Water Security in a New World

Kamel Amer
Zafar Adeel
Benno Böer
Walid Saleh *Editors*

The Water, Energy, and Food Security Nexus in the Arab Region

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Chapter 7
Research and Development to Bridge the Knowledge Gap

Khaled AbuZeid

Abstract The Arab Region, among the driest regions in the world with less than 1.5 % of the world's renewable water resources, hosts more than 5 % of the world's population. It controls about 70 % of the world's fossil oil reserves. Water security, energy security, and food security can no longer be dealt with in isolation in the Arab Region. It may be the most relevant region to a Water-Energy-Food Nexus approach for development. Research and development on the Water-Energy-Food (WEF) Nexus, and the extensive analysis of the water, energy, and food security linkages, is needed to bridge the knowledge gap on their inter-dependencies. Bridging this knowledge gap is essential to assist in policy making related to water, food, and energy planning. This chapter presents some of the research and development results on key policy elements related to the WEF Nexus in the Arab Region. It presents some data and information on some key WEF indicators that could help further research and development on the topic. This chapter considers some of the linkages between water, energy, and food in the Arab Region, addressing research needs for better policy decisions in selecting the appropriate water resource, the appropriate water use, the appropriate water and energy savings measures, and the appropriate food export-import strategies. The WEF nexus is addressed through filling the knowledge gap on the externalities directly or indirectly affecting the WEF security, such as non-conventional water resources, transboundary water resources, blue and green water comparative advantage, as well as food wastage and losses.

Keywords Water · Energy · Food · WEF · Security · Nexus · Wastewater · Reuse · Efficiency · Optimal

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7.1 Introduction

Of all resources, water, food, and energy are most needed to sustain life on earth. These three resources are tightly interconnected, forming a resource and policy nexus. Their insecurity is an impediment to social stability and economic growth. A nexus approach to water, energy, and food security can support the achievement of sustainable development. The nexus approach would highlight the linkages between Water, Energy, and Food into the development planning process to ensure their sustainability. The range of potential risks and uncertainties relating to a single resource is magnified when the links between different resources are taken into account. Water, food, and energy insecurities are impediments to social stability and economic growth (Abu-Zeid 2011).

Water scarcity in the Arab Region is considered one of the major and most critical challenges facing Arab countries. This challenge is expected to grow with time due to many pressing driving forces, including population growth, food demand, unsettled and politicized shared water resources, and climate change, forcing more countries into more expensive water resources, such as desalination, to augment their limited fresh water supplies. The large financial, economic, environmental, and social burdens to be borne cannot be overemphasized. This challenge is exacerbated by its multiple nexuses with the various development sectors, such as water and food, water and energy, and their interdependencies with other resources such as land and wastewater, which carry within them many cross-cutting security issues, mainly water security, energy security, and food security. Water, food, and energy resources are tightly interconnected, forming a policy nexus. Food production is the largest user of water globally. It is responsible for 80–90 % of consumptive water use from surface water and groundwater. Water, however, is also used to generate electricity, and about 8 % of global water withdrawal is used for this purpose. Energy, in turn, is needed to transport and fertilize crops. Food production and supply chains are responsible for around 30 % of total global energy demand. Crops can themselves be used to produce biofuels, but using water for crop production exclusively for biofuels may not be a preferable choice in a water-scarce and food-short region such as the Arab Region. A secondary level byproduct of biofuel from agriculture wastes may be a more acceptable choice.

It is therefore important to address much more explicitly the various linkages of the water sector with other sectors like energy, and food. Moreover, professionals in all sectors, encouraged by governments' strategies for sustainable development, should think and act beyond the boundaries of their own sector, to achieve effective and integrated resources planning and management.

According to the current trends in population growth and their associated water, food, and energy demands in the Arab Region, water security, energy security, and food security are closely linked, perhaps more than any other region in the world, and actions in one area have strong impacts on the others. Hence, a nexus approach that integrates management and governance across these three sectors can improve

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security issues. This can also support the transition to a green economy, which aims, among other goals, at efficient use of resources, and policy coherence.

A proper understanding of the nexus will allow decision makers to develop appropriate policies, strategies, and investments to explore synergies, and to identify trade-offs among the development goals related to water, energy, and food security. Moreover, a nexus perspective increases the understanding of the interdependencies across these three sectors and influences policies in other areas of concern, such as climate change and environment.

In the water value chain, energy is required in all segments; energy is used in almost every stage of the water cycle: extracting groundwater, feeding desalination plants with its raw sea/brackish waters, and producing freshwater, pumping, conveying, and distributing freshwater, collecting wastewater, along with treatment and reuse. In other words, without energy, mainly in the form of electricity, water availability and delivery will not be possible.

It is estimated that in most of the Arab countries, the water cycle demands at least 15 % of national electricity consumption and it is continuously on the rise (Al-Zubari 2013). On the other hand, though less in intensity, water is also needed for energy production through hydroelectric schemes (hydropower) and through desalination (Co-generation Power Desalting Plants [CPDP]), for electricity generation and for cooling purposes, and for energy exploration, production, refining, and oil recovery processes.

