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The Impacts of Climate Change in the MENA Region and the Water-Energy Nexus

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Abstract: The present paper aims to elucidate the impact of climate change on the availability and security of water and energy in the Middle East and North Africa Region (MENA Region). The region is particularly challenged by a number of factors including a large variability of bio-geographical characteristics, extreme population growth over the last few decades and substantial societal and economical transitions as well as armed conflicts in some of the countries of the region. Anticipated changes in climate conditions will exacerbate the challenges with regard to providing sufficient amounts of water and energy to the communities in the region. Impacts of climate change will materialize as an increasing number of heat waves, primarily in urban structures and the decline in water availability as a result of enhanced droughts and a growing numbers of dry spells. The interrelationships between energy and water and their mutual dependencies are addressed by the Water-Energy-Nexus concept. With regard to the challenges addressed here, Cyprus and the Eastern Mediterranean are a particular point in case. Mitigation and adaptation strategies include enhanced efficiency of energy and water use, integrated technology assessments regarding electricity generation and the production of potable water and electricity through concentrated solar power.

Keywords: Water-Energy Nexus; MENA Region; climate change; mitigation/adaptation strategies

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1. Background and Introduction

Water and energy are essential ingredients sustaining life on this planet. However, both quantities are intractably linked through a number of critical conditions, particularly when one considers man-made energy sources and potable water. Examples for these linkages include coolant water needed in electrical power plants or energy required for pumping and transporting drinking water in distribution networks, to name but two examples [8,9]. This notwithstanding, there are links between water and energy to other important issues, as well. Water is considered as the primary rate-limiting factor for food production. Electricity demand is likely to grow significantly in light of increasing needs for space cooling in order to limit the adverse effects of urban-heat-island-induced human health problems.

On a more general level, recent decades have seen rapidly increasing multiple pressures on water-, energy- and food security, an issue that has been described as the Water - Energy - Food Nexus [10]. The underlying driving forces of this Nexus include a variety of more recent developments including: a growing demand on natural resources accompanied by their degradation due to overexploitation, a rapidly evolving urbanization and the emergence and the growth of Mega Cities, which lead to increasing contaminant emissions and growing volumes of waste products on a limited spatial scale. An ongoing trend towards globalization, particularly in the private sector, with associated tendencies to externalize resource use and degradation to distant regions is another driving force underlying the Water - Energy - Food Nexus. Finally -and exacerbating some of the above drivers, changes in global and regional climate conditions increasingly require mitigation and adaptation strategies and -measures at an accelerating pace. An important characteristic of these pressures is their strong inter-linkage, which lead to feedbacks that drive environmental and human systems to critical thresholds and tipping points that seriously affect access to water, energy and food.

The region encompassing countries of the eastern Mediterranean, the Middle East and North Africa, which has been called the MENA Region, is a region full of a varied history and a rich cultural heritage. While no unambiguous definitions exist, the following countries (in alphabetical order) are usually considered belonging to the MENA Region (Figure 1): Algeria, Bahrain, Dijbouti, the Arab Republic of Egypt, the Islamic Republic of Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Libya, Morocco, Oman, Qatar, Saudi Arabia, the Syrian Arab Republic, Tunisia, the United Arab Emirates, West Bank and Gaza, and the Republic of Yemen[5]. In providing this definition, we have no intentions to violate or reintroduce any political or other stipulations and/or to introduce any "hierarchy" or order with regard to MENA countries.

