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A Systemic Approach to Addressing Water-Energy-Food Nexus Security in Arab Countries

نهج نظامي لمعالجة أمن الترابط بين المياه والطاقة والغذاء في الدول العربية

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المستخلص

تواجه البلدان العربية تهديدات متزايدة ناجمة عن تغيّر المناخ، الذي يفاقم التحديات المترابطة القائمة والمتعلقة بأمن المياه والطاقة والغذاء؛ حيث إن الطبيعة المعقّدة لهذه التحديات تستدعي اعتماد نهج نظامي لفهم الترابطات المتشابكة فيما بينها وتطوير حلول متعددة الأبعاد وعابرة للقطاعات. وتوجد فجوة واضحة في أدوات دعم القرار والتحليلات اللازمة لدعم اتخاذ قرارات قائمة على الأدلة فيما يتعلق بأمن ترابط المياه والطاقة والغذاء في المنطقة. وينبغي أن تكون هذه الأدوات متوائمة مع السياق المحلي، بحيث تعكس التنوع الكبير في الظروف بين البلدان، بما في ذلك التباينات في توافر الموارد، والقدرات التكنولوجية، والقدرات البشرية، ومستويات التعرّض لمواطن الهشاشة.

وتهدف الدراسة إلى معالجة هذه الفجوة من خلال الأهداف التالية: استعراض الترابطات بين تحديات نظم المياه والطاقة والغذاء عبر المنطقة العربية؛ وتحديد أوجه الهشاشة الجغرافية والبيئية

الكلمات المفتاحية: الدراسات الأمنية، ترابط المياه والطاقة والغذاء، المنطقة العربية، أمن الموارد، نهج النظم، تغير المناخ، صنع القرار القائم على الأدلة

Abstract

Arab countries face increasing threats from climate change, which exacerbates existing interconnected challenges related to water, energy, and food security. The complex nature of these challenges necessitates a systems approach to understanding their interrelationships and developing multidimensional, cross-sectoral solutions. A clear gap exists in the decision support tools and analyses needed to support evidence-based decision-making regarding the water-energy-food nexus in the region. These tools should be adapted to the local context, reflecting the significant diversity of circumstances among countries, including variations in resource availability, technological capabilities, human capacities, and levels of vulnerability.

This study aims to address this gap through the following objectives: to review the interrelationships between water, energy, and food system challenges across the Arab region; to identify the specific geographic, environmental, socio-

Keywords: *security studies, water-energy-food nexus, Arab region, resource security, systems approach, climate change, evidence-based decision-making*

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economic vulnerabilities of the region's countries; and to identify emerging issues, such as the impacts of climate change, population growth, migration, and conflict, and explore their roles in exacerbating resource pressures and shaping the water-energy-food nexus. The studies recommend developing aligned and evidence-based strategies to enhance the water, energy, and food security nexus in the Arab region..

والاجتماعية والاقتصادية الخاصة ببلدان المنطقة، وتحديد القضايا الناشئة، مثل: آثار تغيّر المناخ، والنمو السكاني، والهجرة، والنزاعات، واستكشاف أدوارها في تفاقم الضغوط على الموارد وتشكيل ترابط المياه والطاقة والغذاء؛ وتوصي الدراسات بتطوير إستراتيجيات متوائمة وقائمة على الأدلة لتعزيز أمن ترابط المياه والطاقة والغذاء في المنطقة العربية.

1. Introduction

As the world undergoes an energy transition and food system transformation amidst growing pressures on water resources, there is a critical need to better understand the interconnections between these systems and the challenges they face. The Water-Energy-Food (WEF) Nexus offers a framework to address these complexities, emphasizing the interdependencies and trade-offs inherent in managing these essential resources. As the 2030 Agenda for Sustainable Development approaches its deadline, there is growing urgency to advance the Sustainable Development Goals (SDGs). These goals inherently recognize the interdependence of global priorities, which demand a systems approach to ensure progress in one area does not come at the expense of another.

Understanding the interconnections between resources systems can help establish security and adaptability in the face of growing resource demand and compound shocks. While modeling these complexities, addressing their nuances, and translating insights into effective policies is a challenging endeavor, it holds the promise of significant economic benefits, enhanced resource efficiency, improved livelihoods, and better public health outcomes (Bazilian et al. 2011). The WEF nexus started becoming more mainstream since 2011, when greater attention was being paid to global economic issues, especially surrounding water resources and food scarcity (The World Economic Forum Water Initiative 2011; Sims and Dubois 2011). The interconnections between water, energy, and food sectors are many, but some key links highlight the extent of the overlap: globally 72% of water resources are consumed by agriculture, and about 14% of water withdrawals go toward energy production (UN Water 2024). Food systems use about 30% of globally available energy (IRENA and FAO 2021). Adopting a systems approach to understanding and addressing the challenges facing these interdependent resource system has become increasingly critical. Such an approach can guide evidence-based policymaking by highlighting trade-offs, forecasting long-term outcomes, and providing a valuable framework for policymakers and researchers to explore viable solutions.

Prior to the WEF Nexus's popularization, there was already substantial interest in the urgency and finiteness of water, energy, and food resources (Simpson and Jewitt 2019). Prior research has primarily examined the interplay between energy production methods and their reliance on water resources, as well as how water management processes depend on energy (Siddiqi and Anadon 2011). Analysis of water and energy resources soon also included how the agriculture sector utilizes energy and water (Sims and Dubois 2011; Rogers 2017). The World Economic Forum Water Initiative introduced the water-energy-food-climate nexus as

a method of understanding and addressing water security in 2011, which highlighted the complex position of water in the global economic system (The World Economic Forum Water Initiative 2011). Interest in the water-energy-food nexus in its current form stemmed from the Bonn2011 Nexus Conference, which was titled "The Water, Energy and Food Security Nexus – Solutions for a Green Economy" (Nexus 2011; Simpson and Jewitt 2019).

The core element of the WEF Nexus framework is its focus on the interdependencies and interconnections between resource systems. Other similar frameworks have sought to expand on the systems approach by including climate, security, ecosystems, soil, and waste (Howells et al. 2013; Rogers 2017; Global Water Partnership 2020; Avellán et al. 2017). Recently, there has been a push to use the WEF nexus to prioritize resource and system resilience, efficiency, and adaptability, in addition to productivity (Mohtar 2017; Rasul and Sharma 2016; Hogeboom et al. 2021; Daher et al. 2022). The WEF nexus considers complex interconnections between resources and multidimensional resource systems, which makes it a growing area of research in the face of global emergent themes of climate change, mass migrations, and non-uniform resource distribution (Daher et al. 2018; 2021).

The Arab region has been a focal point for water-energy research due to its unique resource constraints and contextual challenges, which make the analysis of water, energy, and food systems both necessary and valuable. Studies on water and energy management in the region have underscored the significant dependence of water abstraction and production on energy resources (Siddiqi and Anadon 2011). Recent analysis has considered water-energy connections in a variety of applications, including the energy costs of desalination and groundwater pumping, the costs of importing water-intensive food, water usage for fuel and oil processing, and the efficiency of wastewater treatment and reuse (Maftouh et al. 2022; Rogers 2017). Emerging trends highlight the general increase in demand for resources, decreasing water resources, the region's increased reliance on fossil-fueled desalination, and cheap water tariffs (Maftouh et al. 2022). These trends collectively point to a deepening dependence on energy-intensive water production at a time when both energy systems and water resources are under growing stress.

Arab countries face distinct vulnerabilities in their water, energy, and food systems, with specific hotspots across the region. By 2030 the average water per capita in the Middle East and North Africa (MENA) is expected to fall below the absolute water scarcity threshold, which is defined by having less than 500 m3 of renewable water resources per capita per year (De Waal et al. 2023). Internal water resources paint a similarly bleak picture: two thirds of Arab countries have less than 300 m3 of internal renewable freshwater resources per capita (World Bank 2020b). Most of the water used in the region is generated outside the region (Mendonca et al. 2019). Additional factors straining water resources include poor infrastructure, illegal connections, and inaccurate water meters, which cause about 30% of water to be lost or used informally (De Waal et al. 2023). Water resources in Arab countries are also used for oil extraction, fuel refining and processing, and electricity generation. The MENA region has nearly 46% of the world's desalination capacity, and two-thirds of desalinated water in the region is produced by thermal desalination powered by fossil fuels (Maftouh et al. 2022; De Waal et al. 2023). Additionally, the region faces several pressures on its food systems. Increasing population, changing diets, and scarce water resources strain food

supplies. Cereal production in the region increased by 50% between 1990 and 2011, but despite this the cereal import dependency ratio over the same period has increased by 10%. Furthermore, the MENA region's agricultural sectors use 83% of water withdrawals, highlighting the critical role of agricultural practices and food security in shaping water management strategies (De Waal et al. 2023). Water, energy, and food resource systems in the region have been further strained by environmental and socio-economic factors. Desertification, erosion, increasing groundwater salinity, and water pollution, conflict, and migration complicate resource supplies and further highlight the need for systems-thinking surrounding resources (Hindiyeh, Albatayneh, and AlAmawi 2023; World Bank Group 2022).

Despite growing research on the Water-Energy-Food Nexus, there remains a critical gap in understanding how the vulnerabilities of the Arab region shape WEF nexus dynamics across sectors. Existing studies often lack a comprehensive analysis of these interdependencies across geographical, environmental, and socio-economic contexts, limiting the application of the WEF Nexus framework in addressing the region's multidimensional resource strains. This paper aims to address this gap through the following objectives:

1. review the interconnections between water, energy, and food system challenges across the Arab region.
2. highlight how the water-energy-food nexus framework can be employed to understand and address these challenges across multiple scales in the Arab region, by offering a holistic perspective on the interrelated issues.
3. identify the geographical, environmental, and socio-economic vulnerabilities across the region's countries.
4. identify emergent themes shaping WEF nexus security in the Arab region, including climate change, population growth, migration, and conflict, and explore their roles in exacerbating resource strains and shaping the WEF nexus.