7.2 The Role of Research and Development

The scarcity of fresh water in the Arab Region promoted and intensified Research and Development (R&D) in the technology of desalination and combined co-production of electricity and water, especially in the Gulf Cooperation Council (GCC) countries. Desalination, particularly CPDPs is an energy-intensive process. Given the large market size and the strategic role of desalination in the Arab Region, the installation of new capacities will increase the overall energy consumption. As energy production is mainly based on fossil-fuels, a finite source, it is clear that development of renewable energies to power desalination plants is needed. Meanwhile, to address concerns about carbon emissions, Arab governments should link any future expansion in desalination capacity to investments in abundantly available renewable sources of energy.

There is an urgent need for cooperation among the Arab countries to enhance coordination and investment in R&D in desalination and treatment technologies. Acquiring and localizing these technologies will help in reducing their cost, increasing their reliability as a water source, increasing their economic added value, as well as reducing their environmental impacts. Special attention should be paid to renewable and environmentally safe energy sources, of which the most important is solar, which is abundant in the Arab Region.

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Despite the strong relation, the water-energy-food nexus and their interrelation has not been fully addressed or considered in the planning and management in many Arab countries. However, with the increasing water scarcity, many Arab countries have started to realize the growing importance of this nexus and the need for R&D to bridge the knowledge gap in finding trans-disciplinary and cross-sectoral solutions.

7.3 The State of Knowledge on the WEF Nexus in the Arab Region: Bridging the Gap

In order to bridge the knowledge gap on the water, energy, and food nexus (WEF Nexus) in the Arab Region, this chapter presents some key information required to initiate research and further analysis. It provides in the following sections, several linkages between different aspects of the WEF Nexus looking at water, energy, and food from different angles. This type of information should support a nexus approach to policy decisions related to implementing a fit-for-purpose water allocation strategy. A strategy where the appropriate water resources are used for the appropriate purpose at the appropriate location, and one that optimizes energy use, water use, and food production.

7.3.1 The Water-for-Food Scarcity Impact on Energy

The per capita share of renewable blue (surface and groundwater) water resources is below the water scarcity limit of 1000 m^3/capita/year, in 17 out of the 22 Arab countries (Fig. 7.1). To maintain an adequate level of food and water security, the region has tapped into its reserves of fossil groundwater for food production, and tapped into its reserves of fossil fuel to pump this groundwater, and desalinate seawater for freshwater supply. The impossible sustainability of these fossil reserves calls for the dire need to appropriately address the 3 securities in nexus. The Arab countries are using about 24 BCM/year of fossil non-renewable groundwater which put pressure on fossil energy as well to pump this groundwater. This exploitation of non-renewable groundwater due to the unavailability of adequate renewable freshwater resources is reflected in 10 out of 22 countries in the region exceeding the 100 % threshold of their freshwater sustainability index, indicating high potential for using more energy in these countries to make water available for food production (Fig. 7.2).

With the severe water scarcity situation in the Arab Region, non-conventional water resources including desalination of sea water, as well as treated wastewater, are becoming important. Several countries have started to direct their treated wastewater to food production. Energy requirements for wastewater treatment

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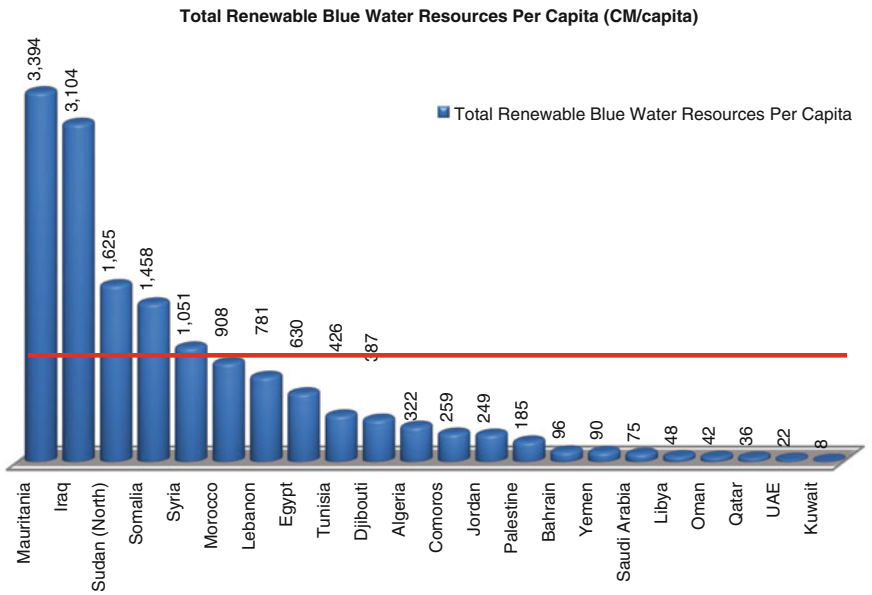

Fig. 7.1 Total renewable blue water resources per capita (CM/capita) in the Arab Region (*Source* AbuZeid et al. 2014)