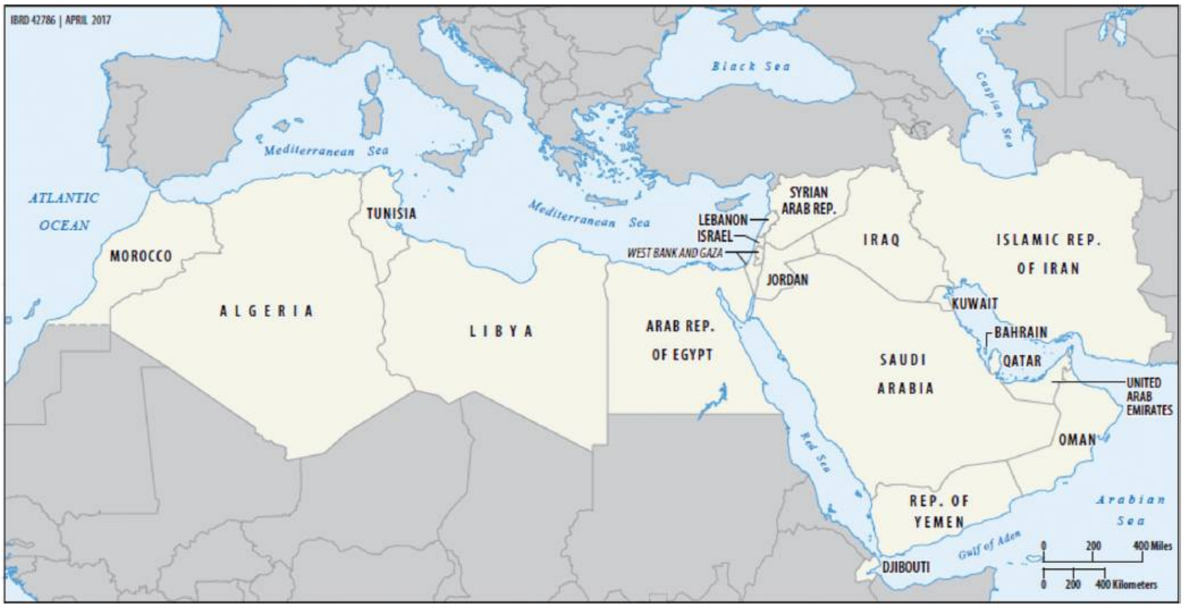

Figure 1: Map of the MENA Region; source: [5]

The MENA Region is expected to experience future climatic changes above the global norm, leading to this region being classified as one of the climate change "hot-spots" on the global scale [11]. This will have significant consequences for the availability of water as well as the need for energy (e.g., for space cooling) and will impact water and energy security in at least parts of the MENA Region.

The region is characterized by stark environmental gradients as well as by differences in the provision of ecosystem services, both East to West and South to North. In addition, the region is characterized by significant differences in the political, economic, societal, ideological and religious settings in each of the MENA countries. Driven largely by varying degrees of natural resource availabilities, some of the countries (particularly those on the Arabic Peninsula), provide sufficient economic prospects to their citizens, while in others a large fraction of the population has to endure significant economic hardships. These differences are reflected in the availability and the pricing of water and energy to MENA communities.

The events of the "Arab Spring", also called "Arabellion", which started in 2010 have resulted in major political, economic and societal transitions and have frequently been accompanied by significant armed struggles within and between countries of the MENA Region. This has not only caused hardships on local population, the demolishing of valuable infrastructure and the obliteration of administrative and governance structures, but has also led to the lack of energy and water resources that can be accessed by individuals and communities. These developments and the still

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ongoing, armed conflicts in parts of the region (particularly in Iraq, Libya, Syria and Yemen) render this region to one of the global political, military and humanitarian “hot-spots”.

The MENA Region has experienced one of the fastest growths in population worldwide. From about 110 million inhabitants in the 1950s, the MENA population has grown to 569 million in 2017 [3]. Regardless of generally declining rates of fertility, absolute population numbers are expected to further double to about 1.1 billion inhabitants by 2100, according to medium variant projections (Figure 2) and will be higher than China’s population, whose population is expected to continue to shrink to just over 1 billion [3].

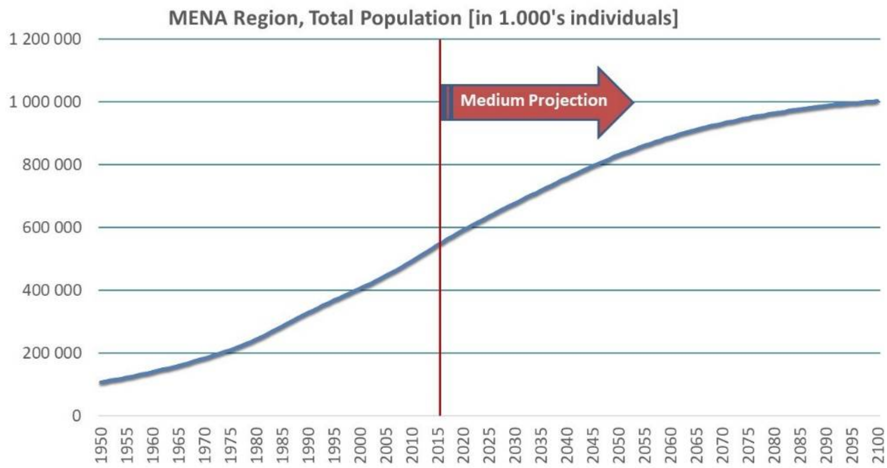

Figure 2: Population development of MENA countries; total population (both sexes combined) , annually for 1950-2100 (Estimates, 1950 – 2015); data source: [3]

Three countries contribute most to population growth in the MENA Region: Egypt, Iraq and Sudan. In 2100, they will account for about 49% of the region’s total population with 199 million, 156 million and 137 million inhabitants, respectively [12].

It is obvious that such growth in population requires increased resources of basic and advanced levels. This proves particularly difficult in countries that are currently resource-poor but labor-abundant. Thus, absolute population growth will mean more water and energy demand. While the MENA region has a formidable renewable energy potential, its significant wind and in particular solar power potentials, however, remain largely under-utilized.

