrogen infrastructure without considering water and renewable-energy integrations risks locking the region into inefficient designs costly to retrofit, in turn increasing the cost and resource scarcity.

The Gulf states must avoid these pitfalls by adopting proactive governance, transparent planning, and regional cooperation.

Policy Priorities for a Water–Hydrogen Nexus

To make hydrogen and water allies rather than competitors in the Gulf region's energy transition, policymakers must adopt an integrated, forward-looking approach. National hydrogen strategies should quantify water needs, identify sustainable sources, and set clear efficiency and conservation targets, building public trust and avoiding misconceptions. Hydrogen projects should pair with renewable-powered desalination, ensuring water demand without deepening fossil fuel dependence, keeping hydrogen's production footprint very low or zero. Investment in water-efficient electrolysis, wastewater-fed systems, and brine utilisation can further diversify supply and reduce pressure on scarce freshwater resources.

Effective implementation requires transboundary mechanisms. Shared frameworks for standards and regional data-sharing can standardise reporting on water, energy, and environmental performance, enabling evidence-based planning. A Gulf water–hydrogen-energy coordination body could align strategies, infrastructure planning, and cross-border investments, strengthening ESG and certification credibility.

Last but not least, bilateral and multilateral collaborations offer models for regional integration. Examples include the UAE-Oman SalalaH2 project,[19] focused on large-scale green hydrogen and ammonia powered by renewable energy, and the ACWA Power-Bapco solar-battery project,[20] that links Saudi Arabia and Bahrain, sharing cross-border infrastructure and standards to support sustainable growth.

A New Narrative for the Gulf's Transition

The story of hydrogen and water in the Gulf is often told as conflict, but the reality is more hopeful. Yes, hydrogen requires water, and yes, the Gulf is water scarce, but the hydrogen's water demand is manageable, and it can accelerate innovation in desalination, circular water systems, and integrated energy–water infrastructure.

Rather than competing, hydrogen and water can reinforce sustainability. For Gulf countries seeking to diversify economies, energy leadership, and resource security, this is an opportunity too valuable to miss.

The question is not whether hydrogen and water compete but whether policymakers, investors, and researchers design complementary strategies. If synergy is achieved, the Gulf will lead the global hydrogen economy while setting a benchmark for solving one of today's greater challenges: how to secure energy and water together in an era of transition.

Lourdes F. Vega is a Full Professor of Chemical Engineering, Khalifa University, Founder and Director, Research and Innovation Center on CO2 and Hydrogen (RICH Center); Theme Lead, Energy and Hydrogen, Research and Innovation Center for Graphene and 2D Materials (RIC2D), UAE.

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Membrane Innovation in Desalination: Redefining Water Security in the MENA Region

Nidal Hilal

For decades, the countries of the Middle East and North Africa (MENA)[a,1] have achieved a remarkable feat of hydrological engineering. Faced with extreme water scarcity, they turned to the sea, building some of the world's largest desalination plants, now responsible for more than half of global desalinated water production. This transformation began in the mid-twentieth century and has since sustained cities, industries, and agriculture.

a Middle East and North Africa (MENA) refers to the group of countries spanning West Asia and North Africa, commonly including Algeria, Bahrain, Egypt, Iran, Iraq, Palestine, Israel, Jordan, Kuwait, Lebanon, Libya, Morocco, Oman, Qatar, Saudi Arabia, Syria, Tunisia, the United Arab Emirates, and Yemen; some definitions also include Turkey, Cyprus, Djibouti, Mauritania, and Sudan, depending on institutional usage.

At the same time, however, these plants have created new strategic vulnerabilities, including high energy dependence, ecological pressures from brine discharge, and rising costs associated with electricity consumption.[2]

The region's next phase of water security will not be achieved simply by building more capacity. It requires a technological and governance transition, one centred on modern membranes,[b] integrated energy-water-food planning, and a regulatory framework that aligns desalination with national development priorities. For policymakers, advancing membrane desalination is no longer just a technical matter; it is a strategic imperative tied to economic resilience, food security, and the stability of rapidly growing digital economies.

Water Security, Food Security, and the Limits of the Status Quo

MENA is the most water-stressed region in the world.[3] In most countries of the region, agriculture accounts for 70 to 90 percent of freshwater withdrawals, yet shrinking aquifers, climate-driven droughts, and population growth are tightening the supply-demand gap. This makes water reliability a direct determinant of food security. Local crop production, from dates to vegetables, depends on predictable irrigation water. When freshwater is diverted to cities or industry, agriculture is the first to suffer, increasing import dependence and exposure to global food-price volatility.

Desalination plays a central role in protecting municipal supply, but the current energy-intensive model contains long-term risks. Reverse osmosis (RO) desalination has reduced energy needs dramatically compared to thermal systems, yet even advanced RO plants operate at two to three times the theoretical minimum energy requirement.[4] This benchmark reflects the unavoidable thermodynamic energy required to separate salt from water, estimated at about 1.06 kWh/m^3 for desalinating 35,000 mg/L seawater at a 50-percent recovery rate.[5] The closer systems get to that minimum, the lower their operating costs and carbon footprint. For policymakers, this gap represents billions of dollars in lifetime operational expenditure and major implications for national emissions targets.

Environmental pressures compound these risks. RO plants with ~50 percent recovery rates produce nearly a liter of hypersaline brine for every liter of freshwater. Discharging this into coastal waters elevates salinity and harms ecosystems central to fisheries and tourism. Brine can also deplete oxygen levels and harm sensitive marine ecosystems, particularly coral reefs and seagrass beds. As desalination scales to support growing cities, economy, agriculture, and emerging digital industries, these challenges will intensify.

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b Membrane desalination refers to a class of water treatment technologies that use semi-permeable membranes to separate dissolved salts and impurities from water, most commonly through pressure-driven processes such as reverse osmosis. These systems rely on physical separation rather than phase change, making them more energy-efficient and scalable than thermal desalination technologies

The Frontline of Change: Advances in Membrane Technology

Membranes sit at the core of RO desalination, dictating the efficiency, cost, and environmental footprint of every plant. Across the region and globally, a new wave of membrane innovation is accelerating. Researchers, including this author's research at NYUAD Water Research Center,[6] are developing polymer membranes with improved permeability and fouling resistance;[7] hybrid membranes that combine mechanical strength with scalability; biomimetic membranes inspired by aquaporins, capable of transporting water at high flux with minimal energy; 3D-printing of novel membranes,[8] and nanostructured membranes with precisely engineered pores that could separate ions, metals, or specific contaminants in a single step.

These advances work toward a common goal: reducing the pressure needed to push seawater through the membrane and minimising the fouling that forces plants to clean, replace, or operate at higher pressures. Reducing fouling rates and extending membrane lifespans can yield greater energy savings than incremental gains in permeability alone. As these innovations move from the lab to the field, pilot projects will likely test these membranes in real plants. The rising tide of membrane innovation promises to raise the sails of MENA's water security, not by breaking physics, but by outsmarting inefficiency.

Renewable-Powered Desalination: Regional Momentum

What once was a limitation, desalination's dependence on electricity, has become a strategic advantage as MENA accelerates its shift toward clean energy. Solar, nuclear, and wind power are increasingly being used to drive these desalination systems, aligning water production with the region's clean-energy transition. With an abundance of sun and wind and an urgent need for water, the logic is clear: let renewable energy fuel desalination. The synergy between membranes and renewable power is increasingly visible across the region.[9] The UAE's Taweelah IWP, for example,[10] integrates one of the world's largest RO facilities with dedicated solar production. Saudi Arabia's Al Khafji solar-powered plant[11] demonstrates the feasibility of large-scale desalination running entirely on solar energy. Oman's pilot membrane installations in Sur[12] explore how advanced membranes and renewable sources can be combined at smaller, more distributed scales.

Together, these examples signal a regional transition toward cleaner and more cost-stable desalination, with potential benefits extending from municipal supply to agriculture and rural development. As solar and wind prices continue to fall, fully renewable desalination becomes increasingly realistic, including off-grid systems that support remote communities, islands, and agricultural clusters. These systems can significantly reduce diesel imports, minimise carbon emissions, and enhance local self-sufficiency.

Toward a Coherent Governance Framework

Technology alone will not be able to secure the region's water future. A more coherent governance framework is required, one that aligns desalination with national priorities across water, energy, food, digital infrastructure, and industry.

A first pillar of this framework is regulation and sustainability standards. Clear guidelines on brine discharge, energy efficiency, and water quality, especially for agriculture and food production, will enable desalinated water to be used reliably across sectors.

Equally important is cross-sector coordination, particularly as emerging industries reshape regional water demand. The rapid expansion of artificial intelligence (AI), cloud computing, and data-centre infrastructure across the Gulf is creating a new class of strategic water consumers. Large-scale AI model training, cloud services, and hyperscale data centres all require substantial volumes of high-quality water for cooling, thermal regulation, and uninterrupted power delivery. This trend is accelerating: recent UAE-US agreements to deepen cooperation in AI,[13] advanced computing, and chip manufacturing signal a regional shift toward digital economies that depend on a stable and scalable water supply.

If managed proactively, desalination can support this growth without displacing water allocated to households or agriculture. If left uncoordinated, however, these rising cooling demands could intensify competition across sectors. Incorporating AI-related water forecasting into desalination planning is therefore essential for future-ready governance.

This need for integration extends to agriculture. Desalination expansion should be planned alongside national food security strategies, ensuring predictable irrigation supplies and promoting treated-wastewater reuse where appropriate. Private-sector participation also plays a vital role.

Public-private partnerships that reward high efficiency, low carbon footprints, and the adoption of advanced membranes can accelerate modernisation across the region's desalination portfolio. Competitive tenders that require renewable-energy integration and high-performance membrane technology ensure that innovation is rapidly absorbed into national infrastructure.

Policy Pathways for a Resilient Desalination Future

Policy and investment decisions will determine how quickly membrane desalination can progress, since MENA governments know water and energy policy must align. To support membrane innovation, policymakers can encourage research funding for new materials and

devices, while reforming water pricing to incentivise efficiency. Clearly communicated water tariffs, for example, can discourage waste while helping consumers appreciate the true value of the resource.

Public-private partnerships allow governments to share the risk of building cutting-edge plants. A number of MENA countries have already issued calls for proposals to build and run state-of-the-art desalination facilities. These initiatives often require the latest membrane technology or renewable energy, fast-tracking innovation into deployment.

Beyond infrastructure, the region is also investing in innovation as a form of water diplomacy. The UAE's Mohammed Bin Zayed Water Initiative[14] has put US$150 million toward accelerating breakthrough water technologies worldwide through the XPRIZE Water Scarcity competition,[15] which challenges scientists and engineers across the world to build affordable, energy-efficient desalination systems. These initiatives go beyond funding; they create a race to the top, turning water scarcity from a crisis into a catalyst for invention.

Furthermore, water knows no borders, aquifers, rivers; even desalination know-how can spill across lines. Arab states and regional bodies can share best practices and pool resources for large research centres. Joint labs and scholarships in water science help the entire region benefit from collective knowledge. Collaboration might even extend to shared desalination projects on international waterways. The following are the key policy pathways:

1. **R&D Incentives:** Grants for universities, research centres, and startups developing next-generation membrane materials, low-pressure RO systems, and renewable-powered desalination technologies.
2. **Infrastructure Modernisation:** Replacing ageing thermal desalination plants with modern membrane-based facilities and hybrid systems that offer higher efficiency, lower emissions, and greater operational flexibility.
3. **Environmental Regulation:** Establishing clear standards for brine disposal, effluent quality, and marine ecosystem protection, while encouraging technologies that minimise brine volumes or enable resource recovery.
4. **Capacity Building:** Training local engineers, plant operators, and regulators in advanced membrane systems, renewable integration, digital monitoring, and best practices in desalination management.
5. **Public Awareness:** Promoting water-conservation initiatives and improving public understanding of the economic and environmental value of clean water to support sustainable consumption.

6. **Food- and Agriculture-Linked Measures:** Introducing incentives for expanded water reuse in agriculture, prioritising treated wastewater as the primary irrigation source over desalinated water, aligning desalination planning with national food security strategies, and establishing clear quality standards for both treated wastewater and desalinated water used in irrigation, controlled-environment farming, and food-production sectors.

By weaving these policies together, MENA countries create fertile ground for membrane innovation, resulting in desalination systems that pump out water as well as the local economies and protect the environment. Policymakers have a chance to turn water scarcity into an opportunity for growth.

The Road Ahead: Challenges and Opportunities

While progress is evident, hurdles remain. A crucial challenge is the management of brine, the excessively salty leftover from desalination. If simply dumped into the sea, it can harm marine life. Smart membranes will partly solve this by producing less brine (higher water yield), but the industry must also invest in brine reduction technologies. Ideas include mixing brine with other waste streams, extracting valuable minerals, or even using it for salt-tolerant aquaculture, turning a problem into an opportunity.

Energy storage and grid integration are other challenges. Renewable-powered desalination[16] works best when the sun shines or the wind blows. To avoid shutdowns at night or on calm days, plants might need battery storage or to stay connected to the grid as a backup. Policymakers can encourage this by aligning electricity and water planning. As battery and grid technologies improve, these issues will become easier to manage.

Indeed, these challenges spur innovation. Companies are testing mobile desalination units on barges or ships to serve remote islands or drought emergencies. There is talk of using AI to optimise plant operations, predict maintenance, and adjust pressure to save energy highlighting the water-AI nexus. As membranes improve, what could follow are foldable desalination units that communities can easily deploy. These solutions could bring clean water to the most remote areas.

The opportunities also extend across the region. MENA's membrane technologies could be exported to other arid parts of the world, from North Africa to Central Asia, creating new industries and jobs at home. Resilient water systems also contribute to stability: water shortages have historically led to stress in many parts of MENA. By securing fresh water, governments buy time for reforms in food production and energy use.

Overall, in MENA, where desert meets sea, membrane innovation could turn scarcity into plenty, and this revolution in desalination is already unfolding in labs, pilot plants, and even on policymakers' drawing boards. The path to water and food security runs through innovation, requiring investment, cooperation, and new ideas. If the region continues on this course, its waters will be cleaner, more abundant, and more dependable, ensuring that even in the driest climes, life can flourish.

Nidal Hilal is Professor and Director, Water Research Center, New York University Abu Dhabi, UAE.