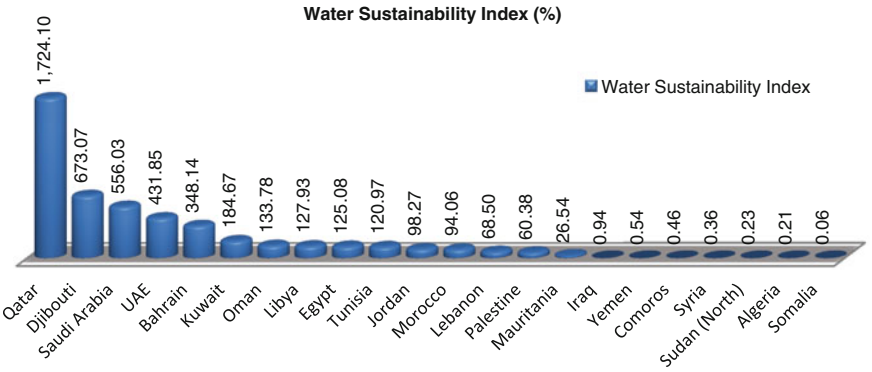

Fig. 7.2 Water sustainability index (%) in the Arab Region (*Source* AbuZeid et al. 2014)

versus desalination for agriculture purposes are going to play an important energy security role in policy making for water and food security. The possibility of generating energy through the wastewater treatment process adds another variable to the Nexus equation. Municipal and industrial wastewater reached 23 billion cubic meters/year (BCM/year) in the region divided among the Arab countries (Fig. 7.3). A small portion of this amount is treated and a smaller amount of about 1.6 BCM/year is reused due to the low level of treatment. Although the

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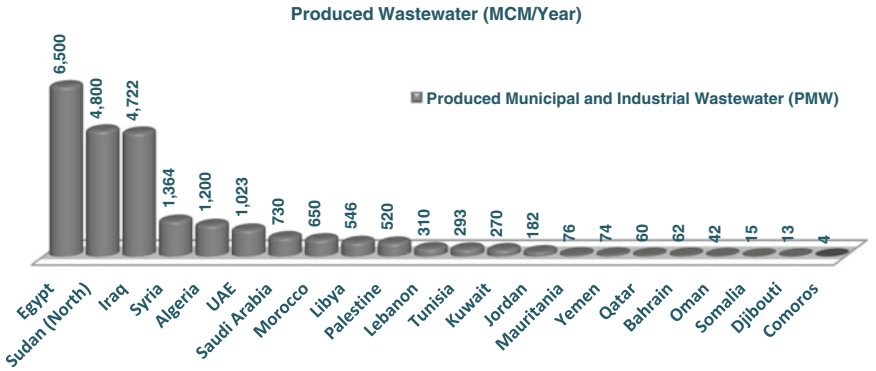

Fig. 7.3 Produced municipal and industrial wastewater in the Arab Region (*Source* AbuZeid et al. 2014)

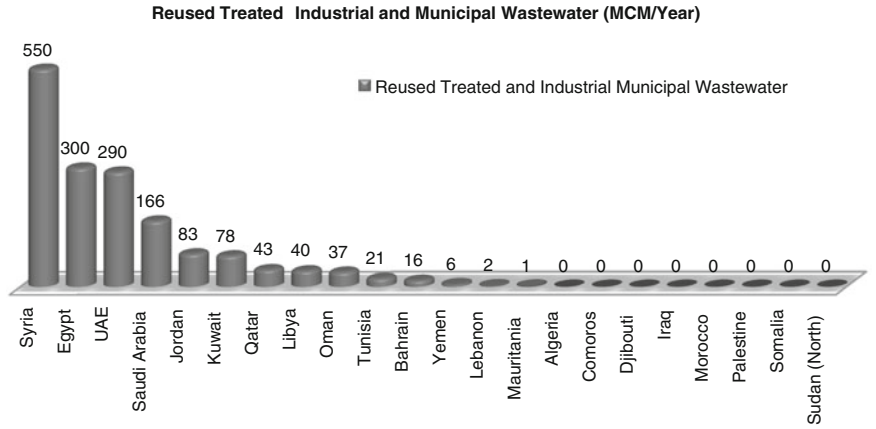

Fig. 7.4 Reused treated industrial and municipal wastewater in the Arab Region (*Source* AbuZeid et al. 2014)

countries that are efficiently reusing wastewater are mostly water-scarce and energy-rich or economically better off, there are a few countries that are not considered energy-rich but may be considered developed in the state of knowledge on water scarcity implications and the urgency of reuse (Fig. 7.4). It is obvious though that the low level of wastewater reuse reflects the high energy costs required to treat, pump, and transport wastewater for recycling. It also reflects the level of urgent need for water, as well as the level of knowledge, research and development in the area of wastewater treatment and reuse.