Figure 3: Population densities of Mediterranean countries including Mediterranean MENA countries; source [1]

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Finally, the MENA Region is one of the most urbanized regions globally. Moreover, population densities and the location of major cities is largely concentrated along the coast of the Mediterranean (Figure 3), enhancing the risks of sea level rise to the habitability of a number of these cities and sub-regions (e.g., the Nile Delta) in the foreseeable future.

To look at Arab states here in particular, the urban population has quadrupled between 1970 and 2010 and is expected to more than double over the next 40 years [13].

In the following, I will address the issue of anticipated climate change in the MENA Region in more detail. I will then explain some of the ramifications of these changes for the Water-Energy Nexus and the water and energy security in the region. This will be followed by some suggestions for possible mitigation and adaptation strategies to minimize adverse developments and I will close with some conclusions.

2. Climate Change in the MENA Region

2.1 Regional changes in temperature and precipitation

As mentioned earlier, climate changes in the Mediterranean Basin are anticipated to significantly exceed global mean values [11]. Given current projections, this will equally apply for most of the other MENA countries and will be associated with increases in the frequency and intensity of droughts and hot weather conditions [14]. In order to derive more detailed information of higher spatial resolutions, global climate model results are being utilized as boundary conditions for regional climate models [e.g., 15,16]. Such studies enable a more concrete assessment of the impacts of these changes, e.g., with regard to sub-regional to local temperature extremes or changes in precipitation.

When considering regional climate modeling results pertaining to expected temperature changes in the MENA Region[1] [Figure 4; 6,17], a number of conclusions can be drawn:

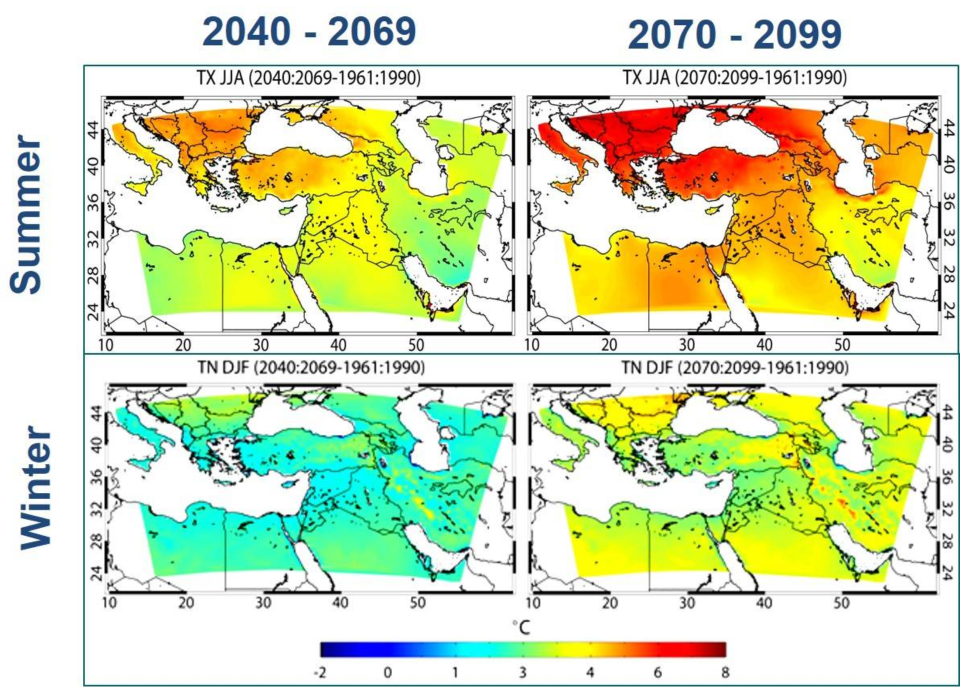

Figure 4: Patterns of changing mean summer maximum (JJA) and mean winter minimum (DJF) temperatures, TX (top) and TN (bottom), respectively, calculated from PRECIS output. The left panels show the mean changes for 2040-2069 and the right panels for 2070-2099 relative to the 1961-1990 control period; source: [6]

[1] Please note: the western MENA countries of North Africa are **not covered** in the models shown here

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- Changes in summer temperatures lie uniformly above those seen for the winter months, which are seen to be more spatially uniform.
- The increases in temperature for the 2070-2099 (3.5–7°C) time slots are significantly higher than for the mid-century period (2040-2069: 3–5°C).
- The largest temperature rises are expected for countries in the northeastern Mediterranean at latitudes north of 36°–38°N across the Balkan Peninsula and Turkey. These temperature increases may be amplified by the depletion of soil moisture, which limits evaporative cooling, prompted by the waning of large-scale weather systems that generate rain [7].

According to newer publications [7,17], observations covering the recent past indicate consistently an increase in heat extremes in the MENA Region, whereas climate model results project a further rise in mean temperatures until the end of the century. This implies that the number of hot days and warm nights may increase significantly. While the average maximum temperatures during the hottest days in the recent past were about 43°C, they may increase to about 46°C by the middle of the century and reach almost 50°C by the end of the century [17].