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Catalysing the GCC's Waste-to-Energy Prospects for Agriculture

Leigh Mante

The Gulf Cooperation Council (GCC) is projected to experience exponential population growth in the coming years, which will undoubtedly compound waste generation. In parallel, the region is accelerating domestic food production efforts to meet growing demand and enhance food security, resulting in increases in agricultural residues and food waste.[1] These trends are driven by factors such as rising affluence, cultural preferences towards consuming new goods, and the short shelf-lives of imported food.[2,3,4] To illustrate, in 2023, the amount of agricultural waste collected in GCC countries increased by 44 percent, while the amount of food waste in 2022 averaged 150kg per capita annually, surpassing the global average by 14 percent.[5,6]

Waste-to-Energy (WtE) refers to the process of generating electricity or heat from waste treatment.[7] While incineration tends to be more prevalent, anaerobic digestion (AD) and pyrolysis are commonly deployed to convert organic matter into biogas and bio-fertiliser.[8] Converting waste into energy presents several co-benefits, namely strategic waste management enforcement, landfill diversion, material recovery, resource looping, and contributions to renewable energy. Given converging national commitments towards promoting circular economy principles and reducing food loss and waste, WtE through AD and pyrolysis offers a nascent yet economically viable solution to address agriculture and food waste, meet facility-level energy needs, and promote regenerative agriculture. This article assesses the evolving WtE landscape across the Gulf, evaluating opportunities and key challenges to leverage WtE within the region's rapidly expanding agriculture sector.

Converging National Policies Enable Catalysation of WtE Growth

All six GCC countries have established targets for renewable energy production, but WtE currently comprises a tiny fraction of this output.[9] Harnessing WtE conversion potential first requires developing a strong foundation for waste collection, separation, and management. Despite progress, the GCC countries' waste management strategies are greatly limited to landfilling, which currently processes more than 85 percent of the region's waste.[10,11] Currently, less than 20 percent of solid waste is adequately treated, and less than 5 percent is recycled.[12] Food waste comprises the largest portion sent to landfills and is the primary source of methane.[13] This strategy will also likely falter in the long term for countries like Qatar, Kuwait, and Bahrain, which have limited land capacity.[14]

A handful of GCC countries have instituted converging waste, energy, and circular economy policy commitments, enabling WtE to gain traction over the last five years. Well-established and commercial-scale plants exist in the UAE and Qatar and are rapidly materialising in Saudi Arabia, Bahrain, Oman, and Kuwait. These plants largely convert municipal solid waste (MSW), which includes organic food waste, to electricity through incineration, a process that releases carbon emissions from burning, albeit to a lesser extent than landfilling.[15]

Country	Waste Policy	Energy Policy	Circular Economy Policy	Food Security Policy	WtE Facilities
UAE	National waste management regulations	UAE's Energy Strategy 2050	UAE Circular Economy Policy 2021 - 2031	UAE National Food Security Strategy 2051aims to reduce food waste by 50 percent by 2030	Sharjah: commercial-scale 30-MW WtE plant launched in 2022 Dubai: 200-MW WtE facility to power more than 120,000 households) Abu Dhabi: 100-MW WtE facility in development to power nearly 20,000 households
Saudi Arabia	Saudi Green Initiative targets 94 percent landfill-waste diversion by 2035	Renewable Vision 2030 aims to produce 3 GW of WtE	Saudi Arabia Circular Carbon Economy (CCE) Framework	Saudi Arabia Food Security Strategy and Implementation Plan up to 2030 Food waste accounts for 40-50 percent of the country's waste	In development: Riyadh (200MW), Jeddah (100MW), NEOM
Qatar	Qatar Third National Development Strategy (2024-2030) aims to reduce waste generation and increase recycling	Qatar National Renewable Energy Policy promotes energy diversification	Qatar National Vision 2030 and Third National Development Strategy	Qatar National Food Security Strategy 2030 and State Food Security Project aims to address 55 -70 percent of food loss and waste through sustainable solutions	Operational: 34-MW WtE facility operating in Mesaieed (since 2011)
Kuwait	Kuwait National Waste Management Strategy (KNWS 2040) aims for 20 percent energy recovery from sewage sludge	Kuwait Energy Diversification Objectives	Kuwait Environment Public Authority	Kuwait Supreme National Committee for Strengthening the Food, Drug, and Water Security System (August 2022)	In development: 100-MW Al Kabd WtE plant, and RDF Plant in Mina Abdullah
Oman	New Waste Management Law	Oman Energy Master Plan 2040	Oman Vision 2040	Oman Sustainable Agriculture and Rural Development Strategy towards 2040	In development: 95-100 MW Barka WtE (operational by 2031) Also deploys landfill gas capture to convert methane
Bahrain	Bahrain National Waste Management Strategy (2018)	National Renewable Energy Plan targets biogas production and landfill gas recovery	National Action Plan, Blueprint Bahrain	Bahrain National Initiative for Agricultural Development	In development: Askar 25MW biopower project

Source: Compiled by the author

Expanding WtE in the GCC's Agriculture Sector

The GCC countries have set forth national vision and food security strategies outlining commitments towards accelerating domestic food production and food waste reduction initiatives.[16] Agriculture, food, and beverage facilities should consider implementing on-site, localised and integrated AD and pyrolysis systems through industrial symbiosis to extend the life of scarce resources and encourage closed-loop processes.[17,18,19] GCC countries are increasingly leveraging AgriTechnologies to boost resource efficiency amidst water and climate constraints, but this can be energy-intensive.[20] Therefore, converting food residue into biogas through anaerobic digestion (AD), a process where micro-organisms decompose organic matter to produce biogas, can help meet facility-level energy needs.[21] Pyrolysis converts organic waste and digestate byproducts from AD into biofuel or biochar, which strengthens soil fertility and water retention, reducing irrigation needs.[22,23,24] The GCC's existing crop commodities (date palms, cereal, fruits and vegetables) and animal waste are all suitable and energy-rich feedstock inputs for AD and pyrolysis.[25,26] One study notes that GCC crop residues offer 1.68 Mtpa of untapped energy, while animal waste offers 25.52 Mtpa, offsetting up to 13.35 percent of current electricity consumption.[27] AD also has a lower environmental impact compared to incineration.[28]

Compared to stand-alone operations, on-site integrated AD and pyrolysis systems offer more cost-effective, water- and energy-efficient solutions.[29] Electricity generated from biogas is minimal compared to conventional sources if pursued on a larger scale.[30] Additionally, unlike MSW feedstock, agricultural waste quantities may fluctuate depending on the harvest season. However, when paired with renewables like solar, biogas can help meet facility-level electricity demand. On-site infrastructure would save resources allocated towards transferring waste for sorting and complement reuse methods like composting. Challenges include managing the heterogeneity of food waste, which risks influencing the quality of feedstock that can be converted into biogas.[31]

Diverting organic waste from landfills would also help reduce water contamination, while biochar products would help reduce dependence on water-intensive synthetic fertilisers.[32] Combining these processes with growing efforts to leverage local water treatment and reuse systems for the agriculture sector would reduce pressure on constrained water systems.[33] Ensuring compliance with water quality standards and monitoring and deploying alongside comprehensive awareness campaigns would prevent unwanted contamination and ease concerns that inhibit technology uptake in the region.[34]

Despite the proven technical feasibility of generating biogas from AD across Oman, Qatar, and Kuwait, the strategy remains heavily underutilised.[35,36,37] The potential electricity generated from Oman's organic waste could offset up to 22.5 percent of the country's total energy consumption, yet it is currently managed through landfills.[38] In Qatar, the traditionally landfilled

organic fraction of municipal solid waste, livestock manure, and sewage sludge waste can all be valorised through AD to generate 3.5 million MWh of surplus clean energy.[39] In Kuwait, food waste is the most energy-rich feedstock, yet biogas contributes to zero percent of the country's renewable footprint.[40]

Scholars note the economic feasibility of AD in the UAE, Saudi Arabia, and Bahrain. In the UAE, AD matches the economic feasibility of incineration. In Saudi Arabia, an abundance of food waste and low annual operational costs make biomethanation (a form of AD) a suitable option.[41] The levelised cost of energy produced from biomass is also comparable to that of solar in Saudi Arabia.[42] In Bahrain, establishing an AD plant to treat biodegradable waste is expected to generate 213.3 GWh/y with approximate annual revenues of US$4.2 million a year from electricity sales.[43]

Organisations like ReFarm in Dubai have taken the initiative to integrate high-tech food waste recycling in their closed-loop food production system.[44] ReFarm is a waste-to-value gigafarm producing more than 3 million kg of food powered with energy produced from incinerating its solid waste. Khalifa University has also researched the use of pyrolysis to transform green farm waste into biochar, which helps sequester atmospheric carbon dioxide when reused in soil, contributing to regenerative agriculture.[45] The Gulf can also learn from Egypt, where companies like Wastilizer convert animal waste into water, biogas and plant fertiliser, enhancing crop and water quality.[46] As domestic agricultural production grows, there is unharnessed potential to leverage on-site WtE in agricultural centres.

Capitalising on the Gulf's WtE Potential: Next Steps

Implementing and scaling pilots remains a challenging feat since developing WtE remains a highly capital-intensive process, competing against lower-cost traditional landfilling methods in the immediate term.[47] Many regulatory frameworks and financial incentive structures are still emerging and lack consistency.[48] Small-scale initiatives would benefit from state-led tax incentives for the private sector, carbon credit allowances, and increasing landfill gate fees to increase appeal for AD development in the GCC.[49] Financial feasibility would increase if combined with strict waste disposal regulations, strengthened integration between research, policy, and development, and the development of markets for biochar and digestate fertiliser.[50] Establishing joint ventures and de-risking innovation through blended finance, like green sukuk, would also help scale efforts.[51]

Effective waste-to-energy operations also hinge on receiving consistent and high-quality feedstock sources to maximise energy generation. However, the efficiency of collection and sorting processes, as well as the quality and scale of logistics and agricultural infrastructure, currently vary among GCC countries, limiting the consistency of feedstock quality.[52] While

countries like the UAE lead in food value chain innovations, others like Oman could benefit from integrated capacity building to facilitate technology adoption by small-scale farmers.[53]

Ensuring consistent feedstock for WtE should not overshadow the underlying need to regulate unsustainable consumption practices. Thus, prevention, reuse, and recycling should remain at the forefront of sustainable waste practices.[54] WtE should incentivise strengthening implementation of stronger public awareness, recycling, and waste segregation programmes to help cultivate better habits, facilitate and improve waste operations.[55]

Conclusion

WtE is rapidly gaining momentum in the Gulf, with the potential to become a highly lucrative industry. Organic waste from food comprises a significant component of MSW but remains highly underutilised in Gulf countries.[56] As the GCC strategises improvements in waste management practices and feasibility studies continue to highlight the versatility of WtE in the region, this solution emerges as a strong contender to promote closed-loop economies, especially for expanding sectors like agriculture. Catalysing WtE in the agricultural sector to reap the strategic benefits for the water-energy-food nexus will require harmonising waste management and water reuse standards across the GCC and reducing upfront financing barriers through public-private initiatives.

Leigh Mante is Junior Fellow, Climate and Energy, ORF Middle East, UAE.

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Water Security Modelling and Drought Forecasting in the MENA Region

Hamed Assaf

Water scarcity has shaped the Middle East and North Africa (MENA) region for millennia. This constant challenge, however, has also been a powerful catalyst for innovation, as evidenced by the ancient dams and sophisticated water management systems found across the region. Today, in an era of accelerating climate change, rapid population growth, and increasing urbanisation, the need for such innovation is more critical than ever. The MENA region is a global climate change hotspot, warming at twice the global average and facing projections of more frequent, intense and prolonged heatwaves and droughts.[1] This environmental stress is compounded by socio-economic pressures, including some of the world's highest population growth rates and a heavy reliance

on water-intensive agriculture for food security. One of the most vital factors in navigating this complex landscape is the ability to accurately understand, predict, and mitigate the impacts of droughts on water security and, consequently, on socio-economic development and geopolitical stability.

To frame the modern challenge, a drought is defined not simply as dryness, but as an extended period of water conditions falling significantly below the established norm for a particular area. This distinction is crucial; droughts are not unique to arid regions, as even humid areas such as those in Latin America and Indochina can also suffer from droughts if dry conditions persist. Conversely, the characteristically dry climate of the GCC is not considered a drought when it falls within normal variability. The true threat of drought unfolds through a cascading sequence of interconnected events. It begins with meteorological drought, a prolonged deficit in precipitation. If this persists, it can lead to an agricultural drought, where soil moisture becomes too low to support crops and rangelands, devastating rural livelihoods. This, in turn, can trigger a hydrological drought, characterised by a major reduction in surface water flows and groundwater levels, causing rivers, lakes, and wells to dry up. Finally, these physical water shortages can culminate in a socio-economic drought, where the disruption to water supply impacts health, social well-being, and economic activities, from energy production to industrial output. The “Day Zero” crisis in Cape Town, South Africa,[2] serves as a stark modern example of this progression, where years of poor rainfall from 2015 to 2020 led to the near-total depletion of city reservoirs, threatening to turn off the taps for millions and causing severe economic disruption.

The Modern Toolkit for Drought Forecasting

Water scarcity modelling and drought forecasting are best understood within the broader framework of integrated water resources management. The process relies on a suite of advanced tools that transform raw data into actionable intelligence. The core challenge, especially in drought forecasting, is that its onset is often a slow, creeping phenomenon; it can take a long period of worsening conditions before a drought is officially recognised, by which time significant damage may have already occurred. Developing reliable early warning systems is therefore paramount, and a combination of advanced technologies is enhancing our ability to do just that.