Agriculture drainage is another element in the WEF Nexus and it is estimated at about 34 BCM/year in the Arab Region (Fig. 7.5). A small proportion of this amount is recycled. Expansion in agriculture drainage reuse for agriculture

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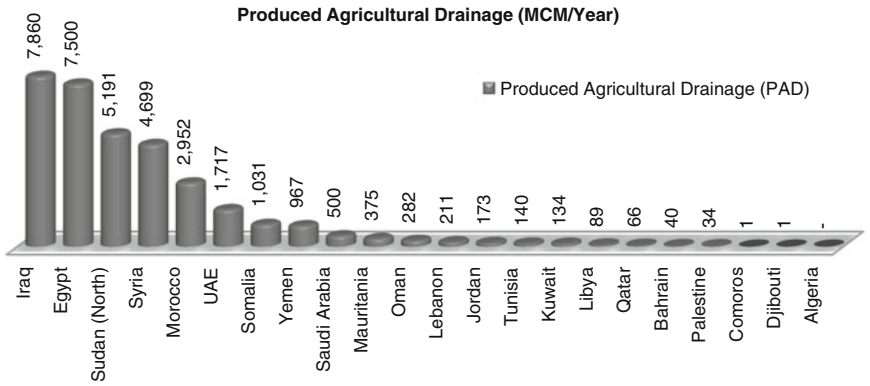

Fig. 7.5 Produced agricultural drainage by country in the Arab Region (*Source* AbuZeid et al. 2014)

purposes is constrained in many cases due to pollution levels from untreated wastewater that reaches agriculture drains. Egypt is an example of a country that is facing a water, energy, and food shortage. It reuses the largest amount of agriculture drainage, for food production in the Arab Region, reaching about 5.5 BCM/year. Historically depending on gravity flow surface irrigation systems in its Nile Valley traditional agriculture lands, and generating substantial amounts of agriculture drainage, Egypt is often faced with a WEF Nexus dilemma when it comes to reuse of this agriculture drainage. On the one hand, it needs the energy to pump part of this drainage water from the agriculture drains into the irrigation canals, to compensate for shortage in water needed for food production. It also needs the energy to pump the seepage groundwater in the Nile Valley to compensate for water shortage in the downstream reaches of its irrigation canals. Farmers downstream also use individual pumps and bear high energy costs to pump agriculture drainage water into their farms to compensate for water shortages. On the other hand, switching from gravity surface irrigation systems in traditional agriculture lands to pressurized modern irrigation systems for more efficient on-farm water use, will not only require a substantial amount of energy, but it will also reduce groundwater seepage and agriculture drainage water which are important sources of water for food production in other agriculture locations.

The water scarcity situation in the Arab Region has forced countries to depend on an energy-intensive resource such as seawater desalination reaching a total production of over 4 BCM/year in 2012 (Fig. 7.6). The growth rate in energy consumption at 8 % in the region, and the low energy use efficiency reaching less than 50 % in some cases within the region, which consumes more than 50 % of its total energy for desalination in some countries, requires an optimal linkage between

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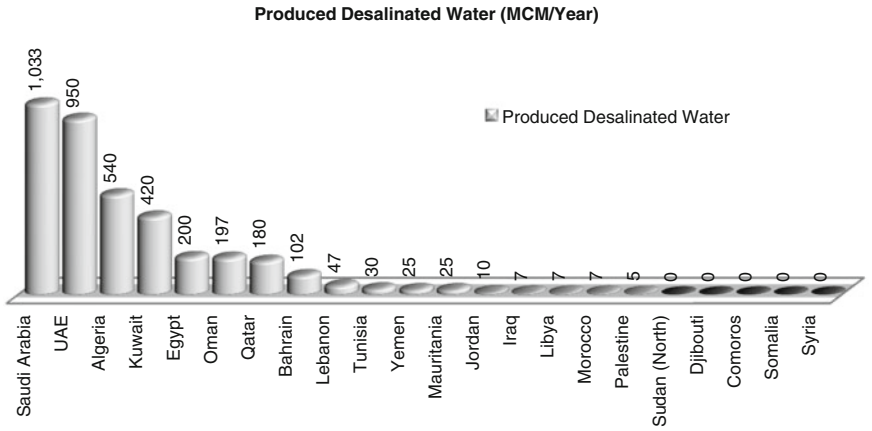

Fig. 7.6 Produced desalinated water across the Arab Region (*Source* AbuZeid et al. 2014)

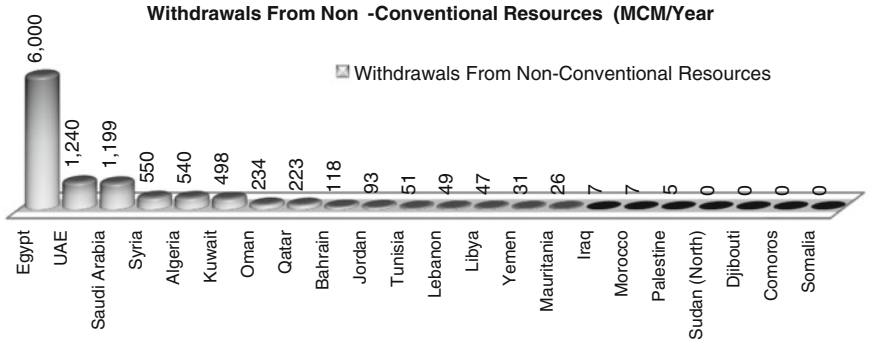

Fig. 7.7 Withdrawals from non-conventional resources within the Arab Region (*Source* AbuZeid et al. 2014)