2. Methods

This review followed a structured approach to examine water, energy, and food related trends and challenges across the Arab region, guided by the following research questions: 1) How do the interconnections between water, energy, and food systems manifest across the diverse contexts of the Arab region?; 2) What geographical, environmental, and socio-economic vulnerabilities shape WEF nexus dynamics in the region?; 3) How do emergent themes, including climate change, population growth, migration, and conflict, exacerbate resource strains and reshape WEF nexus security?; 4) What gaps exist in current WEF nexus tools and approaches for supporting evidence-based decision-making in the Arab region? The analysis integrated data from academic, institutional, and governmental sources to provide a nuanced understanding of the complex interconnections and emerging themes shaping WEF Nexus dynamics. The review began with an exploration of the origins and evolution of the WEF Nexus framework, emphasizing its relevance to resource challenges in Arab countries. That included tracing its development from its introduction at the Bonn2011 Nexus Conference to its growing adoption as a tool for addressing global and regional sustainability challenges.

Data was collected from a range of sources, including academic institutions, international organizations, and national reports. Academic research provided foundational insights into the

socio-economic and resource dynamics of the region. Reports from international organizations, including the United Nations agencies, the World Bank, FAO, IMF, and OECD, offered critical quantitative data and thematic analysis, while government ministry publications provided localized insights into policy and management practices. The review focused on compiling key metrics to characterize WEF Nexus dynamics across the region. These metrics included renewable freshwater resources per capita, non-renewable water use, energy import dependency, demand growth, food import dependency, and agricultural land use. Analyzing these metrics allowed for a detailed understanding of the interconnections between water, energy, and food systems in Arab countries. To ensure a nuanced understanding, the analysis incorporated a contextual and thematic exploration of the challenges facing the region. Particular attention was given to geographical variability, such as the reliance of some countries on transboundary water resources and others on non-renewable groundwater. Emergent themes like climate change, population growth, migration, and conflict were identified and explored for their roles in exacerbating resource strains and influencing WEF Nexus dynamics.

The analysis is structured around the WEF nexus framework, examining regional challenges, vulnerabilities, and governance responses through the lens of cross-sectoral resource interconnections. It also examines governance structures and trends, highlighting the role of integrated management in addressing interconnected resource challenges. For example, Saudi Arabia's Ministry of Environment, Water, and Agriculture (MEWA) was analyzed as a case study to illustrate the benefits of cohesive governance in advancing Nexus-oriented policies. Finally, the findings were synthesized to identify recurring patterns, highlight regional distinctions, and provide actionable insights. Particular attention was given to opportunities for enhancing Nexus-oriented policies through capacity building, regional collaboration, and the development of tailored decision-making tools.

3. WEF Nexus Challenges in Arab Countries

3. 1. WEF Regional Distinctions

While Arab countries face many shared challenges, the distinct characteristics of sub-regions and individual nations create unique contexts. Even neighboring countries with comparable climates may experience vastly different resource dynamics and challenges. A nuanced understanding of these contexts is essential for crafting solutions tailored to their specific needs.

3. 2. Water

In the case of water resources, the type of resource, usage patterns, and approaches to management differ across the region. Some countries in the Maghreb, such as Morocco, Algeria, and Tunisia, primarily rely on internally generated surface water from rainfall. They tend to have more sustainable water withdrawals but are also more vulnerable to climate change impacts that might make year-to-year water resources unpredictable (World Bank 2018; Kandeel 2019). Mashreq countries of Iraq, Syria, and to some extent Jordan and Palestine, are downstream in river systems. These water resources are highly vulnerable to shifting upstream demands and heavily reliant on groundwater reserves. Many are part of transboundary water basins shared with neighboring countries, leading to resource competition and unpredictable usage patterns. As a contrasting case,

Lebanon has high per capita water resources since it relies primarily on abundant renewable internally generated surface and groundwater runoff (Kandeel 2019; World Bank 2018). The Nile Basin countries of Egypt and Sudan are also reliant on surface river water, making their water resources vulnerable to upstream Nile River water demands. In the Arabian Peninsula, almost all water resources come from non-renewable groundwater or non-conventional water from processes such as seawater desalination. Although they are extremely water scarce, these countries have fewer of the vulnerabilities that other water resources in the region face, mostly due to their use of desalinated water. The countries of the Horn of Africa, Somalia and Djibouti, have unpredictable rain that often falls in sudden downpours, making it difficult for them to collect, store, and then efficiently use their rainwater resources (Kandeel 2019). Table 1 summarizes key water resource indicators across Arab countries, organized by sub-region, illustrating the variability in resource endowments and source types that underpin these distinct challenges.

Water resource management is similarly diverse. In many countries, groundwater is not well monitored or billed, or is lost through poor infrastructure, therefore providing little incentive for conservation.

Table 1

Water Resources Characteristics Across Arab Sub-Regions

Sub-region	Primary water source	Key vulnerabilities	Management challenges
Maghreb (Morocco, Algeria, Tunisia, Libya, Mauritania)	Internally generated surface water from rainfall (World Bank 2018; Kandeel 2019)	More vulnerable to climate change impacts on year-to-year water resource predictability (World Bank 2018; Kandeel 2019)	Morocco: aging dams and water storage infrastructure; water losses from high evapotranspiration (GIZ 2019). Tunisia: 28.5% non-revenue water (Langenberg et al. 2021)
Mashreq (Iraq, Syria, Jordan, Lebanon, Palestine)	Downstream transboundary river systems; heavy reliance on groundwater reserves. Lebanon: abundant renewable internal surface and groundwater runoff (Kandeel 2019; World Bank 2018)	Highly vulnerable to shifting upstream demands; resource competition over shared transboundary basins; unpredictable usage patterns, (Kandeel 2019)	Jordan: 52.5% non-revenue water (MWI 2023). Groundwater not well monitored or billed; poor infrastructure provides little incentive for conservation
Nile Basin (Egypt, Sudan)	Surface river water (Nile River)	Vulnerable to upstream Nile River water demands	High dependency on externally generated water resources (Mendonca et al. 2019)
Arabian Peninsula (Saudi Arabia, UAE, Kuwait, Qatar, Bahrain, Oman, Yemen)	Non-renewable groundwater; non-conventional water (seawater desalination) (Kandeel 2019)	Extremely water scarce; reliance on energy-intensive desalination and non-renewable groundwater (World Bank 2018)	Groundwater not well monitored or billed; low water tariffs and subsidies reduce incentive for conservation (Vereinte Nationen 2015)
Horn of Africa (Somalia, Djibouti)	Unpredictable rainfall, often in sudden downpours (Kandeel 2019)	Difficulty collecting, storing, and efficiently using rainwater resources (Kandeel 2019)	Limited water infrastructure

Many countries face water losses from leaks due to aging water network infrastructure. Non-revenue water (water lost through leakage, illegal usage, or administrative inaccuracies) makes up 52.5% of Jordan's water supply and 28.5% of Tunisia's water supply (MWI 2023; Langenberg et al. 2021). Morocco faces aging dams and water storage infrastructure, as well as water losses from high evapotranspiration rates (GIZ 2019).

3. 3. Energy

Energy demand in the Arab countries is high and is expected to continue increasing due to growing populations, changing consumer preferences, urbanization, and industrialization, and an increasing need for cooling. Demand for energy is expected to increase by 2% a year through 2040 (Ersoy and Terrapon-Pfaff 2021). In the Gulf Cooperation Council (GCC) countries, electricity consumption has grown an average of 6-7% each year, with 70% of demand coming from air cooling (Hafner, Raimondi, and Bonometti 2023). Energy resources across Arab countries vary greatly. The Gulf countries have significant fossil fuel resources; in 2017 GCC countries made up 23% of global oil production and 10% of natural gas production (World Bank 2018). The economies of the GCC countries as well as Libya, Iraq, and Iran, are highly dependent on fossil fuel exports, with fossil fuels making up an average of half of their exports (World Bank Group 2022). In general, the region can be categorized into two sub-regions: the Gulf countries, plus Libya and Algeria, are net-hydrocarbon exporters with rich energy resources, and the western Mediterranean countries (other than Libya and Algeria) and eastern Mediterranean countries are net-hydrocarbon importers, who tend to be reliant on energy imports to meet demand. Natural gas has been associated mainly with Qatar, Iran, and Algeria, although it has gained relevance in Saudi Arabia where gas meets domestic energy demand, and Egypt, which has substituted oil production with gas production over the past two decades (Hafner, Raimondi, and Bonometti 2023).

Egypt is the second-largest natural gas producer in Africa and generates approximately 88% of its electricity from fossil fuels, with hydropower contributing about 7% (U.S. EIA 2024). Sudan's electricity profile differs markedly; approximately 60% of its electricity is generated by hydropower, with the Merowe Hydropower Plant (1,250 MW) serving as its largest generation asset (World Bank 2019). However, electricity access in Sudan remains low at approximately 32%, with rural and conflict-affected areas disproportionately underserved (World Bank 2019).

Electric systems in Arab countries are often regionally interconnected. The Maghreb countries (Morocco, Algeria, and Tunisia) share an electricity grid that also connects to Spain via Morocco. Similarly, the GCC countries have a regional power network enabling electricity exchange, while the EIJLLPST interconnection links Egypt, Iraq, Jordan, Libya, Lebanon, Palestine, Syria, and Turkey. These interconnected systems enable electricity transfer within and between Arab sub-regions, but actual trade remains limited. This is primarily due to constraints such as insufficient surplus generation capacity, technical and infrastructural bottlenecks, and regulatory or political challenges (ESMAP 2013). Despite these constraints, the existing grid infrastructure represents a foundation on which deeper energy cooperation and trade could be built.