Hydrological Models

These are sophisticated computer programmes that create a virtual representation of a watershed to simulate the movement of water. They vary in complexity, from simpler “black-box” algorithms that rely on statistical relationships between meteorological variables and runoff, without being explicitly grounded on physical processes, to highly complex, physically based models that simulate the intricate processes of soil infiltration, surface runoff, and

groundwater recharge. Models like the Soil and Water Assessment Tool (SWAT) are particularly powerful, as they can also assess the impact of land use and agricultural practices on water quality and pollutant transport. An extensive review of over 3,000 studies confirmed the immense value of using SWAT for managing water resources in arid and semi-arid irrigated watersheds common in the MENA region.[3] Other tools, such as the Water Evaluation and Planning (WEAP) system,[4] can operate in a forecasting mode, using meteorological forecasts to simulate how different water allocation policies would perform under future drought scenarios. Furthermore, System Dynamics modelling has been used to create interactive platforms that allow policymakers to simulate the consequences of their decisions as a virtual drought unfolds, as demonstrated by a hydro-economic model developed to manage groundwater sustainability in Abu Dhabi.[5]

Climate Models

Complementing these are global and regional climate models, which provide long-term projections of precipitation and temperature patterns that are essential for assessing future drought risk. A study using regional climate models from the RICCAR/CORDEX-MENA initiative and the Standardized Precipitation Index (SPI-3) projected significant shifts in seasonal drought patterns across the region under different greenhouse gas emissions scenarios (RCP4.5 and RCP8.5).[6] The findings suggest that by the mid-twenty-first century, droughts are likely to intensify in the Moroccan Highlands and along the Mediterranean coast and the Mashreq region. To improve long-range forecasts, scientists also leverage teleconnection indices, which are patterns of large-scale sea surface temperature and atmospheric pressure that influence weather globally, such as the El Niño-Southern Oscillation (ENSO), the North Atlantic Oscillation (NAO), the Pacific Decadal Oscillation (PDO), and the Indian Ocean Dipole (IOD). A study in Saudi Arabia, for example, successfully linked the kingdom's wet season to ENSO and PDO, creating a statistical basis for more reliable rainfall prediction.[7]

Remote Sensing and Earth Observation

Perhaps the most transformative technology for drought monitoring has been satellites, which provide a continuous, wide-area view of key environmental variables, offering data for regions where ground-based measurements are sparse or inaccessible. For example, space-observed changes in vegetation health serve as a powerful leading indicator of agricultural drought, as plants in arid regions respond very quickly to a lack of rainfall. The Normalized Difference Vegetation Index (NDVI), derived from satellite imagery, is a globally used metric for monitoring vegetation health and has proven highly effective in identifying the onset and impact of drought on agriculture and pastoralism. The Food and Agriculture Organization (FAO) now provides country-level maps of NDVI to support national drought monitoring efforts.[8] A study in Morocco showed how assimilating satellite-derived data, such as the Leaf Area Index (LAI), into land surface models like NASA's Noah-MP could significantly improve the

model's ability to accurately represent vegetation growth and transpiration, thereby enhancing drought forecasting.[9] Across MENA, however, the effectiveness of these tools is constrained by uneven data infrastructure, ranging from Morocco's relatively established basin-agency networks to severe data scarcity in Yemen and parts of Libya. National security issues and weak data-sharing frameworks also limit access to transboundary aquifer information.

Beyond vegetation, the Gravity Recovery and Climate Experiment (GRACE/GRACE-FO), a joint NASA and German Aerospace Center satellite mission, has revolutionised our ability to monitor groundwater, which is a critical buffer during droughts. By measuring tiny changes in Earth's gravity field, GRACE can track changes in large-scale water storage deep underground. A landmark study using GRACE data revealed a sharp decline in groundwater storage across the Arabian Peninsula's transboundary aquifer between 2002 and 2021, driven primarily by unsustainable agricultural extraction and urban expansion.[10]

Machine Learning and Artificial Intelligence

More recently, machine learning (ML) and artificial intelligence (AI) have emerged as powerful tools in drought prediction. Unlike traditional physical models, which require vast amounts of data and computational power, ML models excel at identifying complex patterns and statistical relationships within historical hydro-meteorological data to produce high-quality forecasts. Techniques like artificial neural networks (ANNs) and advanced Long Short-Term Memory (LSTM) networks are proving particularly effective. A study in Kuwait successfully used an ANN model to forecast droughts with good accuracy up to 24 months in advance.[11] The same study has also developed an ML model that forecasts monthly urban water demand based on temperature as a proxy of extreme conditions. Another study in Iraq demonstrated the power of LSTM models, which were trained on a century-long climate record to produce a highly accurate drought outlook extending to 2060.[12] This success stems from the model's ability to capture the "long-term memory" in climate systems, such as slow-moving groundwater and ocean cycles, that drive drought evolution. For policy uptake, however, ML models must be paired with local technical capacity and basic interpretability measures to ensure that forecasts can be understood and trusted by water managers, especially in countries where institutional capacity is limited.

Outlook for Drought Forecasting and Water Management in MENA

Because MENA relies significantly on irrigated agriculture and food imports, improved drought forecasting has direct implications for food-system stability by enabling better crop planning, effective management of groundwater resources during dry spells, and early interventions to protect rangelands and pastoral livelihoods. Even modest gains in early warning can therefore help reduce exposure to agricultural shocks and food price volatility.

Looking ahead, the integration of these technologies into coherent policy and governance frameworks will be the defining challenge for water management in the MENA region. Four key priorities should guide this effort. First, there is an urgent need to strengthen data infrastructure, investing in both on-the-ground meteorological stations and regional data-sharing platforms to improve the accuracy of early warning systems. Second, the region must advance integrated modelling, developing frameworks that link hydrology, climate, agriculture, and economics to provide policymakers with a holistic view of how drought can cascade through their societies and economies. Third, governments must embrace adaptive management, using drought forecasts to dynamically update reservoir operations and groundwater extraction, pre-emptively adjust water allocations, and trigger mitigation plans before a crisis fully develops. Fourth, climate adaptation must be mainstreamed into all long-term planning, ensuring that new infrastructure projects and agricultural policies are designed to be resilient to the more frequent and intense droughts projected for the future.

Ultimately, the science and technology for forecasting drought are advancing at a remarkable pace. The enduring challenge, as it has been for millennia, lies in translating that knowledge into effective governance, proactive policy, and forward-looking investments to secure a water-resilient future for all.

Hamed Assaf is Dean of the School of Engineering and Computing, American University of Ras Al Khaimah, UAE.

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Nuclear Science and Technology for Food and Water Security in MENA

Leigh Mante and Cauvery Ganapathy

The Middle East and North Africa (MENA) region faces problems of water scarcity, limited arable land, and soil degradation which is exacerbated by climate change, threatening water and food security. As the region experiences rapid population growth,[1] states must contend with increasing demand for water, energy, and food (WEF),[2] which are all inextricably linked. To adapt, the region is striving to improve climate-smart agricultural practices,[3] reduce waste, and increase resilience.

This article argues that the use of nuclear science and technologies can offer viable and sustainable pathways for mitigating these challenges. It maps past and prospective applications of these technologies for food and water security in MENA, while evaluating both feasibility and barriers to implementation and scaling.

The following paragraphs outline the potential applications of nuclear science on various development domains in the MENA region.

Strengthening Climate-Smart Agriculture

The MENA region faces the challenge of land degradation from soil erosion as well as worsening soil quality due to sea level rise-driven salinisation,[4] increasing temperatures, and use of recycled wastewater,[5] negatively affecting crop yields. Nuclear techniques help assess and mitigate soil erosion.[6] Leveraging neutron probing sensors can help measure soil moisture levels to determine optimal irrigation application for soil remediation and crop growth.[a,7] This is useful for saline soil conditions in MENA, where conventional moisture sensing equipment is insufficient. To illustrate, isotopic techniques have supported the cultivation of high production volumes of millet in Lebanon, barley and safflower in Jordan, and quinoa in the United Arab Emirates, materialising through a technical Food and Agriculture Organization-International Atomic Energy Agency (FAO-IAEA) cooperation programme.[8]

Enabling Safe Food Storage

Improving food storage capacities across the value chain is crucial for mitigating food loss and waste in the MENA region. Food irradiation techniques[9] are gentle and non-invasive practices that eliminate microbes by exposing food to radiations like gamma or X-rays, while preserving nutritional value and quality.[10] Contrary to misconceptions, irradiation techniques do not turn food radioactive. Food irradiation yields health and food safety advantages, eliminating microbial contamination and lowering food-borne disease risk, and is considered more effective compared to heat and chemical methods.[11] Moreover, it supplements other shelf-life extension methods.

Food irradiation adoption in MENA is currently in early-stages,[12] with Egypt leading in applications for meat preservation and phytosanitary compliance. Demand for shelf-stable food and vegetable imports in the UAE and Saudi Arabia has contributed to investment in new irradiation infrastructure facilities since 2022. Irradiation solutions are more widespread in North America and Europe, which have developed legal frameworks to reiterate its safety. A 2025 study by Maataoui et al. comparing global acceptance of irradiated food found that MENA countries are more cautious about the viability of irradiated food, demonstrating the need for public information campaigns to increase public acceptance and implementation feasibility in MENA.[13] Increasing food shelf-life can also be valuable for food security considerations in remote MENA locations as well as in conflict zones that need humanitarian supplies.[14]

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a Neutron probes are inserted into the ground, emitting low-levels of radiation which interact with hydrogen atoms in water and measure the reflection of neutrons.

Enhancing Water Access and Efficiency

While the value proposition of nuclear technologies to food production is explained by its unique scientific ability to increase crop yields and food shelf-life, it is necessary to highlight the underlying logic of using nuclear energy *per se* for water desalination, for instance, in a region known for its oil and gas wealth.

Conventional desalination relies on non-renewables like oil and gas which produce significant emissions, despite being reliable. Although many countries in the region have substantial hydrocarbon resources, not all of MENA can count on such fossil fuel abundance. Many countries in the region have suffered fiscal strains due in no small part to rather large energy import bills. For instance, the freeing up of oil and gas resources in places like Egypt, where it is being used for water desalination, would make fiscal sense given high import bills for these hydrocarbons.

On the other hand, the energy-exporting MENA countries must contend with the opportunity cost of the consumption of every barrel of oil domestically—meaning one forex-earning barrel of oil less on the international market. This has cost-implications for many of these countries working towards economic diversification and investment of their hydrocarbon earnings into new sectors such as AI or manufacturing.

Further, there are gradual changes in the revenue buffers from MENA's fossil fuels exports. This downward pressure on revenue streams could reasonably be mitigated to some degree by integrating nuclear energy into the energy portfolio wherever feasible, after duly considering both costs and risks associated with the type. Studies which focused on Tunisia and Algeria compared the use of oil and gas with nuclear for electric power generation and water production, and have effectively demonstrated substantial savings from the latter.[15]

Nuclear energy, with its higher energy density, offers the best baseload alternative to hydrocarbons.[16] Nuclear-powered desalination leverages reactor-generated heat and electricity to split salt from seawater, providing a three-fold advantage of reduced emissions, a stable water source, and low-costs. The integration of nuclear technology into the MENA's water security portfolios has been led by the International Atomic Energy Agency's (IAEA) sharing of toolkits like the Desalination Economic Evaluation Program (DEEP) and the Desalination Thermodynamic Optimisation Program (De-TOP).[17] Egypt, Jordan, the UAE, Saudi Arabia, Kuwait, and Tunisia have all invested under these guidelines in desalination and isotope-tracing.[b,18]

SMR-Powered desalination is under consideration in Saudi Arabia, Egypt, and Kuwait,[19] while the IAEA has evaluated studies on using SMRs to convert Red Sea water into drinking

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b Isotopic techniques measure soil, water, and nutrient interactions to assess the impacts of climate change and weather patterns on soil health and inform soil and water conservation strategies.

water in Jordan. In countries like the UAE which has established a nuclear plant and where desalination is predominantly fuelled by natural gas, coupling desalination plants with future nuclear SMRs is projected to yield feasible[20] and cost-competitive outcomes.[21] Future nuclear and desalination plants can be combined to produce water as the only outcome or yield both electricity and pure water through a co-generation system.[22] This combination, including techniques such as Reverse-Osmosis, Multi-Stage Flash distillation and Multiple Effect Distillation, will have comparably favourable savings in both cost and emissions.[c,23,24,25]

Table 1. Feasibility, Added-Value, and Challenges of Nuclear Science and Technology Applications in MENA

Use-Case	Feasibility	Added Value	Risks and Challenges
Enhancing Water Access and Efficiency	Medium: UAE, Saudi Arabia, Egypt, Kuwait, Jordan	Medium: Nuclear would provide a clean and stable energy source for desalination systems.	Desalination requires substantial amounts of water and can also endanger marine ecosystems without careful planning.[26] Challenges include capital-intensive infrastructure, security, and geopolitical concerns over nuclear plant construction.
Strengthening Climate-Smart Agriculture Practices	Medium: Lebanon, Jordan, United Arab Emirates	Medium: Isotopic techniques would help monitor soil health, mitigate soil erosion, and inform optimal irrigation practices.	Reducing risk of radiation exposure and environmental contamination can be expensive and requires further R&D to improve the methodology of isotope application, safety standards, and exploration of safer alternatives like stable-isotope methods.[27]
Enabling Safe Food Storage	Medium to High: Egypt, UAE, Saudi Arabia	High: Food irradiation is well-researched in other contexts and would help overcome food loss and waste across the food value chain and improve food storage capacities during geopolitical or climate shocks.	Developing infrastructure can be capital-intensive and must overcome public scepticism.[28]

Source: Authors' own, using Neupane et al.[29] and Ihsanullah et al.[30]

c Reverse osmosis converts seawater into freshwater by separating mineral ions, bacteria, and viruses from seawater through a semipermeable membrane. Multi-stage flash desalination turns seawater into freshwater through multiple stages of boiling and turning it into steam. Multiple effect desalination uses heat and electricity to produce water through multiple chambers where steam is used to evaporate and condense seawater.

Challenges to Nuclear Uptake

Environmental

Without integrated planning,[31] the deployment of nuclear energy may inadvertently threaten domestic food and water supply by consuming vast amounts of freshwater resources to cool systems, and thereby competing with other water-intensive sectors. To illustrate,[32] once-through cooling systems withdraw very high volumes of water, recirculating cooling systems cause high water loss from evaporation, and dry cooling systems raise air temperatures. While coastal nuclear plants can leverage desalinated water for cooling, desalination brine discharge can imperil marine ecosystems. Transitioning to water-efficient designs is still in nascent stages.