energy consumption and water production. Use of non-conventional water resources (Fig. 7.7), such as treated wastewater, desalination, and agriculture drainage water (currently reaching 11 BCM/year in the Arab Region), and the use of deep non-renewable groundwater requires policy analysis that should consider the "energy" costs involved in treatment, desalting, and pumping, which requires a Nexus approach in allocating the appropriate "water" resource to "food" production. There is still a knowledge gap in the optimization of water allocation to select the most appropriate water resource for food production, by considering water and energy sustainability, conserving freshwater resources, and utilizing the least amount of energy.

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7.3.2 Energy for Water

The World Water Development Report (2014) presents average energy requirements for developing different water resources (Abdel-Dayem 2014). These energy requirements vary greatly: 0.37 kWh/m^3 for water from lakes and rivers; 0.48 kWh/m^3 for groundwater; 0.62–0.87 kWh/m^3 for wastewater treatment; 1.0–2.5 kWh/m^3 for wastewater reuse; 1.5–3.5 kWh/m^3 for drinking water sophisticated treatment; and 2.58–8.85 kWh/m^3 for salt water desalination.

A quick comparison of these energy requirements of developing different water resources for the purpose of food production, demonstrates that pumping water from open water bodies (being fresh surface water or recycled agriculture drainage water) at 0.37 kWh/m^3 would be more economical than pumping groundwater at 0.48 kWh/m^3. When renewable freshwater is exploited, reusing treated wastewater for food production at 1.5–3.5 kWh/m^3 would be more economical than using desalinated water at 2.58–8.85 kWh/m^3.

The policy decisions that are made today will affect the policy decisions that need to be taken in the future, and this is an important factor when it comes to the exploitation of fossil non-renewable groundwater - a water resource that is often of ultimate quality, and in most cases does not require sophisticated treatment for drinking purposes. What is the best use for that resource? Should it be allocated to agriculture (a water intensive user)? Or is it better for domestic and drinking water? The nexus approach provides some insights to the policy decisions that need to be made. Exploiting non-renewable groundwater in agriculture at 0.48 kWh/m^3 will quickly result in the need to make drinking water available at energy requirements of 1.5–3.5 kWh/m^3 or maybe even at 2.58–8.85 kWh/m^3 if desalination is required. Whereas, strategically using non-renewable groundwater for domestic and drinking purposes at 0.48 kWh/m^3 will sustain it for a longer period of time and will generate wastewater that could be treated and reused for agriculture at energy needs of 1.0–2.5 kWh/m^3. This is an example of a water-for-food policy decision that, when taken within a Nexus approach, could contribute to energy security by providing a long term energy-efficient alternative.

7.3.3 Water for Energy

Mielke et al. (2010) indicates that water use for secondary oil extraction could reach 62.1 gal/MMBtu, and 10.3 gal/MMBtu for oil refining, as well as 315 gal/MWh for steam turbine, and 4500 gal/MWh for hydropower (as evaporation losses).

It is obvious that moving into renewable solar and wind energy would be less water-consumptive than fossil fuel extraction and refining, and even hydropower. However, it is important to harness the little remaining hydropower potential of the available water resources in the Arab Region (Table 7.1). Making use of in-stream turbines for energy production is also important, as well as making use of all water

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Table 7.1 Hydropower potential and utilization in the Arab Region

Country	Gross theoretical hydropower potential (GWh/year)	Technically feasible hydropower potential (GWh/year)	Economically feasible hydropower potential (GWh/year)	Installed hydro capacity (MW)	Hydro generation in 2008 or average/most recent (GWh/year)	% production by hydro in 2008 or most recent (average)	Hydro capacity under construction (MW)	Planned hydro capacity (MW)
Algeria	12,000	4000		278	560	2.7	0	n/a
Comoros				1	2			
Egypt		>50,000	~50,000	2842	15,510	12.6	0	48
Iraq		90,000	67,000	2273	n/a	13	~30	800–5000
Jordan		500 MW		12	62	0.45	0	n/a
Lebanon				280	750	7	76	n/a
Mauritania				30	120	n/a	0	n/a
Morocco		5203	4000	~1265	1318	6.6	~40	84–384
Somalia		600						
Sudan		n/a	19,000	575	4333	55	>1200	2000–3600
Syria				1505	~8000	15	n/a	n/a
Tunisia	1000	250	160	~70	160	3	n/a	>20

Source AbuZeid et al. (2014)

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outfalls, be it wastewater outfalls, cooling water outfalls, or irrigation and drainage gravity channels using mini-hydropower installations. There are still some knowledge gaps in studying the potential of wastewater outfalls and mini-hydropower installation that can maximize the optimal linkages between water and energy.