Projections of changes in the precipitation regime of the MENA Region, derived from regional climate models [6,18], are less robust. This notwithstanding, the overall trend of decreasing precipitation over most of the MENA Region (Figure 5) is consistent with global climate model results [14].

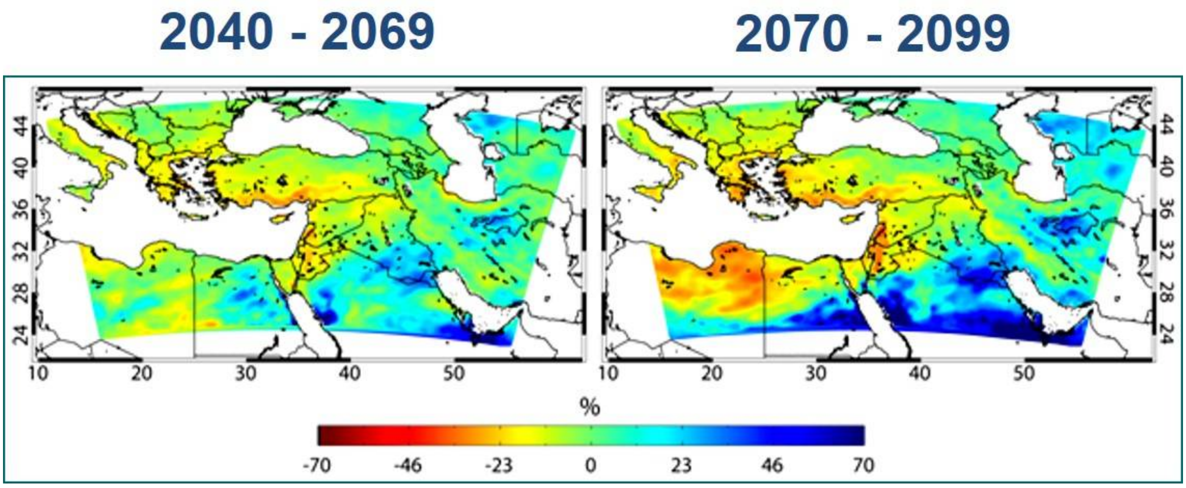

Figure 5: *Patterns of changing annual mean precipitation, from PRECIS output for. 2040-2069 (left panel) and for 2070-2099 (right panel) relative to the control period 1961-1990; source: Lelieveld, pers. comm.*

As can be seen, towards 2040-69, precipitation over much of the MENA Region will have decreased by about 10-20% relative to the 1961-1990 period. The apparent precipitation increase projected for Bahrain, Kuwait and Qatar exceeds 30%, but since absolute amounts are extremely small, these changes are considered insignificant. While many of the countries are expected to see reductions in annual mean precipitation by about 10%, both Cyprus and Lebanon will have a decrease in precipitation in excess of 20%. Even though, precipitation will continue to decline until the end of the century, the overall decrease will be only moderately larger relative to mid-century for most of the region [6, Supplement].

Specific impacts of climate change on water availability and water security in the MENA Region include:

- a lengthening of the dry season for most MENA countries;
- a 30-70% reduction in recharge of aquifers in the Mediterranean Coast, impacting the quantity and quality of ground water [19];
- significant reductions in surface and subsurface water availability directly affecting river flow, instream flow as well as soil water reservoir; the latter will have adverse consequences on food

production and food security, adding the pressure on groundwater aquifers and surface water reservoirs in MENA countries [20];

- in Jordan, available water resources are expected to fall below the 50m³ per capita/year threshold, which has been identified as the minimum amount required for social and economic development [21].

These impacts will require well-considered adaptation strategies, for instance, alternative freshwater sources such as desalination to meet basic needs (see below).

2.2. Enhanced warming in urban structures

Following the UN's World Urbanization Prospect Report of 2014, 54% of the world's population now live in metropolitan areas [22]. By 2050, this percentage will increase to 86% in advanced countries, and 64% in developing nations. In line with these developments, the MENA Region has seen and is continued to experience an accelerating trend of urbanization.

With regard to climate changes, cities experience what has been called the "urban heat island effect" [e.g., 23,24,25], comprising an enhanced heat accumulation within the urban area due to buildings, transportation infrastructure and human activities. The heat accumulations lead to temperature increases within the city limits that are 2 to 3°C higher compared to the surrounding rural areas. Reduced ventilation within cities exacerbates the warming, particularly during summer heat waves. Heat waves can have profound impacts on human health resulting in excess mortality, which is greatest among the elderly and people suffering illnesses [6]. The often observed deteriorating air quality in cities in combination with extreme heat will exacerbate human health risks in urban structures [6].