Moreover, routine emissions can pose adverse ecological risks for soil,[33] groundwater, and marine ecosystems. Nuclear plants situated near shallow aquifers risk potable water contamination, damages the coastal saline agriculture and endangers marine ecosystems. In arid soil, radioactive isotopes can permeate quickly, leading to increased plant uptake.[34] In the long-term, released radionuclides can disrupt ecological food chains, erode genetic diversity, and transport to human food. Although the risk of radioactive waste is substantially mitigated, radionuclides can be released under rare and extreme conditions. Advancements in geospatial technologies and molecular biology techniques can help mitigate these impacts but increasing research on safer alternatives like stable isotopes are also crucial.[d,35]

Regional

The presence of nuclear installations, regardless of their form or scale, increases the security-risk profile of any region, and these must be factored into any considerations regarding the adoption or deployment of the form. Although nuclear-based science inputs for agriculture have marginal exposure to risks of kinetic attacks and damage, the susceptibility of nuclear energy powered desalination plants to similar threats can be considerable. It would be worthwhile to consider the security umbrellas and supervision bandwidths of each country when assessing technology deployment. Furthermore, the level of skills and expertise needed for adoption and implementation of these technologies are substantial, and the region must strengthen its local talent pool.

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d Stable isotopes are non-radioactive and can be used to trace water, carbon, and nitrogen interactions.

Financing

Although governments have signalled interest in leveraging nuclear energy, there remains a lack of infrastructure, funding, and regional coordination to fully capitalise on its potential. Adopting nuclear energy comes with prohibitively high-capex requirements, and governments may be drawn to more cost-effective options.[36] Nuclear energy and its value as a strategic commodity further entrench the centrality of governmental role in adopting this energy form in MENA. The fuel supply chains intrinsic to the entire value chain of nuclear energy's use further ensures that governments would have a more direct participation in the field rather than private players. As such, financing remains a governmental prerogative in the region that could benefit from enhanced cross-border coordination. Notably, the World Bank's decision[37] to reverse its decades long moratorium on financing nuclear energy projects in early 2025, when coupled with the organisation's commitments towards food security as part of its larger human security agenda, could prove to be a valuable harbinger of change for the MENA region.

Conclusion

Advancing beyond feasibility assessments for nuclear techniques requires coordination between academics, technical experts, and policymakers to assess long-term environmental implications, prepare site-specific precautionary and remediation strategies. Notably, initiatives like Atoms4Food[38] and the FAO/IAEA's Centre for Nuclear Techniques for Food and Agriculture[39] coordinate applied research and capacity building and help secure private financing sources.[40]

Thus, establishing regulatory frameworks that cut across the heterogeneity of MENA's constituent national abilities would help create a safe and conducive environment for nuclear deployment for desalination. This can be achieved by creating a regional regulatory and supervisory body to mandate and track adherence to non-proliferation standards.[41] The UAE has, for instance, set a benchmark through a provision to allow inspections of its nuclear facilities at short notice. The body can also mandate integration of mitigation techniques for all future desalination infrastructure and develop a robust data-sharing system to measure water levels and desalination discharge. Such efforts will enable a policy-environment of sharing technical know-how and best-practices, and facilitate trusted adoptions.

Leigh Mante is unior Fellow, Climate and Energy, ORF Middle East, UAE.

Cauvery Ganapathy is Fellow, Climate and Energy, ORF Middle East, UAE.

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The Water-Energy-Food Nexus and the AI Imperative

Diana Francis

Weather is no longer what it used to be. Floods now submerge cities once thought safe from such calamities, heatwaves scorch regions that historically rarely broke a sweat, and droughts stretch far beyond their usual seasons. The familiar patterns that governed our climate have fractured. What we once called “extreme” is fast becoming the baseline.[1] Yet, this is not just a meteorological story; it is a civilisational one. Climate change has moved from an abstract threat to lived experience, and the rise in weather extremes is perhaps its most tangible symptom.

Amidst this turbulence, a new technological frontier is emerging: Artificial Intelligence (AI). Properly harnessed, AI could help us anticipate, adapt to, and even mitigate some of the most severe impacts of a rapidly warming planet. If misused, however, it could only amplify inequities and false confidence.

The task before us is not simply to adopt AI, but to integrate it in intelligent ways, as a tool of foresight, not a substitute for scientific understanding. In arid regions, AI must also manage its own resource footprint, especially its water use and energy demand.

The WEF Nexus

Weather shocks are inseparable from the water–energy–food (WEF) nexus especially in vulnerable regions such as the Middle East and North Africa (MENA)[2] where climate extremes drive water volatility, which then cascades into agriculture and power systems.[3] Agriculture already accounts for the dominant share of consumptive water in the region, while most cereals are imported—this makes local hydrology and external supply chains, together, impactful on food security.[4,5]

In April 2024, the United Arab Emirates (UAE) experienced the heaviest 24-hour rainfall on record, flooding urban corridors, disrupting aviation, and exposing drainage and planning gaps, a stark local expression of global hydrological volatility.[6,7] Recent history also reminds us that rare tropical cyclones from a warming Arabian Sea can strike Oman and spill impacts into the UAE, as with cyclones Gonu in 2007 and Shaheen in 2021.[8]

The Age of Extremes

Across the MENA, weather is rewriting records faster than we can update them.[9] Wildfires ravaged the Mediterranean, droughts dried up major rivers in the Middle East, while in North Africa the balance between deluge and drought has become dangerously erratic. In the Gulf, this now includes record-breaking cloudbursts and rare tropical cyclones from a warming Arabian Sea, alongside long dry spells that stress aquifers and rangelands (e.g., variability in Dhofar's Khareef).[10]

This intensification is not a surprise, nor is it unexplainable; it is physics at work. Warmer air holds more moisture, fuelling heavier rain when storms form; hotter land increases evapotranspiration, deepening drought when rains fail; processes now visible in the MENA and known as "weather whiplash" reflecting the abrupt swing between extremes. The result is volatility across scales: heat domes that linger for weeks, tropical storms that intensify overnight, shifting jet streams and ocean currents that redistribute weather patterns in unpredictable ways.

Infrastructure designed for a gentler climate is struggling, from urban drainage overwhelmed in Dubai to aquifer-dependent farms facing salinisation and declining water tables. Crops fail, grids buckle, and urban heat islands turn deadly.

Where Forecasting Struggles

Traditional weather and climate models, based on physical equations of the Earth System, have advanced immensely since the mid-20th century. They underpin everything from cyclone alerts to climate projections. But even the best models falter under the weight of today's volatility.

Extreme events occupy the statistical tail of probability distributions, meaning there are few examples in the historical record. Models trained or calibrated on past data are, therefore, ill-equipped to simulate "unprecedented" events. Resolution also matters: many models cannot resolve the small-scale processes, convective storms, coastal interactions, urban heat zones, that trigger local extremes.

The result is uncertainty especially in predicting the *timing* and *intensity* of extremes. Uncertainty is most acute for tail risks and locally forced hazards (convective bursts, wadis, urban heat). In the Gulf, a one-hour improvement in nowcast skill can materially reduce flash flood losses. We need tools that learn faster, resolve finer, and are affordable for national meteorological services. Enter AI.

AI Enters the Forecast Room

Artificial intelligence, when coupled with climate science, offers precisely that promise: Speed, adaptability, and scale. AI systems can ingest massive datasets, satellite imagery, radar scans, reanalysis archives, and detect hidden correlations that human-designed algorithms might miss.

Recent breakthroughs such as FourCastNet and GraphCast have shown that learned global models can rival or exceed traditional systems for many variables while enabling large ensembles.[11] Where physical models take hours on supercomputers, AI can now generate forecasts in minutes. At short lead times, deep generative radar models improve 0–90-minute precipitation nowcasts, the window that matters for MENA flash floods.[12]

The real transformation, however, lies in hybrid modelling, systems that merge the strengths of physics-based and data-driven approaches. These "physics-informed" neural networks respect the laws of energy and mass conservation while leveraging AI's ability to learn complex, nonlinear relationships. In essence, they let science set the boundaries while letting AI explore the patterns within them.

Such models are already improving forecasts of heavy rainfall, cyclone intensification, and drought onset. They are also enabling faster ensemble generation, where thousands of simulated scenarios can be produced to quantify risk. In the age of extremes, that probabilistic foresight is invaluable for the MENA region.

Beyond Forecasting: Detection, Attribution, and Action

AI is also expanding the horizons of what forecasting means. It now plays a growing role in detecting, attributing, and translating weather extremes.

Detection involves scanning continuous data streams to flag early anomalies; subtle shifts in sea-surface temperature, unusual humidity buildups, or atmospheric "blocking" that might signal a heatwave. AI excels at spotting such weak signals amid noise.

Attribution, once a slow, post-disaster process, is being accelerated by machine learning. Scientists can now estimate, in near real-time, how much human-driven warming has increased the likelihood or severity of a specific event. This not only informs policy but also strengthens accountability in climate diplomacy.

And then there is translation, turning complex forecasts into operational decisions in the WEF nexus: Which neighbourhoods will flood, which crops are at risk, which basins to recharge, which reservoirs to pre-release, and which irrigation districts to throttle. Gulf examples include Oman's National Multi Hazard Early Warning Centre, both platforms that AI can enhance with smarter triggers and uncertainty information.[13,14,15]

Glimpses of Progress

Across MENA, tangible use-cases are emerging. For instance, irrigation optimisation that combines satellite data and machine learning is supporting date-palm and horticultural production in arid settings, including pilots in Egypt.[16] Groundwater risk mapping now fuses GRACE trends (Gravity Recovery and Climate Experiment), pumping records, and climate reanalysis to highlight hot spots in systems such as the Saqram and the Tigris–Euphrates.[17] Moreover, AI-augmented inflow prediction is being tested to inform multi-objective reservoir operations on the Nile. Beyond speed and precision, cloud platforms are lowering barriers-to-entry by making advanced forecasting tools available without supercomputing infrastructure.

The Cautions We Must Heed

Machine learning models are only as good as the data that train them, and historical climate data are uneven. Regions like the MENA remain under-observed. If AI learns from incomplete or inaccurate data, it may fail to predict extremes precisely where vulnerability is highest.

Indeed, the risks of overreliance on AI are real. Physics-free systems may be fast but wrong. Without open hydrometeorological and agriculture data, AI could only widen regional divides. Then comes the problem of interpretability. Decision-makers cannot base public warnings or policy actions on "black box" outputs. They need explainable AI, systems that reveal *why* a forecast says what it does, and how certain that prediction is.

There is also the question of access. High-performance AI systems demand enormous computational resources and proprietary data. Without deliberate investment in open data and shared architectures, AI could widen the digital divide in climate resilience, making rich nations smarter and poor ones more exposed.

Finally, AI's own carbon footprint is rising. Data centres in the MENA must rely on renewables for both cooling and operations.[18]

Charting a Smarter Future

To harness AI effectively across the MENA water–energy–food nexus, stakeholders should co-design meteorology–water–agriculture services that translate forecast probabilities into operational decisions. In this first step, collaboration is key. Meteorologists, data scientists, and AI engineers must co-design models that combine physics, data, and operational realism. Cross-sector partnerships between research institutions, governments, and the private sector are essential to translate innovation into action.

Second, open science must become the norm. Shared datasets, transparent benchmarks, and open-source models can democratise access and foster trust.

Third, capacity-building is critical. Many developing nations in the MENA need support to adopt and adapt AI tools, from computational infrastructure to technical training. The next generation of meteorologists must be as fluent in machine learning as in thermodynamics.
Finally, AI should serve not just as an early warning system but as an adaptive planner. From optimising reservoir operations to designing heat-resilient cities, AI can help societies prepare before the next shock hits. It must be embedded not at the periphery of policy but at its core.

Conclusion: From Prediction to Preparedness

AI will not stop the storms or the heatwaves, but in arid regions it can protect people, farms, and grids and conserve water used by the digital systems themselves. The measure of success is anticipatory action and prudent resource use across the WEF nexus. Therefore, AI can help us see the extremes coming sooner, understand them better, and respond more wisely. It offers not the illusion of control, but the possibility of foresight.

As the atmosphere grows hotter and more chaotic, our best defence is intelligence, not just artificial, but collective. A smarter planet begins with smarter choices: to integrate AI with science, to share knowledge openly, and to ensure that those most at risk are the first to benefit. The climate of the future is already here. The question is whether our tools and our will can keep pace with it.

Diana Francis is Professor of Atmospheric and Climate Science, Khalifa University, UAE.

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The Food-Water-Energy Nexus in the MENA Region: The Case of Egypt

Isabelle Tsakok

The Looming Water Crisis in the MENA Region

The MENA region has long coped with the problem of water scarcity. However, climate change is transforming the problem into an existential threat as more disastrous weather events are anticipated in the coming years. Precipitation is becoming even more scarce and unpredictable, with higher evapotranspiration undermining agriculture and food and warmer temperatures increasing the spread and virulence of harmful pathogens. Rising sea levels are extending saltwater intrusions along the Mediterranean and other coastal zones. Other factors such as population growth, urbanisation including the influx of climate refugees and those from conflict-ridden zones; and industrialisation, are amplifying the threat of climate change. By 2030, water demand is projected to outstrip supply by 50 percent.[1]

What the impact of the crisis would mean in adaptability terms will vary throughout MENA—a highly diverse region in terms of per capita incomes, political stability, incidence of poverty, and wealth inequality. The factors that impact vulnerability to climate change include:

1. *Per capita income levels:* These range from low-income and conflict-ridden countries such as Yemen (where per capita income is US$ 740); to middle-income like Morocco (US$ 3,740); and high-income like Qatar (US$ 76,720).[2]
2. *Incidence of poverty:* Poverty has increased in MENA from 12.3 percent (2010) to 18.1 percent (2023).[3]
3. *Extensive informal sector:* Most of the poor are employed in the informal sector, which makes them highly vulnerable to economic shocks.
4. *Youth bulge amidst high unemployment:* Compounding the challenge is the youth bulge and high youth unemployment,[a] estimated at around 24 percent (2025).
5. *Income and wealth inequality:* Vulnerability is disproportionate: 50 percent of the population of MENA earn only 9 percent of national income while the middle 40 percent earn 34 percent. The top 10 percent almost 57 percent, of which the top one percent, earn 22 percent (2023). Wealth inequality is even more pronounced as the data on respective shares of wealth show: the majority has only one percent; the middle group, 22 percent; and the top 10 percent has 77 percent. The top one percent within the latter group owns 45 percent of the wealth.[4]
6. *Climate-sensitive agriculture still important:* The importance of agriculture (other than in the oil-rich Gulf states) which is mainly rainfed in MENA also increases vulnerability. Farmers in regions such as the "fertile Crescent" of the Tigris and Euphrates region, along the Mediterranean coastline and the Nile (which account for around 85 percent of freshwater withdrawals in their respective countries), will experience rising temperatures while increased water scarcity are likely to change crop and livestock calendars, undermining potential growth.
7. *Sea level rise as a universal threat:* The heightened danger of widespread saltwater intrusions means that not only agriculture and rural areas are at risk, but urban areas too.