The Horn of Africa countries of Somalia and Djibouti face distinct energy challenges. Somalia lacks a national electricity grid; generation capacity is predominantly privately owned and distributed through microgrids, with an estimated 62% of the population having access to electricity, though access in rural areas falls to approximately 39% (U.S. ITA 2024). Djibouti has achieved higher electricity access at approximately 65%, and imports a significant share of its electricity from Ethiopia (World Bank 2023; IRENA 2022). Both countries rely heavily on imported fuel for power generation and have limited domestic fossil fuel resources, positioning them as net energy importers with significant infrastructure development needs (IEA 2022). Table 2 summarizes energy resource characteristics across Arab sub-

Table 2

Energy Resource Characteristics Across the Arab Region

Sub-region	Net energy status	Primary energy resources	Regional electricity interconnection	Key energy challenges
Maghreb (Morocco, Algeria, Tunisia, Libya, Mauritania)	Mixed: Libya and Algeria are net exporters; others are net importers (Hafner et al. 2023)	Libya and Algeria: fossil fuel resources. Algeria: major natural gas producer. Others: reliant on energy imports (Hafner et al. 2023; World Bank Group 2022)	Shared electricity grid (Morocco, Algeria, Tunisia) connecting to Spain via Morocco (ESMAP 2013)	Net importers reliant on external energy supply; limited actual electricity trade despite grid interconnection (ESMAP 2013)
Mashreq (Iraq, Syria, Jordan, Lebanon, Palestine)	Mixed: Iraq is a net exporter; others are net importers (Hafner et al. 2023)	Iraq: significant fossil fuel resources; fossil fuels make up roughly half of exports. Others: reliant on energy imports (World Bank Group 2022; Hafner et al. 2023)	EIJLLPST interconnection links Egypt, Iraq, Jordan, Libya, Lebanon, Palestine, Syria, and Turkey (ESMAP 2013)	Net importers face energy supply vulnerability; insufficient surplus generation capacity; technical and infrastructural bottlenecks (ESMAP 2013)
Nile Basin (Egypt, Sudan)	Net importers (Hafner et al. 2023)	Egypt: second-largest natural gas producer in Africa; ~88% of electricity from fossil fuels, ~7% from hydropower (U.S. EIA 2024). Sudan: ~60% of electricity from hydropower; Merowe plant (1,250 MW) is largest asset (World Bank 2019)	Part of EIJLLPST interconnection (ESMAP 2013)	Egypt: growing gap between domestic gas supply and demand; substitution of oil with gas production (Hafner et al. 2023; U.S. EIA 2024). Sudan: electricity access ~32%; rural and conflict-affected areas underserved (World Bank 2019)
Arabian Peninsula (Saudi Arabia, UAE, Kuwait, Qatar, Bahrain, Oman, Yemen)	Net exporters (except Yemen) (Hafner et al. 2023; World Bank Group 2022)	Significant fossil fuel resources; GCC: 23% of global oil production, 10% of natural gas (2017). Qatar: major gas producer. Saudi Arabia: gas meets domestic demand (World Bank 2018; Hafner et al. 2023)	GCC regional power network enabling electricity exchange (ESMAP 2013)	Electricity consumption growing 6-7% per year; 70% of demand from air cooling. Economies highly dependent on fossil fuel exports (avg. half of total exports) (Hafner et al. 2023; World Bank Group 2022)
Horn of Africa (Somalia, Djibouti)	Net importers (IEA 2022)	Limited domestic fossil fuel resources; both countries rely heavily on imported fuel for power generation (IEA 2022)	Not part of a regional Arab electricity interconnection. Djibouti imports electricity from Ethiopia (World Bank 2023; IRENA 2022)	Somalia: no national grid; ~62% electricity access, ~39% in rural areas; generation via private microgrids (U.S. ITA 2024). Djibouti: ~65% electricity access; significant infrastructure development needs (World Bank 2023; IEA 2022)

Table 3

Food-Related Characteristics in the Arab Region

Sub-region	Countries	Agricultural land and crop conditions	Food self-sufficiency and imports dependency	Food security and nutrition	Key food system challenges
Maghreb	Morocco, Algeria, Tunisia, Libya, Mauritania	Higher percentages of agricultural land. Under a fifth of crop areas on arid or semi-arid land in Algeria, Tunisia, and Morocco. Mauritania: 100% of crops in arid or semi-arid regions (IFPRI 2018)	High self-sufficiency ratios in wheat production compared to the rest of the Arab world. Most countries have >40% cereal import dependency (FAO et al. 2021; IFPRI 2018)	Tunisia: prevalence of undernourishment <2.5% (FAO et al. 2021)	Water scarcity constraining agricultural expansion; climate variability affecting rain-fed agriculture
Mashreq	Iraq, Syria, Jordan, Lebanon, Palestine	Lebanon: 60.7% agricultural land. Syria: 75.2% agricultural land. Under a fifth of crop areas on arid or semi-arid land in Lebanon, Syria, and Palestine (IFPRI 2018)	Low self-sufficiency ratios. >40% cereal import dependency in most countries (IFPRI 2018)	Iraq: prevalence of undernourishment >23.7% (FAO et al. 2021)	Low self-sufficiency despite relatively high agricultural land in some countries; dependency on cereal imports
Nile Basin	Egypt, Sudan	Egypt: 100% of crops in arid or semi-arid regions. Sudan: significant agricultural land (IFPRI 2018)	Sudan is the least import dependent, importing only 26% of cereal needs (IFPRI 2018)	Insufficient data for some indicators (FAO et al. 2021)	Egypt: agricultural production constrained by arid conditions despite Nile water. Sudan: relatively low import dependency but vulnerable to external shocks
Arabian Peninsula	Saudi Arabia, UAE, Kuwait, Qatar, Bahrain, Oman, Yemen	100% of crops in arid or semi-arid regions. Saudi Arabia: 69.2% agricultural land. Yemen: 44.6%. Rest of peninsula: <15% agricultural land (IFPRI 2018)	Low self-sufficiency ratios. >40% cereal import dependency. Food imports account for 13.6% of total merchandise imports regionally (IFPRI 2018)	Kuwait: prevalence of undernourishment <2.5%; food insecurity affects 12.3% (FAO et al. 2021)	High reliance on food imports despite low undernourishment; extreme water scarcity limits domestic production; high dependency on water-intensive cereal imports (IFPRI 2018)
Horn of Africa	Somalia, Djibouti	Djibouti: 100% of crops in arid or semi-arid regions. Both countries have >50% agricultural land (IFPRI 2018)	High dependency on food imports (IFPRI 2018)	Insufficient data for Somalia and Djibouti (FAO et al. 2021)	Unpredictable precipitation limits agricultural productivity; high food import dependency; limited data availability (Kandeel 2019)

regions, illustrating the distinction between net exporters and net importers.

3. 4. Food

Agricultural production and levels of local food production varies widely across the region. Due to the arid nature of many Arab countries, the prevalence of irrigated crops is high. In all Arabian Peninsula countries, as well as Egypt, Mauritania, and Djibouti, 100% of crops are grown in arid or semi-arid regions. In contrast, under a fifth of crop areas are on arid or semi-arid land in Lebanon, Algeria, Tunisia, Syria, Morocco, and Palestine (IFPRI 2018). These contexts are reflected in Arab countries' food self-sufficiency; the Maghreb countries have higher percentages of agricultural land and high self-sufficiency ratios

in wheat production compared to much of the rest of the Arab world (FAO et al. 2021; IFPRI 2018). In contrast, much of the Mashreq and Arabian Peninsula have low self-sufficiency ratios. Although Saudi Arabia and Yemen have high percentages of agricultural land—69.2% and 44.6% respectively—the rest of the peninsula countries have less than 15% agricultural land. Lebanon and Syria also have high percentages of agricultural land at 60.7% and 75.2% respectively. The Horn of Africa countries have more than 50% agricultural land (IFPRI 2018). This distinction highlights the significant variability in agricultural capacity and food production potential across the Arab region see Table 3.

Closely tied with agricultural challenges is the issue of the high dependency on food imports experienced by most of the region. This is especially true for cereals, which are dietary staples and require more water than other crops. Food imports in Arab countries account for 13.6% of total merchandise imports, making it one of the largest import bills in the world. Most countries have more than a 40% dependency rate on cereal imports. In contrast, Sudan is the least import dependent, only importing 26% of its cereal needs (IFPRI 2018).

Arab countries' diets also vary greatly. The prevalence of undernourishment in the Arab countries ranges from less than 2.5% in Kuwait and Tunisia to over 23.7% in Iraq. For many countries, there is not sufficient data to paint an accurate picture of undernourishment rates. Food insecurity also varies widely, affecting 12.3% of the population in Kuwait compared to 44.8% in Mauritania (FAO et al. 2021). These disparities illustrate how food security outcomes across the region are shaped by a combination of resource endowments, economic capacity, and exposure to external shocks, reinforcing the need for context-specific approaches to food system resilience.

3. 5. Water-Energy Interconnections

Water production utilizes significant energy resources in Arab countries. While some nations, such as Egypt, Sudan, and Morocco, benefit from surface water resources, others depend heavily on energy-intensive methods like desalination and groundwater pumping (Vereinte Nationen 2015). In the Gulf region, desalination and wastewater recycling are primary sources of water; for instance, desalination accounts for 30% of Bahrain's total energy use (Vereinte Nationen 2015; Hindiyeh, Albatayneh, and AlAmawi 2023). Despite advancements in desalination, most Gulf countries, except Kuwait and Qatar, continue to rely heavily on unsustainable groundwater withdrawals to supplement their water supply (World Bank 2018).

Conversely, water resources play a critical role in energy production, supporting processes like fossil fuel extraction, nuclear power generation, and solar energy systems. In some cases, water directly contributes to energy supply, as seen in Egypt, Sudan, and Morocco, where significant surface water resources enable hydropower production. However, this option is far less feasible for most other countries in the region due to limited surface water availability (Alnaqbi et al. 2022).