7.3.4 The Transboundary Dimension of the Water-Energy-Food Nexus

The transboundary nature of the Arab Region's water resources also puts another dimension to the WEF Nexus, whereby 65 % of the region's renewable surface water resources originate outside the Arab countries. Adding the transboundary dimension to the WEF Nexus complicates the issue even more, where water security is closely linked to issues of energy and food security upstream and downstream with different levels of effect depending on the number of riparian countries affected. An upstream infrastructure that may ensure energy security for an upstream country may, not only affect energy security for a downstream country, but could also put its food security at risk. Therefore, the hydropower potential at the transboundary river basin level needs to be assessed in an integrated manner and should be planned jointly so that upstream hydropower projects do not affect downstream hydropower installations or other food production agriculture activities. Likewise, upstream diversions for agriculture purposes upstream should be planned jointly with downstream riparian countries to avoid negative impacts on hydropower energy installations, or food production and agriculture activities downstream.

Tables 7.2, 7.3 and 7.4 provide the state of hydropower potential and installed capacity in the riparian countries of three of the major transboundary river basins intersecting with the Arab Region, namely, the Senegal River Basin, the Euphrates River Basin, and the Nile River Basin, respectively.

7.3.5 The Water-Energy Savings Nexus for Food

The low "on-farm" irrigation water use efficiency, reaching less than 60 % in some cases, coupled with the need for increased energy use to switch to pressurized drip or sprinkle irrigation systems saving on irrigation water use, requires an optimal linkage between energy consumption and water consumption for food production. Although low on-farm irrigation water use efficiency may result in increased agriculture drainage, which some consider as wasted water, yet in some countries in the region, this drainage water is reused several times for food production. Improvements in any one sector may involve tradeoffs in others, and while modern irrigation systems may reduce on-farm irrigation water used for food production, it

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Table 7.2 Senegal River Basin hydropower potential

Country	Gross theoretical hydropower potential (GWh/year)	Technically feasible hydropower potential (GWh/year)	Economically feasible hydropower potential (GWh/year)	Installed hydrocapacity (MW)	Hydro generation in 2008 or average/most recent (GWh/year)	% production by hydro in 2008 or most recent (average)	Hydro capacity under construction (MW)	Planned hydro capacity (MW)
Guinea	26,000	19,300	18,200	123	519	37.8	n/a	>240
Mali		~5000		155	>500	60	140	>100
Mauritania				30	120	n/a	0	n/a
Senegal		4250	2050	66	293	16	0	123

Source CEDARE-AWC (2012)

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Table 7.3 Euphrates River Basin hydropower potential

Country	Gross theoretical hydropower potential (GWh/year)	Technically feasible hydropower potential (GWh/year)	Economically feasible hydropower potential (GWh/year)	Installed hydrocapacity (MW)	Hydro generation in 2008 or average/most recent (GWh/year)	% production by hydro in 2008 or most recent (average)	Hydro capacity under construction (MW)	Planned hydro capacity (MW)
Iraq		90,000	67,000	2273	n/a	13	~30	800–5000
Syria				1505	~8000	15	n/a	n/a
Turkey	433,000	216,000	140,000	13,700	48,000	25.4	8600	22,700

Source AbuZeid et al. (2014)

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Table 7.4 Nile River Basin hydropower potential

Country	Gross theoretical hydropower potential (GWh/year)	Technically feasible hydropower potential (GWh/year)	Economically feasible hydropower potential (GWh/year)	Installed hydrocapacity (MW)	Hydro generation in 2008 or average/most recent (GWh/year)	% production by hydro in 2008 or most recent (average)	Hydro capacity under construction (MW)	Planned hydro capacity (MW)
Burundi	6000	1500	600	50	208	100	1	177
D.R. Congo	1,397,000	100,000 MW	145,000	2410	7303	100	>162	3690–43,000
Egypt		>50,000	~50,000	2842	15,510	12.6	0	48
Eritrea				0	0	0	0	0
Ethiopia	~650,000	>260,000	162,000	669	2700	>95	1277	4170–10,000
Kenya	>24,300	1422 MW		747	3000	63	41	>160
Rwanda		400 MW		55	130	59	0	120–209
Sudan (North & South)		n/a	19,000	575	4333	55	>1200	2000–3600
Tanzania	39,450	20,000		561	2098	61	0	1868
Uganda		n/a	>12500	~395.5	1391	67.9	337	~1000

Source AbuZeid et al. (2014)