The FWE Nexus: Central to a Resilient and Food-Secure Development

The potential destructive impact of climate change is a central concern, although the incidence, severity and persistence of the suffering inflicted will vary. At the same time, the good news is that the crisis can be turned into an opportunity for opening sustainable pathways to resilient, inclusive, and food-secure development. However, it requires decisive

a Youth is variously defined as 15-24 years old; or 15-29; or 15-34.

pro-inclusive and resilient growth actions on a wider front. A critical step in this process is to recognise the close inter-dependencies between water and energy required to produce food and achieve food security in a climate change world.

Amidst worsening climate change, these interdependencies mean that the past approach of resorting primarily to building dams and irrigation canals to increase conventional water supply is no longer sufficient. Increasing non-conventional water supply, among others, is also needed. To combat climate change, the technologies needed to increase the supply of non-conventional water, e.g., desalination, treating and recycling wastewater are energy intensive; as well as technologies that reduce carbon emissions. This means that to increase the supply of non-conventional water, countries must develop renewable energy sources including wind and solar which will replace fossil fuels. Thus, increasing water supply requires energy but producing energy requires water. Countries, even entire regions, will need to shed their silo approach and integrate the FEW nexus in their planning and investments.

Focus on Food Self-Sufficiency

A silo approach is particularly costly in the case of food security policy as the experiences of many countries have repeatedly shown.[5] Many countries in MENA and elsewhere have defined 'food security' to mean not having to import basic staples, or being food self-sufficient (FSS). While food security involves access to basic staples, it entails more: "Food security exists when all peoples at all times have the physical and economic access to sufficient safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life."[6]

Such a holistic concept of food security requires that the four pillars of availability, access, utilisation, and stability are all realised. Import dependence on basic staples can certainly make a country vulnerable in a hostile geo-political, trade, or high-debt environment. But not importing staples does not mean all peoples have sufficient nutritious food to satisfy their hunger and their daily energy needs.

The Challenge of Turning Crisis into Opportunity: The Case of Egypt

Given the centrality of the FWE nexus, MENA's FSS approach to achieve holistic food security in a world being altered by climate change is misguided. Egypt, which has been pursuing food self-sufficiency for decades, is a case in point.[7] Today it remains one of the countries in MENA most dependent on imported wheat and cooking oil.

The chronic underperformance of Egypt's agriculture has been a primary contributor to the fragility of its food security situation. This was made clear with the onslaught of the COVID-19 pandemic, soon followed by global supply chain dislocations and the Russia-Ukraine war

inflating basic food prices in MENA.[8] About half of the water in irrigated agriculture, the biggest user of fresh water from the Nile (around 80-85 percent) is wasted.[9] The majority of farmers use the traditional flood irrigation system on their 2-feddan plots which does not enable them to control the amount of water used.[b]

Moreover, farmers have no incentive to use water efficiently, as they do not pay for the volume of water they use. The farmers also use the scarce water on water-intensive but low-value cereal crops and sugar, for which prices are guaranteed by the state, as they are considered important for FSS. The yields of these low-value crops are projected to fall further by 10 percent (2050) compared to a no-climate-change scenario, due to heat stress (4.9 percent), water stress (4.1 percent), and salinity (1.6 percent).[10]

The Nile, the life blood of Egypt, is threatened not only by climate change but by the completion of the Grand Ethiopian Renaissance Dam (GERD, inaugurated on 9 September 2025) and the fact that there is no satisfactory treaty yet on water-sharing agreements. The problem of the Nile highlights the threat of water wars of other major transboundary rivers of the Tigris and the Euphrates; the Jordan; and the Orontes; and of over 40 transboundary aquifers in the Middle East (20) and North Africa (21).

For Egypt, the lack of water-sharing agreement with Ethiopia threatens its water security as its annual per capita water availability is estimated to be already below 500m^3 in 2025, below the critical water stress level, having declined from 2526 m^3 (1947) to 570 m^3 (2018).[c] Meanwhile, as its scarce water is being threatened, so is its fertile Nile delta from saltwater intrusions which is requiring the building of sand dykes to hold back the sea during stormy weather.[11] Egypt is also losing valuable arable land especially around big cities, at roughly 2 percent per decade as desertification intensifies, and with continued population growth and urbanisation.[12]

The Role of Regional Trade

The stakes can hardly be higher. As for most countries in MENA and elsewhere, Egypt is at an inflection point. How it manages its water scarcity to achieve food security will largely determine whether Egypt successfully transitions onto a path of resilient, inclusive, and food-secure growth.

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b The minority, large commercial farmers specialise in high-value and lucrative horticulture for exports. There is no price control or price guarantees for these high-value crops.

c The UN international standard for annual per capita water availability is 1,000 m^3.

Egypt can turn this crisis into an opportunity by exploiting the 1.4 billion people market with a combined GDP of roughly US$3.4 trillion—a game changer offered by the African Continental Free Trade Agreement (AfCFTA), whose operational phase was launched in July 2019. Egypt can use regional trade to power its growth path. Ghanem[13] proposes a pan-African food security approach instead of pursuing country-by-country FSS which has not worked and has been costly even when water was less scarce. For other non-African MENA countries, this approach of building alliances and supportive institutions to exploit the growth potential of trade is advocated.

The Way Forward

Throughout history, violent conflict has undermined prospects of promoting a sustained, food-secure development. Collaboration, not conflict, is the way forward: the interlinked FEW problems under drier and warmer climate change conditions make solving them by any single country on its own e.g., by resorting to high tariffs and trade protectionism, costly and unsustainable.

Within each country, holistic water management impacting both demand and supply is essential to achieve water security amidst climate change. This, in turn, requires institutional changes to promote water use efficiency in agriculture and urban areas, hardware investments in latest technologies to better monitor water use and availability, and to produce the emission-reducing sources of energy such as wind and solar. To pay for these transformative investments, implementing a robust productivity and growth strategy complemented by the removal of misguided subsidies in a politically sensitive fashion, has the potential of financing the investments needed.

If the history of successful transformations—agricultural and economic—in very different historical and country contexts is of any guide, visionary political leadership committed to the public good has been essential to successfully transform crisis into opportunity.[14] Prospects for MENA to transition into inclusive, resilient, and food-secure development paths are good to the extent that visionary leadership urgently takes the first steps to integrate the centrality of the FEW nexus in their strategic approach to achieving food security and implement complementary measures to address other structural problems: e.g., chronic poverty; high inequalities in income, wealth, and opportunity; and high youth unemployment. Leadership must anchor their decisive policies in the functioning of competent administrations committed to food security for all.

Isabelle Tsakok is Economist and Senior Fellow, Policy Center for the New South, Morocco.

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Reframing the Just Transition in the Arab Region: Food, Water, and the Foundations of Stability with Lessons from Lebanon

Roula Majdalani

'Just transition' has become a global catchphrase in recent times, often framed as an orderly shift, which involves phasing down fossil fuels, scaling up renewables, and cushioning affected workers through social protection. In other words, it is about "just energy transition" to reduce emissions and mitigate the negative impacts of climate change through a cascading process. However, this narrative of a just transition is conceived for economies where public services function effectively, energy access is reliable, and climate policy is pursued primarily through electricity prices and labour-market adjustments. In the Arab region, the framing of what constitutes "a just energy/climate transition" misses the reality. While access

to reliant infrastructure and public services varies across countries due to different levels of socio-economic development, the brunt of climate impacts is unequivocally felt throughout the region.

A just transition must therefore contend not only with decarbonisation, but with dry taps, food-price shocks and, in several countries, systemic service breakdown under fiscal stress and institutional fragility. In a region that contributes relatively little to global emissions yet bears a disproportionate share of climate impacts,[a] climate policy will either stabilise societies or deepen inequality, inflation, and unrest. This article reframes the just transition as a macro-stability strategy anchored in food–water systems rather than a narrow energy-sector adjustment.

In such contexts, justice cannot be reduced to compensating displaced fossil fuel workers or offsetting higher electricity tariffs. For large segments of the population, particularly in least developed and conflict-affected Arab countries, the deeper injustice lies in the erosion of basic services themselves, reliable electricity, safe water, affordable food, and well-functioning public institutions. A just transition is therefore inseparable from social stabilisation, infrastructural service restoration, and economic survival. It is not about managing sectoral shifts within a working economy, but about rebuilding the foundations on which any credible low-carbon pathway must rest.

The Arab Region at the Epicentre of Climate–Water–Food Nexus

The Arab region sits at the epicentre of a converging climate–water–food crisis. Regional climate modelling under the ESCWA-led RICCAR platform projects warming of 1.2–2.6°C by mid-century, rising beyond 4°C by the end of the century, a warming way above the global average projected to increase between 2.7 to 4.4 degrees in the moderate to worst case scenario (Assessment Report 6 of the IPCC 2021 – 2023). Rainfall and mean runoff are expected to decline sharply to approximately 40 percent relative to the 1980–2010 period in Mediterranean coastal zones, where agriculture has traditionally flourished in the Maghreb and Mashreq.[1]

Water scarcity is no longer cyclical but structural. Renewable water availability averages about 609 m³ per capita annually, roughly one-tenth of the global average, and is projected to fall by more than 50 percent by 2050. Agriculture accounts for 85–90 percent of freshwater withdrawals across the region, meaning that hydrological shocks translate directly into food inflation, fiscal stress, and rising import dependence.

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a These include receding levels of renewable water resources, desertification, loss of biodiversity, soil deterioration, and food insecurity.

FAO and the International Center for Agricultural Research in the Dry Areas (ICARDA) projections point to rain-fed cereal yield losses of 15–30 percent by mid-century in large parts of the Maghreb and Mashreq. Declining soil moisture, rising irrigation demand and accelerated groundwater depletion are tightening the water–food constraint precisely as fiscal space for adaptation is shrinking. Water governance has therefore become a central determinant of food security, macro-economic stability, and social stability across the Arab region.

Just Transition Through a Sustainable WEF Transition

Globally, agrifood systems account for 22–33 percent of greenhouse gas emissions[2]. As mitigation gains relative momentum in the energy and transport sectors, policy attention is shifting rapidly toward agriculture. This is a welcome climate action, as Agriculture, Forestry and Other Land Use (AFOLU) generates roughly one-fifth of global emissions and offers major mitigation potential.[3] Yet FAO and ICARDA research show that many low-emission farming practices would also reduce yields or raise production costs, especially for small farmers.[4]

In Arab countries, where 50 to 90 percent of food consumption is imported, this creates a real risk: climate mitigation pathways that lower output or increase costs can deepen food inflation, push farmers out of production, and further strain already fragile societies. Practices such as limiting fertiliser use, restricting irrigation pumping, reducing livestock densities, or shifting to less input-intensive crop systems can, in water-stressed and low-income contexts, reduce effective farm-level returns, particularly among smallholders already operating near subsistence margins. This is why a just transition in the region cannot be framed through energy alone. It must be embedded in a water–energy–food–social protection (WEF-SP) nexus, where irrigation efficiency, groundwater governance, energy pricing, cold-chain infrastructure, and targeted social transfers are treated as components of a macro-stability strategy rather than sectoral policies in silos.

The Case of Lebanon

Lebanon offers a revealing stress-test case for reframing the just transition in the Arab region. More than 80 percent of its food is imported.[5] Agriculture absorbs around 60 percent of national water withdrawals, much of it from weakly regulated and increasingly depleted groundwater. Between 2020 and 2022, 36.5 percent of the population experienced moderate to severe food insecurity, a figure that has since worsened, fuelled by currency collapse, subsidy removal, rising import bills, and recurrent climatic shocks. This combination of fiscal fragility, resource stress, and exposure to global food and energy markets makes Lebanon an early-warning laboratory for the distributional, macro-economic, and food-system risks that climate transitions are beginning to generate across the wider Arab region.

Against this backdrop, Lebanon has articulated a commendable integrated response through its Food System Transformation (FST) Pathway, developed with FAO, World Food Programme (WFP), UN Economic and Social Commission for Western Asia (ESCWA), American University of Beirut (AUB), and national stakeholders.[6] The Pathway explicitly reframes food systems as national stabilisation infrastructure rather than a narrow agricultural agenda. It integrates water governance reform, irrigation modernisation, sustainable access to on-farm renewable energy, ecosystem restoration, nutrition-sensitive social protection, and legal reform under a proposed Right-to-Food framework law, anchoring access to food, water and clean energy as enforceable public obligations.

Importantly, parts of the pathway have moved beyond concept into early implementation. These include irrigation-efficiency pilots, water accounting and governance reforms, nutrition-linked social protection measures, and targeted agricultural support programmes aligned with climate-resilient practices. Yet, at the same time, core elements, such as large-scale aquifer governance reform, irrigation modernisation, and sustainable financing mechanisms, remain largely aspirational.

Years of neglected infrastructure, fragmented institutions, and weak regulatory enforcement, compounded by political paralysis and the absence of a unified national development vision, continue to constrain scale-up. These constraints are further reinforced by the political economy of recovery: IMF[7] programmes and donors require far-reaching structural reforms before financing reconstruction, delaying large-scale investment in food, water, and climate-resilient infrastructure.

Lessons Learnt from Lebanon's Pathway

Lebanon's pathway demonstrates that in fragile, food-import-dependent states, food systems must be treated as macroeconomic stabilisation infrastructure rather than social policy add-ons. It shows the necessity of embedding climate action within water, food, energy and social protection systems; anchoring reform in legal and institutional frameworks rather than short-term projects; and explicitly addressing the political economy of reform, financing, and conditionality.

The proposed Right-to-Food framework law is particularly significant. Beyond its normative value, it would reshape budget priorities, influence subsidy reform sequencing under IMF programmes, and redefine how international finance is allocated between mitigation, adaptation, and social protection, elevating food and water security from discretionary welfare spending to enforceable public obligations.