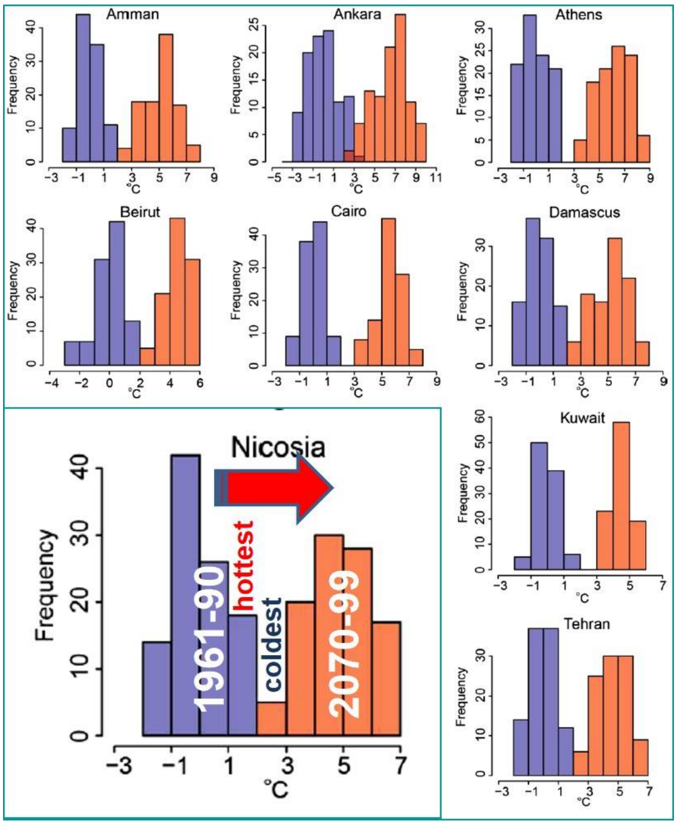

Figure 6: *Recent and end-of-century temperature anomalies for a number of MENA and eastern Mediterranean country capitals. Model calculated frequency histograms (%) of daytime maximum summer (JJA) temperatures deviations from the 3-months-mean, relative to the period 1961-1990, based on the A1B scenario. Blue is for the period 1961-1990 (hence centered around 0oC) and red for the period 2070-2099; the large insert illustrates the major characteristics of the observed warming trend for Nicosia; adapted from [7]*

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Results of regional climate models interpolated to the areas of major cities in the MENA Region have confirmed the expected enhanced warming trend of cities relative to the rest of each country [7]. Figure 6 basically indicates that the coolest summer months during the 2070-2099-time window are warmer than the hottest summer months of the recent past (1961-1990). Thus, we are expecting a major shift in summer temperatures and extreme heat in urban structures. Aside from the already mentioned human health risks, this implies also impacts for the water and energy sector. As to the former, the aforementioned decreases in precipitation will reduce available potable water for city inhabitants.

The demand for energy in the built environment, i.e. private, commercial and public buildings, is directly related to climatic conditions. Thus, the indicated increase in urban heat waves during the summer months implies additional demand for electricity for space cooling in order to maintain comfortable/required indoor conditions. The resultant peak in electricity demand for the summer months is well documented, e.g. for Cyrus.

3. The Water-Energy Nexus

3.1 Basic understanding of the Energy-Water Nexus

The Water-Energy Nexus (WEN), in general, and in the context of the MENA Region, in particular, has been addressed by several authors [4,8,9,20,26]. Figure 7 provides a graphical depiction of major elements of the WEN [4].