3. 6. Water-Food Interconnections

The connection between water and food resources is evident, as agricultural irrigation constitutes the largest use of water in most countries in the region. Other than Lebanon and Bahrain, the majority of countries in the region allocate 50% or more of their water withdrawals to agriculture.

In some cases, such as Syria, Libya, and Sudan over 90% of water withdrawals are dedicated to agricultural purposes (World Bank 2020a).

A common feature connecting water and food in Arab Countries is the widespread focus on achieving self-sufficiency. Although water scarcity is common throughout the region, water tariffs are low and water often subsidized, in part to encourage domestic food supply (Vereinte Nationen 2015). Another related feature of the region that affects water use is the makeup of crops; about 60% of harvested land produces cereals, which require more water and are less valuable than other horticulture crops. Sudan, Yemen, Iraq, Iran, Morocco, and Syria all produce over 50% cereals despite scarce water resources (OECD and FAO 2018). This trend stems largely from 1970s policies, when political concerns led to a focus on food self-sufficiency and expanded agricultural production. Saudi Arabia is a key example; during the 1980s wheat production was encouraged to enhance food security, to the point that Saudi Arabia was a net wheat exporter in the 1990s (Vereinte Nationen 2015). In the late 1990s, policymakers noted the effects of wheat cultivation on non-renewable groundwater and sought to reduce the impacts by decreasing fixed wheat commodity prices and reducing subsidies. In response, farmers initially switched to fodder production, which required even more water. Following a policy in 2008, Saudi Arabia has almost entirely switched to alternative production activities, including greenhouse farming or fruit and vegetable production with drip irrigation (OECD and FAO 2018; Vereinte Nationen 2015).

3. 7. Energy-Food Interconnections

Energy and food systems in the region are deeply interconnected through the energy demands of irrigation, water pumping for irrigation, fertilizer production, food processing, and transportation. In countries like Egypt, Jordan, Lebanon, Morocco, and Tunisia, land productivity has improved, with rising cereal yields in Egypt, Morocco, and Tunisia linked to expanded irrigated areas. This trend indicates an increase in energy usage dedicated to agriculture in these countries. Implementing energy-efficient practices in rural and small-scale farms faces difficulties. Rural areas must navigate a diverse range of local conditions, which makes it difficult to implement standardized solutions. The cost of new energy-efficient technologies, the lack of local financial market instruments designed for farmers, and the appeal of existing fossil fuel-based technologies create additional challenges for sustainable energy technology adoption (ESCWA 2017).

Arab countries make up a significant portion of fertilizer usage and production. Qatar especially uses more nitrogen, phosphorus, and potassium fertilizer than the rest of the region, consuming 10,000 Kg/Ha. Jordan consumes the next highest amount at 1,000 Kg/Ha. Additionally, Jordan, Morocco, and Tunisia account for a significant portion of fertilizer exports. Energy consumption makes up 70% of the cost of manufacturing fertilizers, and overuse of fertilizers leads to land degradation and water pollution (Vereinte Nationen 2015). Moreover, advances in irrigation, including solar irrigation technologies and low-energy drip irrigation technologies are making progress toward decreasing the energy used for food, and many strategies across the region have focused on increasing energy efficiency, rather than decreasing usage (Hindiyeh, Albatayneh, and AlAmawi 2023). Agricultural residues and municipal solid waste also represent an emerging, though largely underutilized, source of bioenergy

Table 4

Resource System Interconnections

Nexus interconnection	Direction of dependency	Key linkages	Regional examples	Quantitative indicators	Sources
Water-Energy	Water production requires energy	Desalination of seawater; groundwater pumping; wastewater treatment and recycling	Gulf region: desalination and wastewater recycling are primary water sources. Bahrain: desalination accounts for 30% of total energy use. Most Gulf countries also rely on unsustainable groundwater withdrawals	Desalination = 30% of Bahrain's total energy use. MENA has ~46% of global desalination capacity; two-thirds produced by fossil-fueled thermal desalination	Vereinte Nationen 2015; Hindiyeh et al. 2023; World Bank 2018; Maftouh et al. 2022; De Waal et al. 2023
	Energy production requires water	Hydropower generation; water for fossil fuel extraction and refining; cooling for thermal power plants	Egypt, Sudan, and Morocco: surface water resources enable hydropower production. Hydropower is far less feasible for most other countries due to limited surface water availability	Globally, ~14% of water withdrawals go toward energy production	Alnaqbi et al. 2022; UN Water 2024
Water-Food	Food production requires water	• Agricultural irrigation • Livestock watering • Food processing	• Most countries allocate >50% of water withdrawals to agriculture (except • Lebanon and Bahrain) Syria, Libya, Sudan: >90% of withdrawals for agriculture • ~60% of harvested land produces water-intensive cereals	• Agriculture uses 83% of regional water • withdrawals >90% in Syria, Libya, and Sudan	World Bank 2020a; De Waal et al. 2023; OECD and FAO 2018
	Food and water policies shape resource use	• Subsidized water tariffs encourage agricultural water use • Crop selection policies affect water demand • Food self-sufficiency goals drive water-intensive production	• Saudi Arabia: 1980s wheat self-sufficiency policy depleted non- renewable groundwater • Farmers initially switched to more water-intensive fodder production • Post-2008 policy shifted to greenhouse farming and drip irrigation	• Cereal import dependency rose 10% despite 50% production increase (1990-2011) • Water tariffs are low and often subsidized across the region	Vereinte Nationen 2015; OECD and FAO 2018
Energy-Food	Food production requires energy	• Irrigation pumping • Fertilizer manufacturing • Food processing and transportation • Mechanized agriculture	• Egypt, Morocco, Tunisia: rising cereal yields linked to expanded irrigated areas, indicating increased energy use in agriculture • Jordan, Morocco, Tunisia: significant fertilizer exporters	• Energy = 70% of fertilizer manufacturing cost • Qatar: 10,000 Kg/Ha NPK fertilizer per hectare of cultivated land • Jordan: 1,000 Kg/Ha	Vereinte Nationen 201115; ESCWA 2017

Nexus interconnection	Direction of dependency	Key linkages	Regional examples	Quantitative indicators	Sources
	Agricultural biomass as energy source	Crop residues and livestock manure converted to biogas, heat, and electricity; municipal solid waste-to-energy pathways	Biomass by-products from agri-food activities can be used to produce energy for processing, storage, and cooking. The potential for bioenergy from agricultural residues in the region remains largely underutilized	Agri-food systems consume ~30% of globally available energy	IRENA and FAO 2021

in the region. Biomass by-products from agri-food activities, including crop residues and livestock manure, can be converted to biogas, heat, and electricity (IRENA and FAO 2021). While the potential for bioenergy from agricultural residues in the Arab region remains largely underutilized, scaling up these pathways will require addressing challenges common to bioenergy development in arid and semi-arid contexts, including waste collection logistics, competing uses for agricultural residues, and the need for supportive regulatory frameworks (IRENA and FAO 2021) Table 4 summarizes the water-energy, water-food, and energy-food interconnections discussed above.

4. Socio-Economic Factors and Regional Distinctions

While the biophysical interconnections between water, energy, and food systems reflect some of the critical resource challenges in Arab countries, it is equally important to consider the socio-economic factors that shape and intensify these dynamics. Socio-economic conditions—such as population growth, urbanization, economic development, and governance structures—not only influence resource demand but also contribute to regional distinctions in how these resources are managed and utilized. The following section explores these socio-economic factors and illustrates their contributing role to the complexities of WEF Nexus management across the Arab region.

4.1. Demographic Features

A variety of socio-economic factors impact how Arab countries use their resources and what challenges they face. The GDP per capita across the region typically reflects energy resources, with the highest GDPs per capita in the Gulf countries. Qatar has the highest GDP per capita at 71,568 USD per capita in 2023. Kuwait, the United Arab Emirates, and Saudi Arabia follow, with between 30 and 50 thousand USD per capita. The lowest GDPs per capita are found in Yemen and the Horn of Africa, and many conflict-afflicted countries do not have recent data available (IMF 2024).

When considering the future of Arab countries, the makeup of youth in the region is significant. People under 30 years of age make up 55% of the population across the MENA region, and youth unemployment rates are higher than most other regions (OECD 2022). Youth populations range from around 75% in Yemen, Mauritania, Palestine, and Iraq to around 40% in the United Arab Emirates, Bahrain, Qatar, and Kuwait. While youth unemployment remains a pressing issue, particularly for young women—79% of whom report a lack of job opportunities (ASDA'A BCW 2021) —some Gulf countries stand out with unemployment rates below 10% (OECD 2022).

In contrast with other world regions, over 30% of unemployed people in the MENA region have a university degree (Kabbani 2019). One reason for this disconnect may be that traditional curricula lack many of the skills and literacies that are necessary for changing work fields. 87% of young Arabs are concerned about the quality of their education (ASDA'A BCW 2023). A survey on youth engagement in water-related sectors found gaps in technical skills, including those in spatial analysis, big data analysis, IoT technologies, digital literacy, and technical writing, were impeding youth from entering water-related sectors (Abadi, Blodgett, and Daher 2023). Bridging the gap between educational outcomes and labor market needs could empower youth across the region to contribute meaningfully to sustainable resource management and to addressing water-energy-food nexus challenges.

In addition to unemployment and educational challenges, migration and conflict profoundly impact resource utilization and management in Arab countries. The region has experienced significant displacement due to conflicts in Syria, Yemen, Libya, and Iraq, leading to large numbers of refugees and internally displaced persons. Host countries like Jordan and Lebanon face increased demands on their water, energy, and food systems, intensifying existing resource strains. For instance, the influx of refugees in Jordan has escalated water consumption, exacerbated the nation's water scarcity and increasing reliance on energy-intensive water production methods.