Lebanon illustrates that technical coherence alone does not deliver transformation. Even a well-designed pathway remains aspirational when public institutions lack coordination

capacity, infrastructure is degraded, and large-scale financing is conditioned on politically contested reforms. This binding constraint is not unique to Lebanon; it reflects a structural regional reality affecting many Arab economies navigating reconstruction, debt consolidation and climate volatility simultaneously.

Many Arab states, including Jordan, Tunisia, Iraq, Yemen, and parts of the Maghreb, share Lebanon's structural profile: high food-import dependence, declining water availability, fiscal compression, fragmented governance and growing climate volatility. Lebanon's FST Pathway therefore offers a replicable prototype, not as a finished model, but as a governance and policy framework for aligning climate action with macro-economic stability and social resilience.

While Lebanon reflects the vulnerabilities of fragile and middle-income Arab economies, its experience also carries important lessons for the Gulf Cooperation Council (GCC) states. Despite stronger fiscal positions and more advanced infrastructure, GCC countries face parallel structural exposures: extreme water scarcity, near-total dependence on food imports, and rising climate volatility. Lebanon's pathway highlights that food and water security cannot be treated as peripheral sustainability agendas. Even in high-income settings, failure to integrate groundwater governance, irrigation efficiency, domestic production resilience, cold-chain infrastructure, and nutrition-sensitive social protection into national climate strategies risks deepening import dependence and increasing fiscal exposure to global food price shocks. For GCC states, the lesson is clear: long-term climate resilience will depend not only on decarbonising energy systems, but on treating food and water security as core components of national stability, sovereign risk management, and economic diversification strategies.

Therefore, policymakers in Lebanon as well as in the Arab region should consider the following dimensions to ensure that a just transition is on the right track:

1. **Treat food systems as national stabilisation infrastructure**, central to fiscal planning, food-price management and social cohesion, rather than as peripheral agricultural or welfare sectors.
2. **Build transformation through governance processes, not only projects**, by embedding food–water–climate coordination within durable national institutions and cross-sector planning frameworks.
3. **Use rights-based and legal frameworks to ensure** that food and water security remain binding public obligations rather than discretionary social expenditures.
4. **Address implementation bottlenecks at the outset of any planning process**, particularly the interaction between institutional capacity, financing constraints and policy conditionality, and design transition pathways that are sequenced realistically within these constraints.

Finally, a just transition in the Arab region should start with food and water security, not end with it. Climate action cannot be reduced to emissions pathways; it must be anchored in macro-economic management, social protection systems, and governance reform. Indeed, food systems shape inflation, fiscal exposure, household vulnerability, and political stability. Climate justice will therefore be judged not only in terms of carbon outcomes, but in whether countries can protect access to food, water, energy, and livelihoods as climate shocks intensify. This is the practical test of the just transition for the region.

Roula Majdalani is Senior Climate Change Advisor, ICARDA, Lebanon; and Distinguished Associate Fellow, Carboun Institute, Netherlands.

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Integrating the Water-Energy-Food-Environment (WEFE) Nexus Concept into National Strategies and Planning: Jordan's Experience

Majd Al Naber

Ensuring water, energy, and food security has become one of the most pressing issues for countries that are suffering from limited natural resources, resource depletion, extreme climate change, water shocks, and ecosystem degradation. Typically, across the world, water, energy, food and the environmental ecosystems are managed and governed in silos, each with its own institutional structures and priorities. This fragmented approach is increasingly proving insufficient for addressing today's complex challenges. The Water-Energy-Food-Ecosystems (WEFE) Nexus approach provides an integrated framework for sustainable resources management by addressing the interdependencies to enhance resilience and maximise co-benefits while reducing trade-offs.

The Imperative for a WEFE Nexus Approach

Water scarcity affects more than 40 percent of the global population, with approximately 80 percent of those affected residing in the West Asia North Africa (WANA) region.[a,1] The region is characterised by chronic water deficits, where freshwater demand already exceeds renewable supply, and it is projected to worsen due to population growth, urbanisation, economic development, and the continued depletion of both surface and groundwater resources. The agriculture sector remains the dominant water users, consuming more than 80 percent of WANA's freshwater withdrawals.[2]

The agri-food system relies on both water and energy inputs across its value chain, including production, processing, transport, and storage. Concurrently, water supply systems are highly energy-intensive for abstraction, pumping, distribution, desalination, and wastewater treatment. Energy systems, in turn, depend on water for cooling, fuel processing, and power generation. These strong interdependencies across sectors increase system vulnerabilities and underscore the importance of complementarity.

The Jordan Context

Jordan is one of the most water-scarce countries in the world, with annual renewable freshwater availability estimated at less than 65 cubic metres per capita,[3] far below the absolute scarcity threshold of 500 cubic metres. The country imports 74 percent of its energy needs,[4] making it vulnerable to international market fluctuations and geopolitical disruptions. Although the country has made strides in expanding renewable energy, particularly solar and wind, its energy system remains carbon-intensive and dependent on external suppliers. Food security is equally strained, with limited arable land and high production costs, Jordan relies on imports for more than 85 percent of its food.[5]

Global supply chain disruptions, such as those witnessed during the COVID-19 pandemic and the Russia–Ukraine crisis, have underscored the vulnerability of such import-dependent systems. Overlaying these structural challenges is the demographic pressure caused by multiple waves of refugees—Jordan hosts one of the world's largest numbers of refugees per capita, adding the compound effect of climate change.

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a A geographical area comprising countries in the western part of Asia and the northern part of Africa (Jordan, Syria, Lebanon, Palestine, Iraq, Bahrain, Kuwait, Oman, Qatar, UAE, Saudi Arabia, Egypt, Sudan, Algeria, Morocco, Tunisia, Yemen, and Libya).

In Jordan, water and irrigation, energy, agriculture, and environment fall under separate ministries, each with their own management and governance approaches, budgets, and strategic priorities. For instance, the Ministry of Water and Irrigation prioritises supply and demand management through the expansion in utilisation of non-conventional water resources such as treated wastewater and desalination that needs energy as well, and reduction in the non-revenue water which is already over 40 percent,[6] while the Ministry of Agriculture aims to enhance food security, economic growth, and sustainability by promoting climate-smart practices, digital transformation, and improved resources management. Meanwhile, the Ministry of Energy is working on green energy transition, and the Ministry of Environment is giving priority to the green economy through climate action. Moreover, Jordan's current legal frameworks do not explicitly mandate nexus-based planning and coordination.

In such a context, the Jordanian government recognised that nexus becomes a must and started planning for the integration of the WEFE Nexus concept into strategies and national planning. The water-energy nexus was first officially acknowledged in 2017, driven by the financial and operational challenges faced by the Ministry of Water and Irrigation, particularly in relation to rising energy costs associated with groundwater abstraction, conveyance, treatment, and desalination. Subsequently, the nexus approach was expanded to encompass food and environmental dimensions within the framework of Jordan's Economic Modernisation Vision in 2023. This was also pushed by Jordan's low grade of 42.7 in the WEF Nexus Index[b] value in 2023, placing the nation in the 152nd position out of 181 countries assessed by the index.[7] The Modernisation Vision explicitly recognised the need for integrated resource governance and recommended the establishment of a Water-Energy-Food-Ecosystems (WEFE) Council to enhance cross-sectoral coordination and strategic alignment.

In practice, the Ministry of Planning and International Cooperation (MoPIC) took under its umbrella the responsibility to manage the WEFE nexus. The recommendation of establishing the WEFE council evolved into the establishment of a WEFE Technical Coordination Committee, composed of representatives from the ministries of Planning and International Cooperation, Water and Irrigation, Agriculture, Energy and Mineral Resources, and Environment.

Unlike previous sector-based coordination mechanisms, this structure shifted WEFE governance from ad-hoc inter-ministerial consultation to a formalised, mandate-driven decision-making platform, directly linked to national planning and processes under MoPIC's leadership.

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b The Water-Energy-Food (WEF) Nexus Index is a composite indicator that aggregates 21 globally available indicators related to the availability and accessibility of water, food, and energy resources.

The Technical Coordination Committee is mandated to facilitate inter-ministerial coordination and stakeholder consultation, support evidence-based decision-making, and advance the operationalisation of the WEFE nexus across policies and programmes by gathering and analysing data, identifying and prioritising new initiatives, and overseeing the implementation and monitoring of the nexus roadmap. The Committee reports to a high-level Steering Committee, represented by senior officials as well as the Higher Council for Science and Technology. The committee serves as key decision-maker for managing and overseeing WEFE Nexus initiatives, leading institutional and regulatory reforms, securing funding, and supporting proposal development. It also endorses strategies, plans, and projects, thereby ensuring political oversight, institutional accountability, and alignment with national priorities. The committee reports to the Minister of MoPIC, who in turn reports to the prime minister of Jordan. This arrangement has enhanced accountability by clearly defining reporting lines, strengthened budget alignment through MoPIC's planning mandate, and reduced fragmentation by institutionalising cross-sector coordination within a permanent national structure rather than temporary project-based platforms.

In parallel to the willingness to adopt the nexus approach as reflected at the strategy and governmental levels, there are different national initiatives at the projects and programme levels the country is conducting to enhance its resilience toward resource security. These include the national conveyer where water to be desalinated from the Red Sea south of Jordan utilises green energy and is transferred to the central part of the country in an attempt to meet water demand while the variation in elevation will be utilised to generate energy.

Water authorities are also integrating photovoltaic (PV) systems into pumping stations, wells, and treatment facilities. These efforts have demonstrated up to 30-40 percent reductions in operational energy costs for the water sector,[8] which directly decrease the water-energy bill at the ministry level, enhance the financial sustainability and free resources that can be redirected toward infrastructure upgrades, service expansion, or social support mechanisms, while simultaneously reducing sectoral carbon emissions. In the agriculture sector, Jordan has one of the highest treated-wastewater reuse rates in the region, with more than 90 percent of treated wastewater being used for agricultural purposes.[9] This decreases the pressure on freshwater resources and increases its portion for domestic usage, thereby enhancing water security. Moreover, adopting solar irrigation at the farm level has reduced both water and electricity consumption, incentivising water-saving technologies and climate-smart agriculture while increasing food production, reducing import vulnerabilities, and enhancing farmers' income and resilience.

From a policy perspective, the recent national strategies, such as the Jordan Water Strategy 2023-2040, the updated Nationally Determined Contributions (NDC), the Green Growth Plan, and sectoral action plans, have begun incorporating nexus principles. These frameworks

highlight the need for cross-sector coordination, resource efficiency, and climate resilience. This momentum provides a critical window to institutionalise nexus planning across ministries.

Conclusion

Jordan's experience provides a useful example of how resource-scarce countries can leverage the WEFE Nexus to strengthen national resilience. While institutional, technical, and financial challenges persist, the country has recorded progress through its renewable energy expansion, wastewater reuse systems, agricultural modernisation, and national-level policy reforms.

Jordan's WEFE Nexus experience reflects both context-specific and transferable elements. The central role of MoPIC as the institutional anchor for WEFE governance is closely linked to Jordan's strong national planning architecture and may not be directly replicable in countries where planning authority is decentralised. Similarly, Jordan's high dependence on imported energy, its large burden of hosting refugees, and extreme water scarcity, shape a unique policy urgency that influences national prioritisation of the nexus approach.

A number of components of Jordan's WEFE model offer high transferability to other resource-scarce and climate-vulnerable countries. These include the establishment of formal inter-ministerial coordination mechanisms with clear reporting lines, the integration of nexus principles into national strategies and budgeting processes, the use of renewable energy to reduce water-sector operational costs, large-scale treated wastewater reuse for agriculture, and the alignment of climate, water, energy, and food policies under a shared resilience framework. Most importantly, Jordan demonstrates that institutionalising the WEFE Nexus does not require the creation of entirely new ministries, but rather the strategic reconfiguration of governance, planning, and accountability structures.

As such, Jordan's experience provides a practical governance and policy blueprint that can be adapted, rather than replicated, by other countries facing similar resource constraints, offering valuable lessons on how to operationalise the the WEFE Nexus beyond conceptual frameworks.

Enhancing the adoption of the WEFE nexus, first as a concept and framework, and ultimately as a practical approach embedded in national planning and strategies, is essential to ensuring resource security, improving productivity, and sustaining livelihoods in resource-scarce and climate-vulnerable contexts.

Majd Al Naber is Director General, West Asia-North Africa (WANA) Institute; Director, Science for Society Centre and Acting Manager, Sustainable Development Goals Division, Royal Scientific Society (RSS), Jordan.

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Iran's Water Crisis: Historical Roots, Ideological Dimensions, and Policy Challenges

Kamyar Kayvanfar

Iran's water story is intertwined with its modern political evolution. During the Pahlavi era, the country's national strategy centred on industrialisation and modernisation. Through the White Revolution (1963), the Shah sought to transform Iran into a modern, industrial state capable of rivalling Western economies. Agriculture was not neglected maliciously but deprioritised, a calculated choice that reoriented capital, labour, and infrastructure towards factories, oil, and heavy industry.[1]

Land reform broke up large estates and dismantled the landlord-peasant hierarchy. Aimed at equity, it instead disrupted efficient farming and alienated rural elites. Lacking capital or irrigation infrastructure, many smallholders saw the Shah's modernisation as a betrayal of Iran's agrarian roots.

This resentment became politically significant. The Islamic Revolution of 1979 found many of its earliest supporters among disaffected rural and small-town populations. Clerical leaders, including Ayatollah Khomeini, who came from a modest rural background, capitalised on this grievance.[2] After the Revolution, policy underwent a decisive shift: agriculture was transformed from being an economic sector to an ideological symbol of national authenticity and revolutionary justice.

The Iran–Iraq War (1980–1988) further reinforced this shift. Wartime self-reliance fostered the ideology of *"khodkafa'i",* meaning self-sufficiency.[3] Food production became an emblem of resilience against foreign dependence. The government promoted extensive agricultural expansion, constructing dams and subsidising water-intensive crops such as wheat, rice, and sugarcane, even in arid regions.

In Shia tradition, the denial of access to water during the Battle of Karbala—when Imam Hussein's camp was cut off—became a powerful moral reference.[4] After the Revolution, this symbolism shaped welfare policy, where the state declared that no one should be denied water. Regulatory barriers to household access were loosened, enshrining water as a right rather than a commodity.[5] This theological commitment, however, encouraged overconsumption and reduced incentives for conservation, setting the conditions for long-term depletion.