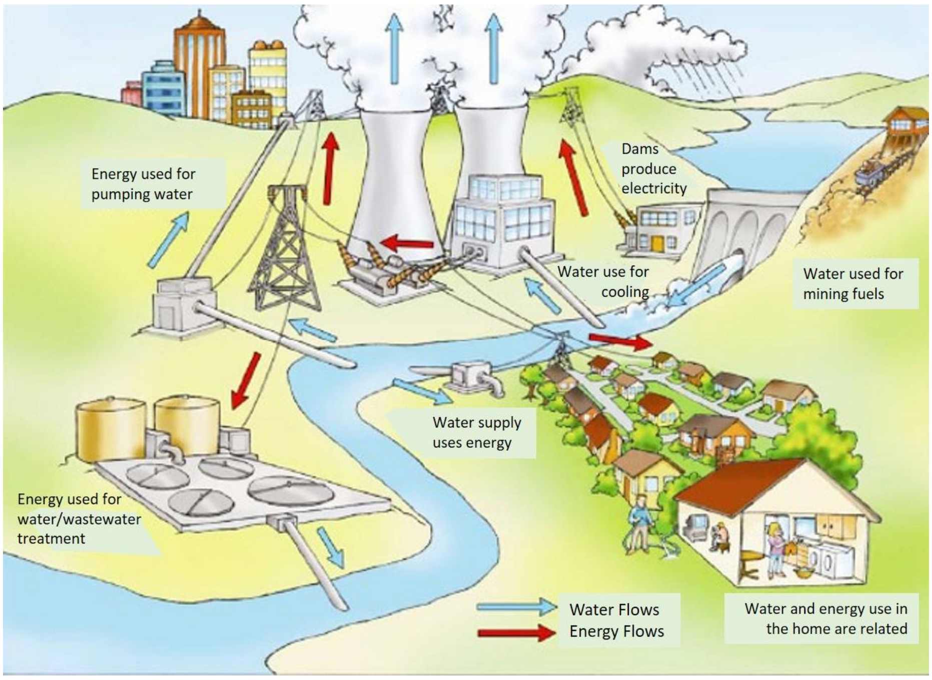

Figure 7: *Selected processes depicting the major elements of the Water-Energy Nexus [modified after 4]*

As can be seen satisfying even a basic need of providing drinking water from conventional sources requires substantial amounts of energy. More specifically, energy is needed for

- conveyance and pumping,
- water treatment,
- water pumping,
- end use,
- waste water treatment,
- and constructing, operating and maintaining water-supply facilities.

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The energy needs for unconventional sources such as seawater desalination will be even higher (see below).

The energy sector needs water for the extraction and refinement of natural resources, specifically in mining and quarrying and for hydrocarbon extraction and refining as well as for the cooling of conventional power plants. In addition, water provides the source of energy in hydroelectric power plants.

3.2 The Energy-water Nexus in the MENA Region

Given the already described increasing demand for energy and water, it is obvious that these resources and their interrelationships represent important issues in the MENA region. Economic development, population growth, changes in lifestyle and shifting demand patterns, as well as high inefficiencies that result from technical and managerial inadequacies, on the one hand, and energy and water subsidies in several countries of the region are drivers for the increasing demand in both sectors.

In order to satisfy these demands, especially that for electricity, the construction of additional or alternative/renewable electricity generation capacity is urgently needed to prevent a deteriorating energy security in the region. Information provided by the current policy scenario of the *World Energy Outlook 2016* shows that from 2014 to 2040 the installation of new electricity generation capacities in the Middle East alone is projected to equal 294 GW, representing more than a doubling of the 285 GW installed in 2014 [27]. This does not only imply significant investments in the coming years, but also requires the application of holistic assessment approaches for decisions about electricity generation technologies. This will be needed in order to consider the issues relating to the WEN appropriately, as the consumption of water varies widely among different electricity generation technologies [26].

Water constraints are related to rising temperatures and declining precipitation. However, increasing water temperatures have resulted in reduced electricity generation in hydro, coal and nuclear power plants during the last years in several countries worldwide [28]. It is likely that this trend will increase with progress in climate change. Today the MENA Region is not only one of the world's most water-scarce regions, but several countries in the region face already water stress [29]. As has been seen, countries with high population numbers will have the highest gaps in available water under average future climate scenarios. The total unmet demand for water in the Region is expected to amount to 199 km^3 [29]. MENA countries with crude oil and gas production, i.e., Iraq, Iran, Egypt and Saudi Arabia face particularly high water demand gaps, not the least due to the fact that hydrocarbon extraction and refining requires substantial amounts of water.

In order to address specifically the need for potable water in the future, energy intensive desalination of seawater is going to play a key role in the water supply system of MENA countries. In fact, desalination is already employed heavily in some of the MENA countries, particularly in the Gulf States, in Israel and in Cyprus. Desalination costs are strongly correlated with energy prices [30]. Consequently, water pricing becomes an issue affecting social inequalities and may lead to political and societal instabilities.

In order to satisfy the energy demands for desalination facilities, the installation of new power generating facilities will be needed [26], which –in turn- will require copious amounts of cooling water. Considering fossil-fuel based electricity generation, an increase by 40% of power generation in Middle Easter countries has been estimated in order to secure water supply in 2050 [26].

Energy requirements for desalination plants depend on the:

- volume of water produced;
- salinity and temperature of the feed-water;
- quality of the water produced; and
- desalination technology used.

While several desalination technologies exist, the reverse osmosis technology (RO) is most commonly employed [31]. Taking into account the additional pumping requirements involved in conveying the feed, concentrate, and permeate steam, the overall energy needs amount to 3.7 kWh_e/m^3 of product in RO seawater desalination [32].