4. 2. Economic Structures

Economic structures, such as subsidies and tariffs, play a large role in incentivizing resource usage patterns and priorities. It is common for water costs to be low and highly subsidized for agriculture in Arab countries, and as a result there is little incentive to use water economically (Vereinte Nationen 2015). Additionally, the energy used to pump water and irrigate crops generates income, which creates little incentive for energy ministries and utility companies to make energy usage more efficient or decrease energy spent toward water. Furthermore, energy for groundwater pumping is also often subsidized (Vereinte Nationen 2015). In Tunisia, for example, energy subsidies have historically made up to 20% of the public budget, and a survey of 45 water supply and sanitation utility companies across the region found that 41 of them have been unable to consistently cover basic operational costs from customer tariffs (Ersoy and Terrapon-Pfaff 2021; De Waal et al. 2023).

4. 3. Governance Structures

In additional to demographic factors, governance structures impact how resources are managed in Arab countries. Historically, many countries in the region have maintained separate ministries for water, energy, and agriculture, leading to siloed approaches that often overlook the interconnections between these sectors. This disjointed management structure can result in conflicting policies, inefficiencies, and missed opportunities for integrated resource management. For example, water used for agriculture might be subsidized heavily, while energy policies may inadvertently encourage inefficient groundwater pumping, exacerbating resource depletion. More recently the interconnections between these resource systems are being brought to the forefront of governance structures. Several Gulf countries, including Bahrain, Kuwait, Qatar, and the United Arabic Emirates (UAE), have integrated their energy

and water governing entities into a single ministry, primarily because the production of desalinated water heavily involves energy management. Similarly, these countries also have integrated state-owned water and electricity production enterprises (De Waal et al. 2023). This integration is useful for managing desalination but also encourages water and energy efficiency during groundwater pumping, irrigation, and in utility infrastructure. Countries with significant agricultural output and water scarcity, have typically formed a single ministry responsible for both water and agriculture, and Saudi Arabia restructured to create one ministry of environment, water, agriculture (De Waal et al. 2023). The Ministry of Environment, Water, and Agriculture (MEWA) in Saudi Arabia exemplifies the country's efforts to adopt integrated governance structures to address interconnected water, energy, and food challenges. Established in 2016, MEWA consolidated responsibilities for water, agriculture, and environmental management under a single ministry, reflecting a systems-thinking approach to resource governance. Through initiatives like the National Transformation Program, MEWA has focused on sustainable water supply, efficient agricultural practices, and addressing food security risks. Notably, the ministry launched a Water Rationalization Program in 2019, aiming to reduce Saudi Arabia's high per capita water consumption by 43% by 2030 through public campaigns and the distribution of water-saving tools. MEWA's integrated approach underscores the importance of cohesive governance in advancing WEF Nexus objectives and enhancing sustainability in resource management.

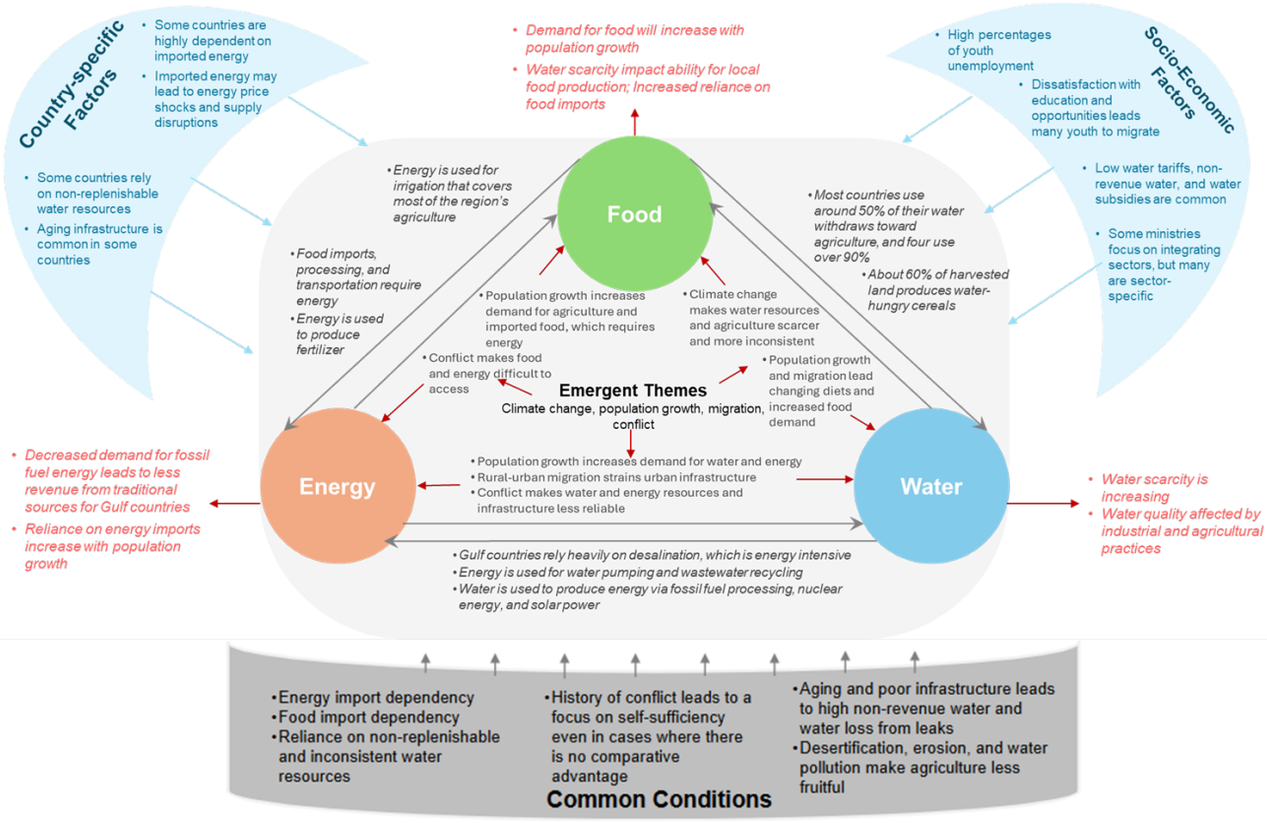
5. Emergent Themes Affecting WEF Nexus Security

Water-Energy-Food Nexus security in the Arab region is increasingly shaped by a set of critical and interrelated emergent themes. These themes, including climate change, population growth and migration, and conflict, are creating new layers of complexity for resource management and security. Each of these factors not only exacerbates existing challenges but also introduces unique pressures that vary across sub-regions, influencing the dynamics of water, energy, and food systems in distinct ways Figure 1.

5. 1. Climate Change

Water-energy-food nexus security across Arab countries is shaped by several emerging themes. These themes will influence future resource security and affect country-specific contexts. One of the themes with the most over-arching influences is climate change. Temperatures of 56˚ C would be common if global temperatures increase to 4˚ C average above pre-industrial temperatures, with summer temperatures in parts of Algeria, Saudi Arabia, and Iraq increasing by up to 8˚ C on average (Ezzeldin, Adshead, and Smith 2023). These higher temperatures will worsen desertification, drought, and water evapotranspiration (World Bank 2018). Climate change will also have more intensive effects on cities due to the urban heat island effect, which causes cities to have temperatures that are 2-3˚C higher than the surrounding areas. This will exacerbate the already growing energy demand for cooling units (Lange 2019). Higher temperatures also make the region more at risk of wildfires. In Lebanon and Syria, hundreds of wildfires have already impacted residential areas, leading to evacuations and displacements (Ezzeldin, Adshead, and Smith 2023). The MENA region is predicted to lose 75% of its freshwater availability in a 4˚ C world. Precipitation variability is expected to affect

Figure 1
Emergent Themes and the WEF Nexus in Arab Countries



Note. Developed by the authors.

the Mediterranean coasts and Arabian Peninsula, which will have substantial effects on agriculture (World Bank Group 2022). Climate change will have different effects on different sub-regions. In the Maghreb, aridity and drought will increase water stress and decrease agricultural productivity, which will affect farmers' livelihoods, national economies, and food security. This may lead to increased rural-urban migration and socio-economic tensions. Similarly, the Mashreq region will also see unusual heat and less precipitation, as well as decreased river runoffs from upstream now water. This will also lead to a decrease in rain-fed agriculture and have negative effects on farmers' livelihoods, national economies, and food security, and leading to the possibility of rural-urban migration and increased socio-economic tensions. In the Arabian Peninsula, extreme heat and increased precipitation inconsistencies will lead to extreme weather. This area may also be challenged by a global decline in demand for fossil oil as renewable energy becomes more common (Ezzeldin, Adshead, and Smith 2023).

5. 2. Population Growth and Migration

Another emergent theme that intersects with water-energy-food nexus security are the increasing population sizes and shifts in migration patterns. The MENA region's population is expected to double by 2050, which will exacerbate

resource demand and demand for employment. Population growth is especially high in the oil-rich countries. These countries have both high birth rates, which are supported by oil wealth, and high immigration rates leading to a large expatriate population. (IFPRI 2018). Migration within and out of the region will also create new challenges; about half of youth in Levant and North African countries want to emigrate, primarily due to lack of job opportunities, economic instability, and conflict. In contrast, less than a third of youth in Gulf countries say they are considering moving abroad (ASDA'A BCW 2023). Refugee influxes also present significant and sudden population shifts that can strain existing resources. These current sentiments suggest future migration flows will continue to be uneven across the region, with many moving toward the Gulf countries. In the UAE, for example, the relatively small national population does have a high growth rate, but much of recent population growth has come from immigration from other countries in the region. This trend is likely to continue due to the UAE's foundational oil wealth (IFPRI 2018). Internal migration from rural to urban areas has also grown considerably and is expected to continue to grow—the region's urban population is expected to double by 2050 to nearly 400 million (World Bank 2018). Often, rural-urban migration will be triggered by worsening returns on traditional agricultural labor or the desire for better jobs (IFPRI 2018). Urbanization continues to increase resource demand in cities; increased urbanization leads to increased water and energy demand in urban areas. Additionally, the shift to urban areas often leads to dietary changes away from traditional whole foods and toward processed foods and animal proteins. These foods tend to require more water, leading to additional strain on water resources (FAO et al. 2021).