Cultural and Ideological Dimensions

Water in Iran is not merely a natural resource; it is an ideological artefact, woven into revolutionary identity. The Islamic Republic presents access to water and bread as proof of divine justice and government compassion. Subsidies, particularly for rural farming, have become mechanisms of political inclusion and loyalty.[6] Farmers, long considered the *"guardians of the revolution,"* benefit disproportionately from cheap electricity and irrigation water.

This is more than populism; it reflects the regime's rural roots. Early leaders saw agriculture as a sacred labour and a revolutionary duty, enshrining self-sufficiency as moral virtue, while subordinating industry to social equity and privileging loyalty over efficiency.

Bread, in this context, is ideological. It appears in countless Persian idioms symbolising honour, livelihood, and divine blessing. To suggest that bread or the water that produces it should be treated as a priced commodity is politically toxic. Thus, proposals for water pricing reform are routinely denounced as "anti-Islamic" or "elitist."

The symbolic resonance of bread in Persian and Islamic culture amplified this commitment. Ensuring that "bread is always on the table" and "is not coming from alien foreign countries" became both a social contract and a theological duty.

This ideological framing has contributed to policy paralysis. Decision-makers, many of whom rose through revolutionary or wartime institutions rather than bureaucratic channels, approach the water crisis through a wartime lens where shortages are to be endured, not prevented. Scarcity becomes another battlefield on which citizens must display patience and faith. Such framing discourages reform: subsidies persist, consumption continues, and the very narrative that once united the state and society now impedes the strategic planning required for sustainability.

Current Challenges

The consequences of these intersecting forces are profound. Iran's water crisis now encompasses structural, governance, and social dimensions.

Infrastructure and Industrial Conflict

While early post-revolutionary governments invested heavily in dams and canals, the "water mafia" built dams that were rarely filled. This caused the water tables in the plains to drop from the 1990s onwards, turning once-fertile lands to dust.

More critically, the state is now both the regulator and a competitor. Many of Iran's largest water-consuming industries, including steel, petrochemicals, and energy, are state-owned or linked to quasi-military foundations. The government thus profits from the same inefficiencies it is tasked to correct.[8] Any regulatory reform that would constrain industrial water use would also threaten its own revenue streams.

Corruption and Illegal Extraction

The widespread illegal drilling of wells exacerbates depletion.[9] Thousands of unauthorised wells continue to extract groundwater unchecked, often with political protection. Corruption and weak law enforcement mean that even where laws exist, they are selectively applied. Officials who benefit from these networks have little incentive to impose penalties.

Technocratic Gaps and Policy Inertia

Following the Iran–Iraq War, many veterans entered the civil service. Their revolutionary credentials ensured loyalty but not technical expertise. Decision-making in water policy remains dominated by military and ideological figures rather than hydrologists or economists.[10] Consequently, solutions tend to mirror wartime logic—reactive, short-term, and framed as resistance rather than reform.

Emergency Governance

Iran's broader political culture reinforces this short-term approach, where the state operates in perpetual emergency, responding simultaneously to sanctions, inflation, energy shortages, and social unrest.[11] In such an environment, water reform is perpetually deprioritised. Investment cycles remain short, with a preference for visible, rapid projects such as building dams rather than long-term basin management.

Social and Security Implications

Rural areas, once pillars of revolutionary legitimacy, are now epicentres of discontent. The drying of rivers like the Zayandeh Rood in Isfahan has provoked repeated protests by farmers demanding state accountability.[12] In Khuzestan, where mismanaged dams and industrial diversions have devastated agriculture, demonstrations have turned violent. Migration from desiccated villages to urban centres adds to unemployment, housing shortages, and public discontent.

The Way Forward

Iran has the scientific capacity to manage its water resources more sustainably, but its political structure and ideological imperatives obstruct reform.

Agricultural Diversification and Imports

Iran could reduce pressure on its aquifers by importing water-intensive crops such as rice and sugarcane, focusing instead on drought-resistant varieties. However, this clashes with the doctrine of self-sufficiency, a pillar of revolutionary identity.[13] Politicians fear that admitting reliance on imports would symbolically betray the Revolution's promise of independence. Beyond crop diversification, Iran could modernise irrigation networks by replacing flood irrigation with efficient drip systems, thereby optimising agricultural water usage. Small-scale groundwater recharge projects, combined with soil moisture monitoring, could help stabilise rural livelihoods without the large capital requirements of new dams.

Reforming Subsidies and Governance

A rational pricing system could discourage water wastage, but removing subsidies risks alienating the regime's most loyal base: rural farmers. The experience of 2019, when fuel price hikes sparked nationwide unrest, remains a deterrent. More fundamentally, as the state itself is a major water consumer, genuine regulation would require the government to restrict its own enterprises, something it has consistently resisted.[14] Complementary to pricing reform, investment in urban wastewater recycling and industrial water recirculation could reduce total freshwater withdrawals. Desalination, though renewable energy-intensive, could provide a strategic reserve for coastal cities like Bandar Abbas and Bushehr, easing pressure on inland aquifers.

Technocratic Empowerment

Replacing military and clerical decision-makers with technically trained administrators would ensure more consistent water management. However, such a transition would require shifts in authority that the Islamic Republic is unlikely to endorse. As long as key decisions are shaped by a "resistance" framing of scarcity, policy responses are likely to continue emphasising short-term rationing and tighter control over demonstrations, instead of pursuing broader structural reforms.

Institutional Independence

Iran's water agencies require autonomy from political and industrial interests. The government must cease to act simultaneously as producer, regulator, and beneficiary.[15] Only then can regulation be credible. But this would entail disentangling vast networks of patronage and parastatal control, a challenge few within the system are willing to confront.

Structural Barriers

Ideology remains a major obstacle, but it is compounded by other factors: the rural social foundation of the regime, the symbolic centrality of bread, and the entrenched belief that endurance equals strength. These collectively prevent rational recalibration. The leadership's wartime mentality of expecting citizens to "fight through droughts" perpetuates short-termism and discourages development.[16]

Conclusion

Iran's water crisis is no longer a resource issue; it is a mirror of inept governance. The same revolutionary values that once stabilised the regime now obstruct its adaptability. Self-sufficiency has become self-defeating, and ideological loyalty has become institutional inertia.

Corruption, mismanagement, and competing state interests compound the problem. Each new "solution" is reactive, be it water rationing, ad-hoc transfers, or temporary desalination plants.

Iran's leadership faces a strategic choice: either continue rationing scarcity or redefine water as a national, not ideological asset. This would require depoliticising agriculture, empowering technocrats, and planning in terms of decades rather than electoral cycles. Without such a shift, Iran risks a future where its wells, like its political power, run dry.

Kamyar Kayvanfar is a Communications and Public Affairs professional in the United Kingdom.

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India and the Gulf: A New Strategy for Water, Energy, Food, and Ecosystem Security

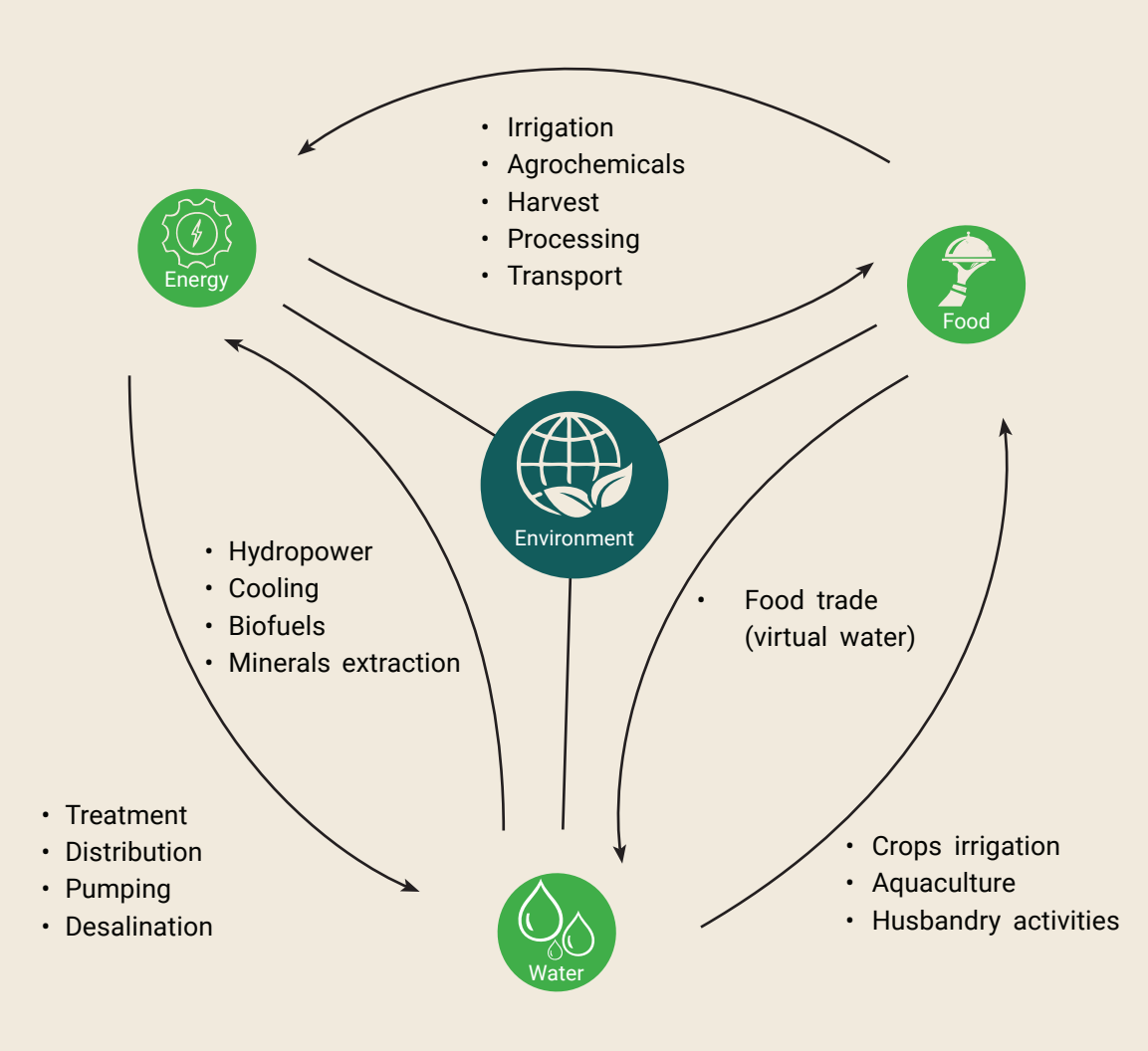
Suparana Katyaini and Bassel Daher

Water, energy, food, and ecosystems (WEFE) are deeply interconnected, and these linkages sit at the core of today's most critical global security challenges. With climate pressures intensifying, cities expanding, and populations growing, the interconnections among agrifood system transformation, energy transition, integrated water management, and land governance are not parallel agendas. They shape each other's risks and opportunities in ways that determine whether communities move toward resilience or deeper vulnerability. Within an interdependent nexus, stresses in water, energy, or food systems reinforce one another through feedback loops, translating localised shocks into power shortages, agricultural disruption, and food insecurity, and underscoring the

need for integrated governance and resource-efficient practices (Figure 1). Recognising and operationalising this interdependence in planning, management, and investment is therefore essential for navigating an increasingly complex and uncertain resource landscape.[1,2,3]

Despite the clear need for addressing these WEFE challenges as a nexus, policy signals and investments often remain in silos. Such fragmentation amplifies systemic vulnerability, producing cascading cross-sectoral failures while undermining opportunities for coordinated, resilience-building interventions.

Figure 1: The WEFE Nexus



Source: Salmoral et al. (2019)[4]

Building on this foundation, this article discusses India and the Gulf countries of Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, and the United Arab Emirates (UAE). Both regions face mounting pressures across WEFE systems, though the nature of these pressures differs in ways that are structurally complementary rather than symmetrical.[5]

India, for one, must manage food production for a large and growing population under increasing water stress, groundwater depletion, and climate variability, while simultaneously navigating energy access, affordability, and emissions constraints within a complex, multi-level governance landscape.[6,7] Meanwhile, the Gulf countries are confronting extreme physical water scarcity that severely limits domestic agricultural potential, yet they possess abundant energy resources, high fiscal capacity, and globally significant infrastructure for desalination logistics[a] and trade. Food security in the Gulf is therefore intrinsically tied to energy-intensive water supply systems and to reliable international supply chains, making the region highly exposed to shocks across energy markets, maritime trade, and climate-sensitive food production elsewhere.[8,9] These contrasting WEFE profiles create a shared vulnerability to systemic risk, but also a clear basis for cooperation grounded in complementary resource endowments, production capacities, and governance strengths. The article argues that India and the Gulf can benefit from a shared yet context-specific WEFE strategy, rooted in comparative advantage and improved resilience through partnership and trade that is grounded in a systems nexus approach.

From a WEFE perspective, deeper cooperation between India and the Gulf countries reflects a rational alignment of comparative advantage rather than a trade-off between self-sufficiency and security. India retains relative advantages in food production due to its agro-ecological diversity, labour availability, and expanding capacity in water-efficient and climate-smart agriculture, whereas the Gulf's extreme water scarcity fundamentally constrains domestic food production despite substantial energy resources. For water-scarce, energy-abundant economies, importing food grown in more resource-productive contexts, supported by energy-enabled logistics, cold chains, and strategic trade agreements and investment frameworks, can be more sustainable than pursuing water-intensive domestic production.

Existing frameworks such as the India–UAE Comprehensive Economic Partnership Agreement (CEPA) provide an institutional basis for re-orienting food and energy trade through a WEFE lens, enabling both regions to reduce pressure on stressed water systems while enhancing supply-chain resilience.[10] When governed through integrated WEFE strategies that account for embedded (virtual) water, energy use, and ecosystem impacts, such cooperation strengthens regional and global food security by aligning production, trade, and energy systems with long-term resource sustainability.[11,12,13,14]

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a These countries produce nearly 50 percent of the world's desalinated water, with Saudi Arabia as the top global producer.