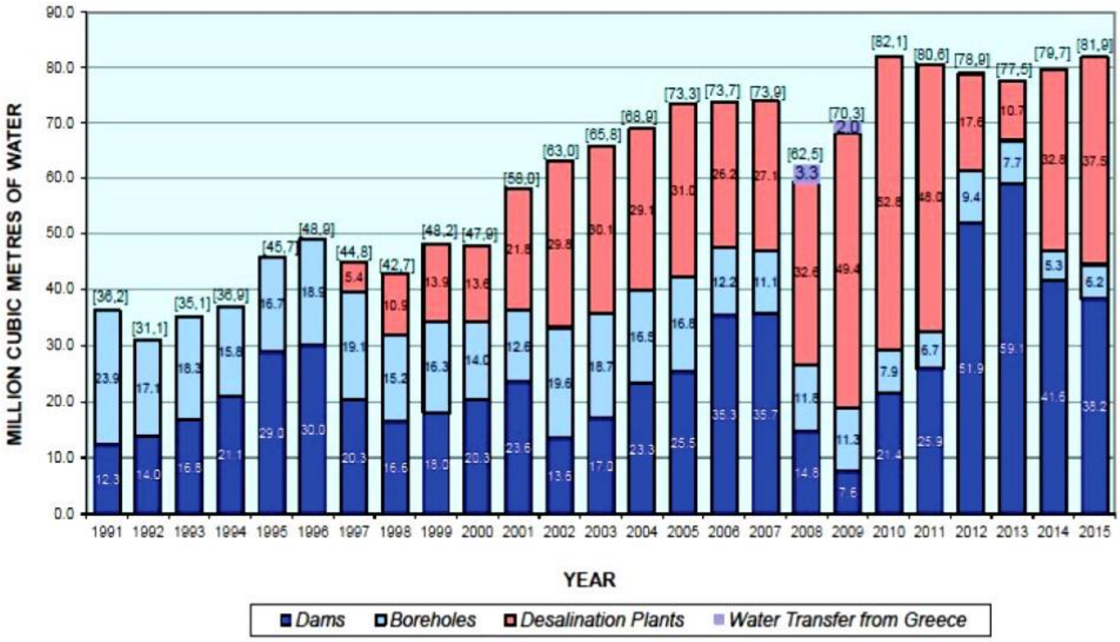

Figure 8: *The supply of water to domestic consumers by the Cyprus authorities for 1991-2015; source:* [2]

Looking specifically at the case of Cyprus, ever since desalination had been introduced in 1996/97, its importance for the provision of drinking water has steadily increased (except for selected "wet years"; Figure 8). In 2015, the total volume of desalinated seawater amounted to about 37,5×10^6 m^3 in 2015 [2]. This implies that 0,14 GWh of electricity had to be expanded for its production. In the same year, the Electricity Authority Cyprus, which supplies the bulk of electricity to the Cypriot consumers, generated 4,128 GWh of electricity consuming 947 226 tonnes of (largely fossil) fuel [33]. Thus, about 3,4% of electricity produced in Cyprus had to be used for desalination.

All of the considerations above underline the fact that the interrelationships between water and energy, in general, and in the MENA Region/countries, in particular, and in light of the anticipated changes in climatic conditions require heightened attention with regard to effective mitigation and adaptation strategies that will briefly be described in the following section.

4. Adaptation-/Mitigation Options and Strategies

4.1 General considerations

In order to maintain energy- and water security as well as adequate indoor living conditions in the MENA Region undergoing progressive shifts in climate conditions requires well-conceived measures. These measures should aim at minimizing adverse effects of these changes (adaptation) and should address the reduction of forcings behind their origin (mitigation) effectively. In general, we need to find ways to enhance the adaptive capacity on the local, national and regional scales. Even though the total population accounts for only 5,8% of the global population, the emission of carbon dioxide from MENA countries stands at 8,6% [34]. Thus, mitigation measures are equally required in some of the MENA countries, specifically in Iran and Saudi Arabia. These countries rank seventh and eighth in the list of carbon emitting countries worldwide [34].

4.2 Options/Measures/Strategies: Water

Water, adaptation options/strategies include (but are not limited to):

- planning for extremes (floods): modeling and mapping flood extends and hazards,
- artificial recharge of groundwater resources by reservoirs and check dams,
- recharge of groundwater in severely depleted aquifers by tertiary-treated sewage water,
- (limited) use of tertiary treated sewage water in private households, public works and agriculture,

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- shifts from water intensive to draught tolerant crops,
- supplemental irrigation of rain-fed winter crops instead of full irrigation of summer crops,
- rainwater harvesting for irrigation,
- more effective and more appropriately timed irrigation measures,
- policies to reduce water demand, such as subsidies and extension support for modern irrigation systems,
- reforestation of marginal, abandoned agricultural lands,
- analysis of environmental flow requirements and options,
- improving rainfall-runoff management and use in urban areas, such as rain water harvesting for landscaping and groundwater recharge,
- improved leakage detection in urban water distribution systems,
- offering incentives for reduced water consumption in private households through tailored tariff systems.

These measures require actions and innovations in technology, agronomy and agriculture, civil and water engineering, and in public water administration. While a number of these measures are well underway in some of the MENA countries, a more integrative and holistic assessment of activities needed to advance adaptation and mitigation in the water sector is still largely forthcoming.