5. 3. Conflict

Conflict, both past and ongoing, has a strong influence on resource availability and management. In many cases, the distinction between conflict and non-conflict countries is directly tied to resource outcomes. For instance, non-conflict countries are generally food secure, while conflict-afflicted countries have less food security than the average of least developed countries. In general, agriculture is one of the more resilient industries amidst conflict, but increasing fuel prices, decreasing labor availability, and inconsistent governmental structure negatively impact agricultural production (OECD and FAO 2018). Furthermore, conflict often directly affects agriculture by destroying crops, harming farmers, or driving farmers away from conflict areas (Carnegie Endowment for International Peace 2015). Conflict can damage infrastructure and halt trade, limiting water and energy resources. In Lebanon, which is experiencing spill-over conflict as well as political fragility, water and energy supplies are sporadic and inconsistent due to failing utility infrastructure and the disruption of traditional fuel supplies from Syria (World Bank Group 2022; Daher et al. 2022).

6. Toward Evidence-Based Decision-Making: Review of Existing Tools and Gaps in Nexus Analytics

A growing body of literature and community of researchers has emerged over the past decade, catalyzed by the Bonn Conference and Word Economic Forum report mentioned in the introduction. A large portion of this research

community has focused on a critical gap which is the lack of tools available to decision makers that can guide evidence-based policy making. This resulted in the emergence of several WEF nexus tools, with varying levels of accessibility, applicability, and complexity. One analysis found that out of 46 tools surveyed, less than half were available to public users, and most tools are only applicable at one scale (global, regional, country, or local), making them less useful for policy makers trying to explore WEF nexus resources and evaluate policies across different spaces. Less than a third of the 46 tools possess geospatial capabilities, and less than half of those had hard-linked GIS integration (Taguta et al. 2022). Given these limitations, there is a need for tools that can be more context-specific, customizable, and accessible. This is particularly critical in Arab countries, where adaptation of tools developed within other contexts is necessary.

Another analysis found that integration tools best suited for modeling complex WEF nexus interactions often lack capacity-building and guideline components. Furthermore, most tools focus on inter-sectoral trade-off quantification rather than risk assessment. Inclusion of both complex modeling and more fundamental capacity building and education aspects of WEF nexus analysis could make these tools more accessible and useful for policy makers, since integration tools require granular data and trained analysts to ensure proper application (Dargin, Daher, and Mohtar 2019). The gap between tools with conceptual and approachable features and tools with complex but tailorable analyses highlights the need for tools that can be both specific and accessible to policymakers and practitioners.

Additionally, the social and economic dimensions of the WEF nexus often pose significant challenges for data collection and application. Some WEF nexus models attempt to address these challenges by integrating interdisciplinary and mixed methods approaches. Ultimately, many studies have highlighted the benefit of collaborative research, qualitative analysis, and participatory approaches to capture context-specific factors, but few WEF tools have been developed with socio-economic factors in mind (Albrecht, Crootof, and Scott 2018).

Useful WEF nexus tools exist, but more work needs to be done to customize these tools and make them applicable to Arab countries. Data collection at the local and country level is necessary to capture specific contexts and create detailed policies. Furthermore, additional work to educate policymakers and practitioners on existing tools and their applications would be facilitated by the development of tools that include capacity building, risk-assessment, and guideline components, in addition to the complex data analyses.

7. Discussion

Climate change is a defining challenge of our time, with a profound impact on countries' security. It is a crisis and threat multiplier. It can exacerbate conflict, fragility and geopolitical competition. Increasing temperatures cause rising sea levels, wildfires and more frequent and extreme weather events, disrupting our societies, undermining security and threatening people's lives and livelihoods. Moreover, as of 2010, the Middle East witnessed a surge in armed conflicts (Syria, Libya, Yemen) that have led to increased refugee flows and consequently exerted significant pressures on already fragile resource systems, especially in the developing countries in the region.

This review reveals several key patterns across the Arab region that respond to the

research questions guiding this analysis. First, the examination of water, energy, and food systems across sub-regions demonstrates that resource challenges are not uniform. Maghreb countries face climate-driven water variability in rainfall-dependent systems, Mashreq countries face transboundary dependency and resource competition over shared basins, Nile Basin countries depend heavily on externally generated water, Gulf countries face the paradox of energy abundance alongside extreme water and food scarcity, and Horn of Africa countries face infrastructure deficits across all three sectors. These distinctions underscore that region-wide policy prescriptions are insufficient; effective interventions must be tailored to sub-regional and national contexts (World Bank 2018; Kandeel 2019).

Second, the interconnection analysis (Sections 1.4-1.6) reveals that bidirectional dependencies between sectors create reinforcing vulnerabilities. The Saudi Arabia case, where food self-sufficiency policies of the 1980s drove non-renewable groundwater depletion over decades before policy correction, illustrates how well-intentioned sector-specific interventions can generate cascading unintended consequences across the nexus (Vereinte Nationen 2015; OECD and FAO 2018). Similarly, the region's reliance on fossil-fueled desalination ties water security directly to energy markets, creating compounding risks when either system is disrupted (Maftouh et al. 2022).

Third, emergent themes (Section IV) do not affect sub-regions equally. Climate change most threatens rain-fed agricultural systems in the Maghreb and Mashreq, while population growth and urbanization are placing particular pressure on Gulf countries with high immigration rates and rapidly growing cooling demands (Ezzeldin, Adshead, and Smith 2023; Hafner, Raimondi, and Bonometti 2023). Conflict has disproportionately affected food security and infrastructure in the Mashreq, with spillover effects on neighboring host countries such as Jordan and Lebanon (World Bank Group 2022; Daher et al. 2022).

Multi-sectoral decision-makers lack the tools for quantifying the impact of growing climatic, demographic, natural disasters, and geopolitical shocks on these interconnected resource systems, and improving communities' resilience and regional security. Such tools would require a convergent approach, bringing different disciplinary experts to co-create multifaceted solutions that respond to the social, economic, technological, and policy dimensions of this grand challenge.

The review of existing WEF nexus tools identifies a fourth pattern: a persistent disconnect between the complexity of the tools available and their accessibility to the policymakers and practitioners who need them most (Taguta et al. 2022; Dargin, Daher, and Mohtar 2019). Most existing tools operate at a single scale, lack capacity-building components, and have not been adapted to the specific data environments and governance structures of Arab countries. Addressing this gap requires not only technical development but also what has been termed "simplexity," the art and science of translating complexity into actionable insight without losing the nuance that context-specific decision-making demands (Daher 2025). For the Arab region, this means developing tools that can capture the interconnections between water, energy, and food systems while remaining accessible to decision-makers operating within diverse institutional, economic, and data-availability contexts. As this review has shown, the region

spans a wide spectrum of governance maturity, from countries with integrated WEF ministries such as Saudi Arabia's MEWA to countries with fragmented or conflict-disrupted institutional structures (De Waal et al. 2023). Tools designed for data-rich environments with strong institutional capacity may be unusable in contexts where data collection infrastructure is limited or where governance structures are in flux. A simplexity-oriented approach would prioritize tools that can operate across this spectrum: capable of integrating granular, multi-sectoral data where it exists, while still generating actionable insights from incomplete or aggregated data where it does not.

Equally important is recognizing that sustainability priorities and the metrics used to assess them are not uniform across the region. For a Gulf country managing desalination-dependent water supply, the critical nexus metric may be the energy intensity of water production; for a Mashreq country navigating transboundary water competition, it may be the reliability of upstream flows and their implications for irrigated agriculture; for a Horn of Africa country with limited infrastructure, it may be basic access to electricity and water services (Kandeel 2019; World Bank 2018). These differing priorities shape what counts as progress and what trade-offs are acceptable, which means that tools and the indicators they employ must be co-created with the stakeholders and communities who will use them and be affected by their outputs (Daher 2025). The co-creation process ensures that tools reflect local definitions of resource security and sustainability, and it builds the cross-sectoral relationships and shared understanding among water, energy, and food actors that are prerequisites for integrated governance. Without this participatory foundation, even technically sophisticated tools risk producing outputs that are misaligned with decision-makers' actual priorities, or that fail to account for the socio-economic and political realities that shape how resources are managed in practice (Albrecht, Crootof, and Scott 2018).

There is also a need for capacity building to develop and customize such tools. Applying WEF nexus thinking will create new roles and opportunities and require new skills for those in existing roles. The WEF tools that can accomplish complex analysis of resources and socio-economic factors require proficiency with data collection, data science, and spatial data analysis. Aligning education and training opportunities with the need for WEF nexus and systems-oriented data analysis can yield great benefits for the substantial unemployed youth population in the region, especially given the demand for education and job opportunities. Furthermore, capacity building is also necessary for practitioners and policymakers to understand how to use WEF nexus tools and how to apply results. From a more holistic perspective, capacity building is necessary to develop and foster a common systems-thinking understanding throughout the region with the public and those that work in water, energy, and food sector security.

Resilience through regional integration and cooperation

The Arab region's diverse resource endowments and socio-economic contexts present significant opportunities for collaboration and regional integration to address Water-Energy-Food Nexus challenges. Some countries have taken a proactive lead in renewable energy development, such as Morocco, which plays a leading role in solar and wind energy, and the United Arab Emirates, which has invested heavily in solar power infrastructure.