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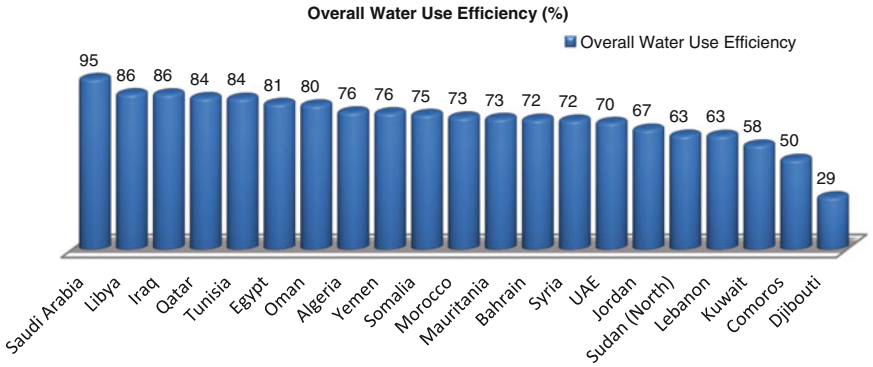

Fig. 7.8 Overall water use efficiency (%) (*Source* AbuZeid et al. 2014)

could consume more energy and reduce return flows to groundwater and drainage water that may be used for food production in other locations. It is important to consider an objective of overall water use efficiency coupled with an energy use efficiency objective rather than looking at on-farm irrigation efficiency in isolation. Figure 7.8 shows the overall water use efficiency for Arab countries considering the water reuse factor in these countries. It is obvious that a higher energy use is needed to achieve higher water savings in the agriculture sector.

7.3.6 Food Security, Virtual Water Trade, and the WEF Nexus

Each country in the Arab Region is far from having enough water to grow its basic food needs. Thus, the idea of food self-sufficiency is now switched to the concept of food security. Recent studies by CEDARE and the Arab Water Council shows that although the Arab Region uses about 212 BCM/year of virtual water in food production within the region, the Arab countries are importing 274 BCM/year of virtual water in food products while exporting about 55 BCM/year of virtual water in food products (AbuZeid et al. 2014). Figures 7.9 and 7.10 show the amount of virtual water import and export respectively for the Arab countries for 2012.

It would be very expensive and energy intensive, and for some countries practically impossible, if the Arab Region would produce all its food needs locally to achieve food self-sufficiency. Theoretically speaking, locally producing the amounts of imported food products of year 2012, the Arab Region would require about 1700 GWh/year of energy to desalinate the required amount of sea water, and additional energy to convey the water for agriculture, and even more for pressurized irrigation and fertilization.

The knowledge gap on the required amount of water and energy needed to achieve food self-sufficiency, and the knowledge gap on sustainability issues of

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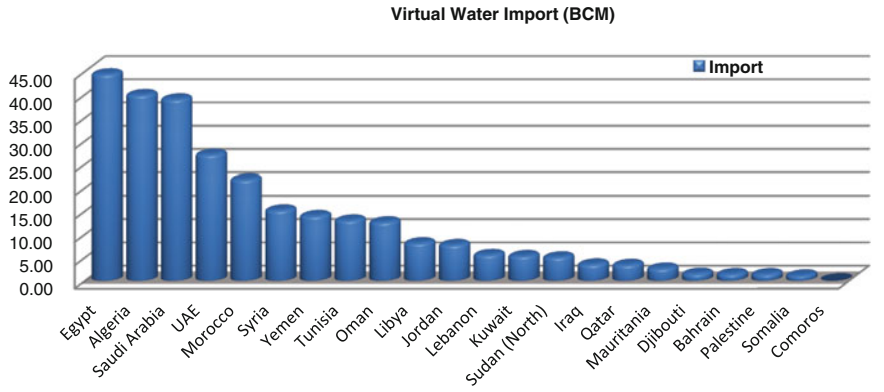

Fig. 7.9 Virtual water import in the Arab Region (BCM) (*Source* AbuZeid et al. 2014)

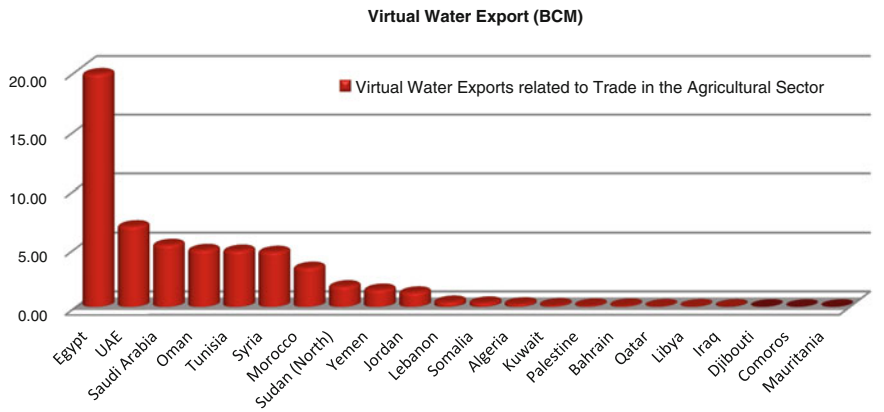

Fig. 7.10 Virtual water export in the Arab Region (BCM) (*Source* AbuZeid et al. 2014)

fossil groundwater and fossil fuel, are influencing strategies and policies that may not be appropriate for a water scarce region, such as the Arab Region.