Within this shared context, the rest of this article outlines three priority I's for further strengthening a practical roadmap for sustainable development: integrate, innovate, impact. First is to identify and integrate key policy priorities across sectors to manage the WEF nexus effectively. Second is to innovate methodologies (tools and analysis) for holistic and systemic WEF management. Third is to map the impacts for future courses of action.

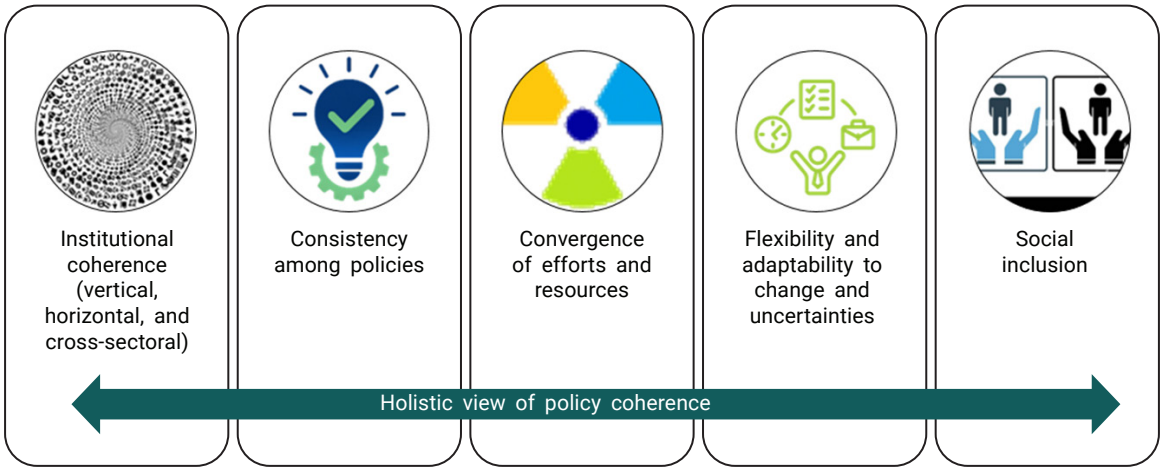
A first step is to integrate thematic focus on the nexus. India and the Gulf region share the challenge of coordination across complex institutional landscapes, where policies for water, energy, and food are often managed within separate ministries in India, while the governance is more centralised in Gulf nations with high government capacity and substantial financial resources to invest in high-cost solutions. Further, a lack of standardised integrated data collection and sharing mechanisms across the sectors to accurately model and manage the trade-offs (e.g., quantifying the energy used to pump water for a specific crop) is a challenge. To overcome this obstacle, there is a need for new ways of thinking about integrated governance at multiple levels and through multiple lenses.

Second, the transition toward sustainable WEFE security in both India and the Gulf requires moving beyond traditional sectoral planning by adopting innovative methodological approaches to unlock more coherent and effective planning. These methods focus on holistic coverage of WEFE systems and are critical for understanding complex trade-offs and identifying synergies. To achieve integrated planning, policy coherence driven by collective action is the essential foundation for sustainable development. SDG Target 17.14 identifies policy coherence as a critical mechanism to advance the entire 2030 Agenda through integrated partnerships and collective action. In this process, "simplexity"—the ability to simplify complex issues into actionable insights without losing nuance—is pivotal.[15] Simplexity works by distilling the drivers and tradeoffs within WEFE systems into forms that decision-makers can use, such as scenario pathways, hotspots analyses, and clear option spaces. It enables stakeholders to see where coordinated action is most feasible, which leverage points matter, and how different interventions interact across systems. By turning complexity into structured, decision-ready insight, simplexity creates the practical foundation needed for coherent planning and action.

For the Gulf, this may involve advanced systems modelling to optimise the costly desalination-energy nexus, integrating future climate change impacts with renewable energy deployment schedules and resource pricing mechanisms. As the Gulf's food resilience is linked to the stability of a high-tech energy chain considering desalination serves as the primary metabolic input for both human consumption and food production, and energy requirements for intense cooling required for climate-controlled agriculture. This creates a unique vulnerability where energy market volatility or grid disruptions translate directly into immediate water and food insecurity, requiring a transition toward renewable-powered desalination and circular brine management.[16]

In India, it refers to the use of remote sensing and geospatial analysis to accurately map groundwater depletion driven by subsidised energy use, alongside data-driven policy coherence frameworks (like the five-dimensional model in Figure 2). An important consideration would be a holistic outlook to plan alignment of policy actions across federal, state, and local governance levels. By leveraging these computational and integrated governance tools, both regions can effectively analyse the entire resource chain, allowing policymakers to design flexible and adaptive strategies that manage scarcity, enhance efficiency, and minimise adverse cross-sectoral impacts while advancing inclusivity.

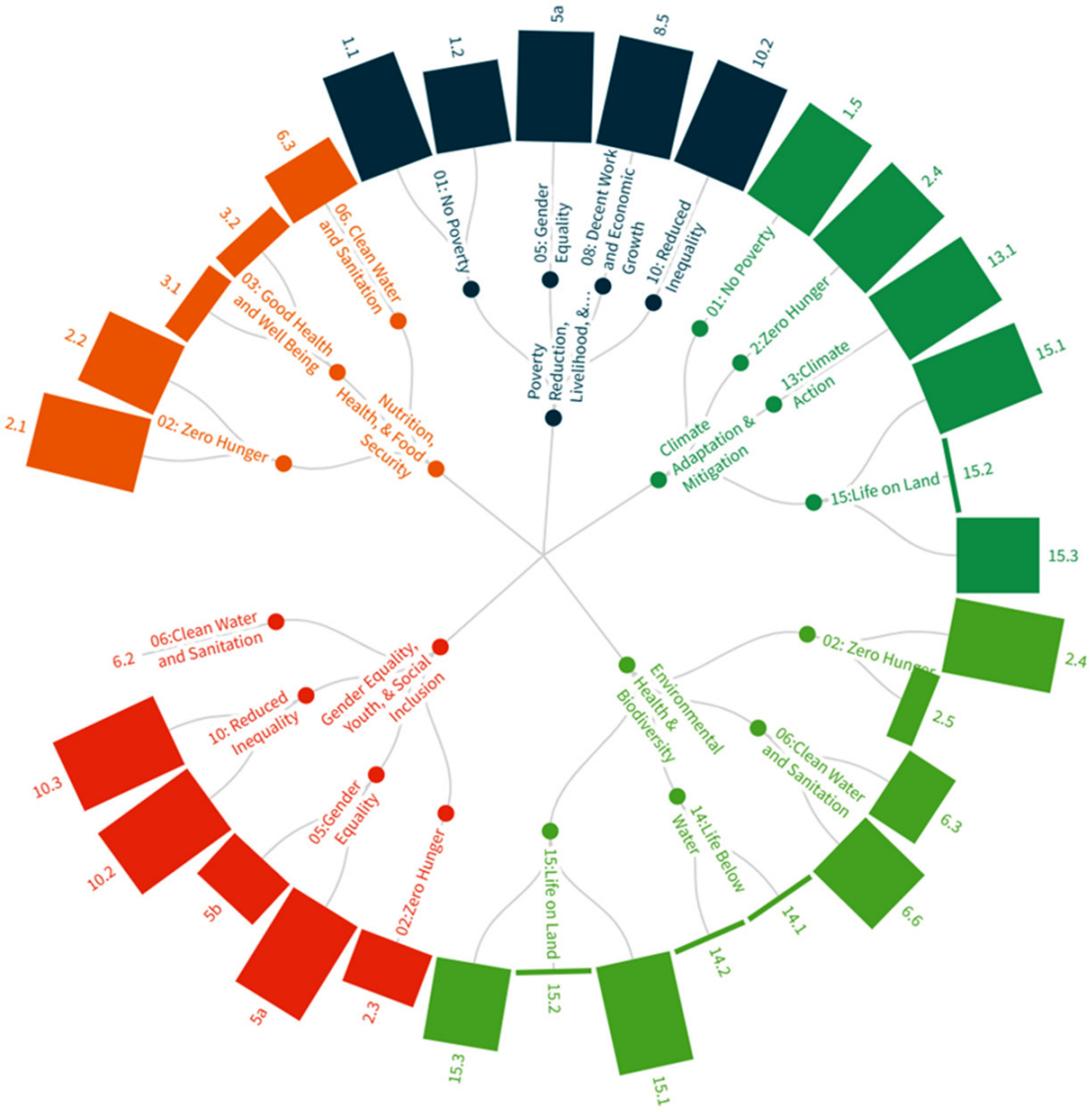
Figure 2: A Multidimensional Framework for Synchronising WEFE Policy Coherence



Source: CEEW and IWMI (2023)[17]

Third, mapping the impact of key policy interventions is critical in demonstrating how national initiatives advance SDGs, a crucial element to inform policy actions for positive impact. For example, microirrigation, a climate-smart and water-saving technology, is promoted in India through the 'Per Drop More Crop' (PDMC) initiative. Policy actors from the national and state departments of agriculture, and representatives of research institutes confirm that it has had a positive impact on multiple SDGs targets.[18] The core value proposition of PDMC—enhancing water use efficiency—drives strong linkages with SDG 6 (Clean Water and Sanitation) by ensuring sustainable utilisation, and supports SDG 2 (Zero Hunger) by increasing productivity and promoting sustainable agriculture (Figure 3). Further, it improves farm-level incomes and reduces input costs (through efficient fertiliser and water use), contributing to SDG 1 (No Poverty) and SDG 8 (Decent Work and Economic Growth). Such impact mapping offers granular evidence needed to transition from reactive crisis management to proactive, climate-resilient scaling.

Figure 3: SDG Impact Mapping: The Reach of the 'Per Drop More Crop'



Source: CEEW and IWMI (2024)[19]

Note: The bar height indicates the intensity of linkage with SDG targets.

In conclusion, strategic alignment between India and the Gulf represents a learning space for solving the world's most pressing security challenges. There is a wide landscape of collaborative opportunities between India and the Gulf that could be mutually beneficial. This article identifies technology transfer, policy exchange, and joint research as instrumental avenues to build and strengthen collaboration.

- **What India can learn from the Gulf:** India could learn from the Gulf's expertise in high-tech, large-scale infrastructure that has led to a spectrum of solutions to regional water security and water-efficient agriculture. Specifically, the Gulf's global leadership

in desalination and smart-grid integration offers a roadmap for India's coastal urban centres and industrial hubs to achieve water and energy security independent of erratic monsoon cycles.

- **What the Gulf can learn from India:** India's experience in coordinating policy action across multiple levels of government offers relevant perspectives on managing cross-sectoral priorities. Approaches that link national objectives with state- and local-level implementation highlight ways to support coherence across systems and scales. These perspectives may complement the Gulf's established strengths in infrastructure and technology, particularly in efforts to integrate ecosystem considerations and stakeholder engagement within ongoing resource planning processes.

As both regions play important roles in global food and energy systems, closer collaboration can support collective efforts to anticipate and manage systemic risks. Joint WEFE-oriented initiatives, spanning research, technology exchange, and policy dialogue, can contribute to more resilient supply chains and more informed resource planning. By framing WEFE security as a shared governance opportunity and integrating data, analytical tools, and outcome-oriented indicators, India and the Gulf can jointly advance a model of collaborative resource leadership that supports climate resilience, ecosystem stewardship, and sustainable development in the Global South.

Suparana Katyaini is Programme Lead, Sustainable Water, Council on Energy, Environment, and Water (CEEW), India.

Bassel Daher is Assistant Director, Sustainable Development, Texas A&M Energy Institute, United States.

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About the Authors

Mohamed Abdelraouf is Program Director, Sustainability Research, Gulf Research Center, Kingdom of Saudi Arabia.

Kristian P. Alexander is Senior Fellow and Lead Researcher, Rabdan Security and Defense Institute (RSDI), United Arab Emirates.

Majd Al Naber is Director General, West Asia-North Africa (WANA) Institute; Director, Science for Society Centre and Acting Manager, Sustainable Development Goals Division, Royal Scientific Society (RSS), Jordan.

Hamed Assaf is Dean of the School of Engineering and Computing, American University of Ras Al Khaimah, United Arab Emirates.

Bassel Daher is Assistant Director, Sustainable Development, Texas A&M Energy Institute, United States.

Diana Francis is Professor of Atmospheric and Climate Science, Khalifa University, United Arab Emirates.

Cauvery Ganapathy is Fellow, Climate and Energy, ORF Middle East, United Arab Emirates.

Nidal Hilal is Professor and Director, Water Research Center, New York University Abu Dhabi, United Arab Emirates.

Mannat Jaspal is Director and Fellow, Climate and Energy, ORF Middle East, United Arab Emirates.

Suparana Katyaini is Programme Lead, Sustainable Water, Council on Energy, Environment, and Water (CEEW), India.

Kamyar Kayvanfar is a Communications and Public Affairs professional in the United Kingdom.

Maja Kent is Non-Resident Research Fellow, Centre for Climate Diplomacy (CCD), Anwar Gargash Diplomatic Academy (AGDA), United Arab Emirates.

Roula Majdalani is Senior Climate Change Advisor, International Center for Agriculture Research in the Dry Areas, Lebanon; and Distinguished Associate Fellow, Carboun Institute, Netherlands.

Leigh Mante is Junior Fellow, Climate and Energy, ORF Middle East, United Arab Emirates.

Fatin Samara is Professor of Environmental Sciences, American University of Sharjah, United Arab Emirates; Deputy Director, EWSERC; and Adjunct Faculty, American University, Washington DC.

Maya Wael Ahmed Mohamed Tarrad is a Chemistry Graduate, American University of Sharjah, United Arab Emirates.

Isabelle Tsakok is Economist and Senior Fellow, Policy Center for the New South, Morocco.

Lourdes F. Vega is Full Professor of Chemical Engineering, Khalifa University; Founder and Director, Research and Innovation Center on CO2 and Hydrogen (RICH Center); and Theme Lead, Energy and Hydrogen, Research and Innovation Center for Graphene and 2D Materials (RIC2D), United Arab Emirates.

ORF
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12.03, Convention Tower,
Dubai World Trade Centre,
Dubai, United Arab Emirates
www.orfme.org

RSDI
مركز ربدان للأمن والدفاع
Rabdan Security & Defence Institute

65, Al Inshirah, Al Sa'adah
Abu Dhabi, 22401, UAE
+971 2 5999 111
https://rsdi.ae | info@rsdi.ae