Others, like Egypt, benefit from hydropower resources through the Nile River, while Gulf nations like Saudi Arabia and the UAE have integrated energy and water ministries to better manage desalination and energy-intensive water production. The Gulf countries, have water scarcity and rely on imported food, but have knowledge and experience with desalination and integrated water-energy-food ministries (Vereinte Nationen 2015). Egypt and Sudan, and to a lesser extent Morocco, have experience with hydroelectricity (Alnaqbi et al. 2022). Lebanon, Syria, and the Horn of Africa countries have comparative advantages in agriculture with less arid land than the rest of the region (IFPRI 2018). Morocco, Egypt, and Tunisia have some of the highest wind speeds in the world and therefore have high potential for wind energy (World Bank Group 2022). Agricultural capacity also varies across the region; countries like Sudan and Morocco have relatively high arable land and agricultural productivity, while others, such as the Gulf states, rely on advanced irrigation technologies and greenhouse farming to mitigate water scarcity.

Regional integration and cooperation offer a pathway to leverage these comparative advantages. Understanding the diversity of Arab countries is the first step to identifying opportunities for cooperation. Arab countries have a wide array of strengths and weaknesses, ranging from natural resources, economics, and knowledge. This diversity has the potential to be a source of strength for the region. For example, electricity trade can capitalize on countries with abundant renewable energy potential, such as wind power in Morocco and hydropower in Egypt and Sudan, enabling energy diversification across the region. Bi- and multilateral agreements could also facilitate resource-sharing mechanisms, reduce pressures on individual nations, and enhance collective resilience. Addressing WEF nexus challenges through regional, bilateral, and multilateral agreements can help alleviate pressures facing countries and can allow the region to benefit from the comparative advantage each country has.

8. Conclusion

The WEF Nexus framework holds significant potential for addressing resource challenges in Arab countries. While the region faces shared issues such as water scarcity, reliance on imports, and transitions in energy sources, each country possesses unique strengths and vulnerabilities. The complexities introduced by climate change, population growth, migration, and existing economic policies further underscore the need for nuanced and targeted solutions. WEF Nexus tools can provide valuable insights by analyzing resources, evaluating policies, and developing intentional strategies tailored to individual contexts. However, effectively utilizing these tools requires capacity building for youth entering the workforce, practitioners, and policymakers, as well as the establishment of integrated governance structures that embrace systems thinking. Furthermore, WEF Nexus analysis can identify opportunities for regional, bilateral, and multilateral agreements to share knowledge, foster collaboration, and leverage the comparative advantages of each country. Through these avenues, the diversity of Arab countries can be harnessed to create more resilient and sustainable water, energy, and food systems.

This review makes three specific contributions to the literature on WEF nexus security in the Arab region. First, by structuring the analysis

around sub-regional groupings, it moves beyond individual country case studies to reveal patterns in how resource challenges, vulnerabilities, and management approaches differ across the Maghreb, Mashreq, Nile Basin, Arabian Peninsula, and Horn of Africa. Second, by documenting the bidirectional nature of WEF interconnections and the cascading effects of sector-specific policies, it demonstrates that effective resource governance in the region requires integrated, cross-sectoral approaches that anticipate unintended consequences. Third, by mapping the diversity of resource endowments, governance structures, and emergent pressures, it identifies concrete opportunities for regional cooperation that leverage each sub-region's comparative advantages. Translating these insights into action will require embracing simplexity: distilling the complexity of interconnected resource systems into clear, context-specific, and actionable strategies that empower decision-makers across the region (Daher 2025).

Addressing these interconnected challenges requires adopting a comprehensive systems approach that recognizes the interdependencies across water, energy, and food sectors. Such an approach moves beyond siloed solutions, emphasizing the need to balance trade-offs, anticipate cascading impacts, and design integrated policies that enhance resilience across sectors. Without this paradigm shift, efforts to address individual challenges risk undermining progress in others. The WEF Nexus framework provides the foundation for this transformation, offering the tools and methodologies needed to enable holistic, cross-sectoral strategies that ensure sustainable development in the face of mounting complexities.

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Conflicts of Interest

The authors declare no conflicts of interest.

References

Abadi, A, L Blodgett, and Bassel Daher. 2023. "Union for the Mediterranean Water and Youth Engagement Strategy 2023-2028." UfM. https://ufmsecretariat.org/wp-content/uploads/2023/03/UfMWaterYouthStrategy_2023.pdf.

Albrecht, Tamee R, Arica Crootof, and Christopher A Scott. 2018. "The Water-Energy-Food Nexus: A Systematic Review of Methods for Nexus Assessment." *Environmental Research Letters* 13 (4): 043002. https://doi.org/10.1088/1748-9326/aaa9c6.

Alnaqbi, Shaima, Shamma Alasad, Haya Aljaghoub, Abdul Alami, Mohammad Abdelkareem, and Abdul Olabi. 2022. "Applicability of Hydropower Generation and Pumped Hydro Energy Storage in the Middle East and North Africa." *Energies* 15 (7): 2412. https://doi.org/10.3390/en15072412.

ASDA'A BCW. 2021. "Arab Youth Survey 2021: Hope for the Future." ASDA'A BCW. https://arabyouthsurvey.com/wp-content/uploads/whitepaper/AYS-2021-WP_English-14-Oct-21-ABS-FINAL.pdf.

———. 2023. "Arab Youth Survey 2023: Living a New Reality." ASDA'A BCW. https://arabyouthsurvey.com/wp-content/uploads/whitepaper/AYS-2023-Whitepaper_English.pdf.

Avellán, Tamara, Mario Roidt, Adam Emmer, Janis

Von Koerber, Petra Schneider, and Wolf Raber. 2017. "Making the Water–Soil–Waste Nexus Work: Framing the Boundaries of Resource Flows." Sustainability 9 (10): 1881. https://doi.org/10.3390/su9101881.

Bazilian, Morgan, Holger Rogner, Mark Howells, Sebastian Hermann, Douglas Arent, Dolf Gielen, Pasquale Steduto, et al. 2011. "Considering the Energy, Water and Food Nexus: Towards an Integrated Modelling Approach." *Energy Policy* 39 (12): 7896–7906. https://doi.org/10.1016/j.enpol.2011.09.039.

Carnegie Endowment for International Peace. 2015. "Food Insecurity in War-Torn Syria: From Decades of Self-Sufficiency to Food Dependence." Carnegie Endowment for International Peace. June 4, 2015. https://carnegieendowment.org/research/2015/06/food-insecurity-in-war-torn-syria-from-decades-of-self-sufficiency-to-food-dependence?lang=en.

Daher, Bassel. 2025. "Simplexifying Sustainability." Nature Sustainability. https://doi.org/10.1038/s41893-025-01650-5

Daher, Bassel, Silva Hamie, Konstantinos Pappas, Mohammad Nahidul Karim, and Tessa Thomas. 2021. "Toward Resilient Water-Energy-Food Systems under Shocks: Understanding the Impact of Migration, Pandemics, and Natural Disasters." *Sustainability* 13 (16): 9402. https://doi.org/10.3390/su13169402.

Daher, Bassel, Silva Hamie, Konstantinos Pappas, and Julie Roth. 2022. "Examining Lebanon's Resilience Through a Water-Energy-Food Nexus Lens." *Frontiers in Sustainable Food Systems* 6 (May):748343. https://doi.org/10.3389/fsufs.2022.748343.

Daher, Bassel, Rabi Mohtar, Efstratios Pistikopoulos, Kent Portney, Ronald Kaiser, and Walid Saad. 2018. "Developing Socio-Techno-Economic-Political (STEP) Solutions for Addressing Resource Nexus Hotspots." *Sustainability* 10 (2): 512. https://doi.org/10.3390/su10020512.

Dargin, Jennifer, Bassel Daher, and Rabi H. Mohtar. 2019. "Complexity versus Simplicity in Water Energy Food Nexus (WEF) Assessment Tools." *Science of The Total Environment* 650 (February):1566–75. https://doi.org/10.1016/j.scitotenv.2018.09.080.

De Waal, Dominick, Stuti Khemani, Andrea Barone, and Edoardo Borgomeo. 2023. *The Economics of Water Scarcity in the Middle East and North Africa: Institutional Solutions.* The World Bank. https://doi.org/10.1596/978-1-4648-1739-7.

Ersoy, Sibel Raquel, and Julia Terrapon-Pfaff. 2021. "Sustainable Transformation of Tunisia's Energy System: Development of a Phase Model." Climate Change, Energy and Environment. Friedrich Ebert Stiftung, Wuppertal Institut. https://library.fes.de/pdf-files/bueros/tunesien/18722.pdf.

ESCWA. 2017. "Arab Region Progress in Sustainable Energy Global Tracking Framework Regional Report." E/ESCWA/SDPD/2017/2. Beirut: United Nations Economic and Social Commission for Western Asia. http://www.unescwa.org/publications/arab-region-progress-sustainable-energy-global-tracking-framework-regional-report.

ESMAP. 2013. "Middle East and North Africa Integration of Electricity Networks in the Arab World Regional Market Structure and Design." ACS7124. Energy Sector Management Assistance Program. https://documents1.worldbank.org/curated/en/415281468059650302/pdf/ACS71240ES

W0WH0I0and0II000Final0PDF.pdf.

Ezzeldin, Khaled, Daniel Adshead, and Paul Smith. 2023. "Adapting to a New Climate in the MENA Region." UN Environment Programme. https://www.uncclearn.org/wp-content/uploads/library/Adapting-to-a-new-climate-MENA.pdf.

FAO, IFAD, UNICEF, WFP, WHO, and ESCWA. 2021. *Near East and North Africa Regional Overview of Food Security and Nutrition 2020 - Enchancing Resilience of Food Systems in the Arab States*. Cairo: FAO. https://doi.org/10.4060/cb4902en.

GIZ. 2019. "Evaluation Nexus: Interdépendances Des Secteurs de l'eau, de l'énergie et de l'alimentation En Tunisie." Nexus Dialogue Programme Dans La Région MENA. GIZ.