7.3.7 The Blue and Green Water Effect on the WEF Nexus

Using green water through rain fed agriculture for food production uses less energy than using blue water through irrigated agriculture. Due to the scarcity of rainfall in the Arab Region, agriculture is mostly irrigated in the Arab Region depending on groundwater and surface water abstractions mostly from trans-boundary rivers originating outside the region. Although green water (from direct rainfall for rain fed agriculture) use for food production in the Arab Region reached 51 BCM/year,

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blue water (abstracted from rivers and groundwater for irrigated agriculture) use for food production reached 231 BCM/year, putting more pressure on energy. It is recommended to make use of green water for food production whenever it exists to relieve the pressure on energy resources.

7.3.8 *Food Wastage: Adding to the Water-Energy-Food Nexus*

It is also worth mentioning, that food wastage is closely linked to virtual water wastage, and could also be considered as an indirect contributor to energy wastage. Figure 7.11 shows food losses in the Arab Region and Central Asia as a percentage of food production indicating 20 % to more than 50 % wastage among several categories of food including fruits and vegetables, root and tuber crops, cereals, fish and seafood, oil seeds and pulses, meat, and milk and dairy products.

Figure 7.12 shows food wastage in tonnage during different stages including food production, post harvesting and storage, processing and packaging, distribution and consumption. Translating this food wastage of about 80 million tons into virtual water, it could reach an amount of about 50 BCM/year. Noting that the region indicated here is larger than the Arab Region, this food wastage could also translate into a substantial amount of energy wastage affecting not only food and water security but also energy security.

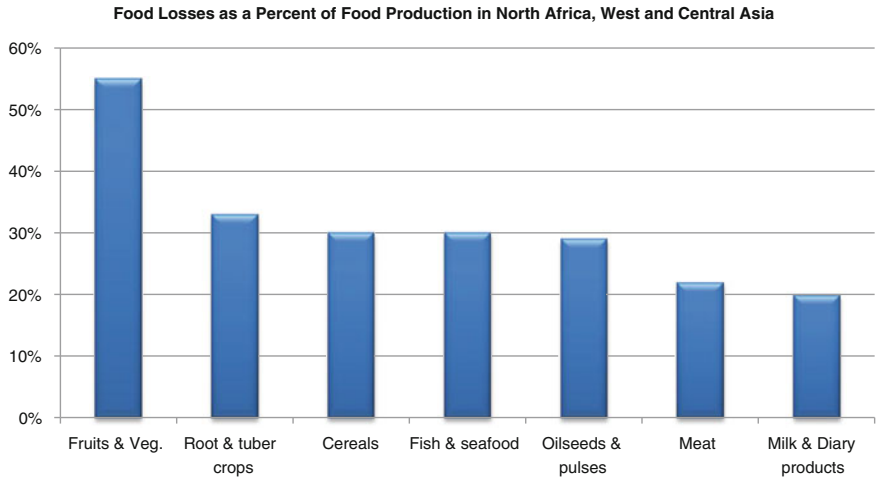

Fig. 7.11 Food losses as a percent of food production in North Africa, West and Central Asia (*Source* AbuZeid 2013)

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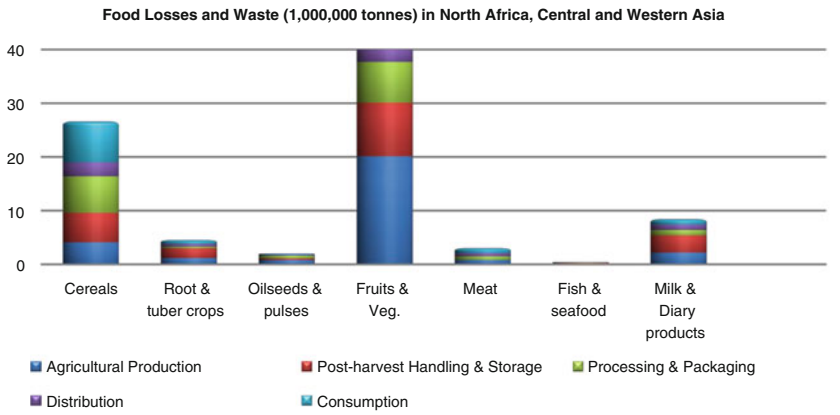

Fig. 7.12 Losses and waste (1,000,000 tons/year) in North Africa, Central and Western Asia (modified from FAO 2011)

7.4 Conclusion

Achieving water security, energy security, and food security in the Arab Region requires advancing the state of knowledge, enhancing research and development in the technologies used for efficient water use, efficient energy use, renewable energy development, and increased crop productivity. Applied research on decision making and multi criteria analysis is important in the field of water, energy, and food planning. Policy decisions to be made in any of the water security, energy security, or food security fields should not be done in isolation but rather within a nexus approach. Research on the WEF Nexus should consider the fit-for-purpose water use, the long term implications of using fossil reserves, the transboundary dimension of the WEF Nexus, the green water comparative advantage for food production, the optimization of virtual water trade, the measures needed to reduce food wastage, water wastage, and energy wastage, and the trade-offs between increasing water efficiency, increasing water recycling, and the corresponding energy needs.

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