Global Water Partnership. 2020. "Nexus: Water, Food, Energy, and Ecosystems (WFEE)." Global Water Partnership. September 8, 2020. https://www.gwp.org/en/we-act/themesprogrammes/Nexus-ater-Food-Energy-Ecosystems/.

Hafner, Manfred, Pier Paolo Raimondi, and Benedetta Bonometti. 2023. "The MENA Region: An Economic, Energy, and Historical Context." In *The Energy Sector and Energy Geopolitics in the MENA Region at a Crossroad*, by Manfred Hafner, Pier Paolo Raimondi, and Benedetta Bonometti, 3–25. Perspectives on Development in the Middle East and North Africa (MENA) Region. Cham: Springer International Publishing. https://doi.org/10.1007/978-3-031-30705-8_1.

Hindiyeh, Muna, Aiman Albatayneh, and Rana AlAmawi. 2023. "Water Energy Food Nexus to Tackle Future Arab Countries Water Scarcity." *Air, Soil and Water Research* 16 (January):11786221231160906. https://doi.org/10.1177/11786221231160906.

Hogeboom, Rick J., Bas W. Borsje, Mekdelawit M. Deribe, Freek D. Van Der Meer, Seyedabdolhossein Mehvar, Markus A. Meyer, Gül Özerol, Arjen Y. Hoekstra, and Andy D. Nelson. 2021. "Resilience Meets the Water–Energy–Food Nexus: Mapping the Research Landscape." *Frontiers in Environmental Science* 9 (March):630395. https://doi.org/10.3389/fenvs.2021.630395.

Howells, Mark, Sebastian Hermann, Manuel Welsch, Morgan Bazilian, Rebecka Segerström, Thomas Alfstad, Dolf Gielen, et al. 2013. "Integrated Analysis of Climate Change, Land-Use, Energy and Water Strategies." *Nature Climate Change* 3 (7): 621–26. https://doi.org/10.1038/nclimate1789.

IEA. 2022. *Clean Energy Transitions in the Greater Horn of Africa*. International Energy Agency. https://www.iea.org/reports/clean-energy-transitions-in-the-greater-horn-of-africa.

IRENA. 2022. "Energy Profile: Djibouti." International Renewable Energy Agency. https://www.irena.org/-/media/Files/IRENA/Agency/Statistics/Statistical_Profiles/Africa/Djibouti_Africa_RE_SP.pdf

IFPRI. 2018. "Agriculture and Economic Transformation in the Middle East and North Africa: A Review of the Past with Lessons for the Future." 0 ed. Washington, DC: International Food Policy Research Institute. https://doi.org/10.2499/9780896292956.

IMF. 2024. "World Economic Outlook Database October 2024." International Monetary Fund. https://www.imf.org/en/Publications/WEO/weo-database/2024/October.

IRENA and FAO. 2021. *Renewable Energy and Agri-Food Systems: Advancing Energy and Food Security towards Sustainable*

Development Goals. IRENA and FAO. https://doi.org/10.4060/cb7433en.

Kabbani, Nader. 2019. "Youth Employment in the Middle East and North Africa: Revisiting and Reframing the Challenge." Brookings Institution.

Kandeel, Amal. 2019. "Freshwater Resources in the MENA Region: Risks and Opportunities." Middle East Institute. July 10, 2019. https://www.mei.edu/publications/freshwater-resources-mena-region-risks-and-opportunities.

Lange, Manfred A. 2019. "Impacts of Climate Change on the Eastern Mediterranean and the Middle East and North Africa Region and the Water–Energy Nexus." *Atmosphere* 10 (8): 455. https://doi.org/10.3390/atmos10080455.

Langenberg, Victor, Anne van der Heijden, Arjen de Vos, and Beatriz Gonzalez. 2021. "Status of Water Resources and Opportunities in Algeria, Morocco and Tunisia - Water in Agriculture in Three Maghreb Countries." MLNV. https://onagrihome.files.wordpress.com/2022/05/waterinagriculturemaghrebfinalreport.pdf.

Maftouh, A., O. El Fatni, M. Fayiah, R. K. Liew, S. S. Lam, T. Bahaj, and M. H. Butt. 2022. "The Application of Water–Energy Nexus in the Middle East and North Africa (MENA) Region: A Structured Review." *Applied Water Science* 12 (5): 83. https://doi.org/10.1007/s13201-022-01613-7.

Mendonca, Veera, Momo Duehring, Arthur van Diesen, Jan Beise, Sinae Lee, Anastasia Mshvidobadze, and Kanshen You. 2019. "MENA Generation 2030." UN0229230. UNICEF. https://www.unicef.org/mena/reports/mena-generation-2030.

Mohtar, Rabi H. 2017. "A Call for a New Business Model Valuing Water Use and Production: The Water, Energy and Food Nexus Holistic System Approach." *Water International* 42 (6): 773–76. https://doi.org/10.1080/02508060.2017.1353238.

MWI. 2023. "National Water Strategy 2023–2040." The Ministry of Water and Irrigation. https://www.mwi.gov.jo/EBV4.0/Root_Storage/AR/EB_List_Page/national_water_strategy_2023-2040.pdf.

Nexus. 2011. "Bonn2011 Nexus Conference // The Water, Energy and Food Security Nexus - Solutions for a Green Economy." Nexus - The Water, Energy & Food Security Resource Platform. November 18, 2011. https://www.water-energy-food.org/events/conference-the-water-energy-and-food-security-nexus-bonn2011-nexus-conference.

OECD. 2022. *Youth at the Centre of Government Action: A Review of the Middle East and North Africa.* OECD Public Governance Reviews. OECD. https://doi.org/10.1787/bcc2dd08-en.

OECD and FAO. 2018. *OECD-FAO Agricultural Outlook 2018-2027*. OECD-FAO Agricultural Outlook. OECD. https://doi.org/10.1787/agr_outlook-2018-en.

Rasul, Golam, and Bikash Sharma. 2016. "The Nexus Approach to Water–Energy–Food Security: An Option for Adaptation to Climate Change." *Climate Policy* 16 (6): 682–702. https://doi.org/10.1080/14693062.2015.1029865.

Rogers, Peter. 2017. "The Triangle: Energy, Water & Food Nexus for Sustainable Security in the Arab Middle East." In *Water, Energy & Food Sustainability in the Middle East,* edited by Sohail Murad, Elias Baydoun, and Nuhad Daghir, 21–43. Cham: Springer International Publishing. https://doi.org/10.1007/978-3-319-48920-9_2.

Siddiqi, Afreen, and Laura Diaz Anadon. 2011. "The

Water–Energy Nexus in Middle East and North Africa." *Energy Policy* 39 (8): 4529–40. https://doi.org/10.1016/j.enpol.2011.04.023.

Simpson, Gareth B., and Graham P. W. Jewitt. 2019. "The Development of the Water-Energy-Food Nexus as a Framework for Achieving Resource Security: A Review." *Frontiers in Environmental Science* 7 (February):8. https://doi.org/10.3389/fenvs.2019.00008.

Sims, Ralph E. H., and Oliver Dubois. 2011. "Energy-Smart Food for People and Climate - Issue Paper." Food and Agriculture Organization of the United Nations. https://openknowledge.fao.org/server/api/core/bitstreams/b9f2c018-1a88-429e-a1fe-d59d9c938b59/content.

Taguta, Cuthbert, Aidan Senzanje, Zolo Kiala, Mphatso Malota, and Tafadzwanashe Mabhaudhi. 2022. "Water-Energy-Food Nexus Tools in Theory and Practice: A Systematic Review." *Frontiers in Water* 4 (March):837316. https://doi.org/10.3389/frwa.2022.837316.

The World Economic Forum Water Initiative, ed. 2011. *Water Security: The Water-Food-Energy-Climate Nexus*. Washington, DC: World Economic Forum Springer e-books.

UN Water, ed. 2024. *Water for Prosperity and Peace.* The United Nations World Water Development Report 2024. Paris: UNESCO.

U.S. Energy Information Administration. 2024. "Country Analysis Brief: Egypt." U.S. EIA. https://www.eia.gov/international/content/analysis/countries_long/Egypt/.

U.S. International Trade Administration. 2024. "Somalia - Energy and Electricity." https://www.trade.gov/country-commercial-guides/somalia-energy-and-electricity.

Vereinte Nationen, ed. 2015. *The Water, Energy and Food Security Nexus in the Arab Region.* ESCWA Water Development Report 6. Beirut: United Nations.

World Bank. 2018. *Beyond Scarcity: Water Security in the Middle East and North Africa*. Washington, DC: World Bank. https://doi.org/10.1596/978-1-4648-1144-9.

———. 2020a. "Annual Freshwater Withdrawals, Agriculture (% of Total Freshwater Withdrawal) - World Bank Data." World Bank Open Data. 2020. https://data.worldbank.org.

———. 2020b. "World Bank Data - Renewable Internal Freshwater Resources per Capita." World Bank Open Data. 2020. https://data.worldbank.org/indicator/ER.H2O.INTR.PC?locations=ZQ-EG-PS-DZ-BH-DJ-IR-IQ-IL-JO-KW-LB-LY-MT-MA-OM-QA-SA-SY-TN-AE-YE.

World Bank Group. 2022. "Middle East & North Africa Climate Roadmap (2021-2025) - Driving Transformational ClimateAction and Green Recover in MENA." https://thedocs.worldbank.org/en/doc/6f868d4a875db3ef23ef1dc747fcf2ca-0280012022/original/MENA-Roadmap-Final-01-20.pdf.

World Bank. 2019. Diagnostic Review of Sudan's Electricity Sector. World Bank. https://openknowledge.worldbank.org/server/api/core/bitstreams/142c0f15-20d8-54e6-a92c-bfbdbccbaccb/content.