4.3 Options/Measures/Strategies: Energy

The employment of renewable energies in combination with enhanced energy efficiency provide significant opportunities to reduce greenhouse gas emissions and to increase energy security in the MENA Region. The latter is particularly relevant with regard to the aforementioned additional electricity needs for space cooling, on the one hand, and for the generation of potable water through desalination, on the other. In addition, renewable energy generation requires significantly less water for cooling compared to fossil-fuel based power plants. These considerations should be taken into account by decision makers in MENA countries with regard to the installation of additional power generation technologies, which is needed to satisfy the growing water stress in the region [26].

A technology, which holds particularly high potential in the MENA Region is the concentrating solar power (CSP) technology. CSP plants represent solar-thermal facilities for electricity generation that combine the capability of a thermal energy storage medium with alternative hybrid operations employing either solar energy harvested or fossil or bio-fuels. This enables -at least potentially- the provision of electrical power on demand, 24h a day and 365 days a year [for more details, see: 31]. The core element of a CSP plant is a field of large mirrors reflecting the captured sun rays to a small receiver element, thus concentrating the solar radiation intensity by about 80 to several 100s times and producing high temperature heat at several 100 to over 1000°C. This heat can be either used directly in a thermal-power-cycle based on steam turbines, gas turbines or Stirling engines, or accumulate in a heat storage medium such as molten salt, concrete or phase-change material to be delivered at a later point to the power cycle for night-time operation. While wind and photovoltaic power systems (PV) deliver fluctuating power and either allow only for intermitting solar operation or require considerable conventional backup, a concentrating solar power plant can deliver stable and constant power capacity, due to its thermal energy storage capability and to the possibility of hybrid operation with fuel. This represents one of the major advantages of the CSP technology compared to other renewables [35]. As a consequence, CSP plants can save more fossil fuel and replace more conventional power capacity compared to other renewable energy sources such as PV and wind power [for more details, see: 31].

4.4 CSP for the co-generation of electricity and desalinated seawater

While CSP plants for electricity generation have been developed fully and employed in commercial operations, a more recent innovation aims to utilize solar power for the co-generation of electricity and desalinated seawater (DSW) through CSP (called here: a CSP-DSW plant) [31]. A CSP-DSW plant addresses a number of particularly pressing problems in many countries, e.g., Cyprus, including:

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- the generation of electricity by renewable sources rather than by the burning of fossil fuels,
- a reduced dependence on fossil fuel and the international energy markets if energy is produced conventionally and
- the need for an environmentally friendly production of potable water through desalination.

Thus, if realized, substantial benefits may be gained, despite the likely substantial capital investments needed to realize CSP-DSW plant [for more details, see: 31].

The co-generation of electricity and water in a CSP-DSW plant has been studied in detail by the Energy, Environment and Water Research Center (EEWRC) of The Cyprus Institute [36,37].

The design incorporates a number of innovative elements/technologies, including [31]:

- energy harvesting by a field of Heliostats on a hilly, south facing, location near the sea,
- capturing of the solar energy by a central receiver and conversion to heat to be stored in a salt container of novel design at high temperatures,
- steam generation from the heat reservoir of the salt container or from an alternative thermal storage concept,
- electricity production using a commercially available steam extraction turbine,
- generation of desalinated water through the use of an innovative Multiple Effect Distillation facility (MED) with a Thermal Vapor Compressor, from the heat output of the steam turbine and other heat sources of the system,
- alternatively, or in addition, desalinated seawater can also be generated by an RO plant principally driven by electricity produced in the Power Cycle of the combined CSP-DSW plant.

It is obvious that the integration of all major components of this plant represents a tremendous integration/optimization task. However, to date, the plant is almost fully operational and planning is underway for the design of a prototype plant [38].

5. Conclusions

Based on numerical climate modeling, more extreme climatic conditions are expected in the MENA Region. These changes will have economic implications as well as human health and environmental consequences. Climate change impacts on water, energy and food securities are significant. It therefore becomes mandatory that a more comprehensive nexus approach to adaptation and mitigation is being employed. While many promising adaptation/mitigation options/strategies exist, their implementation is often hindered by a prevalence of sectoral/silo thinking and thus still forthcoming in many of the MENA countries. In addition, a multi-level concept including all relevant stakeholders and a multiscale approach to policy making across political borders will be needed to address the challenges of the WEN.

More specifically, the challenges to energy and water security and their links to ongoing and future climate change will risk the reinforcement of existing social inequalities and may thereby trigger additional political instability in the MENA Region. In addition, a continued reliance on energy and food subsidies aimed to legitimize existing political regimes proliferates an inefficient use and distribution of energy and water [39].

Due to the fundamental links between energy, water, climate, development and political stability, policy-makers need to address these interdependent challenges to enable growth without neglecting its distributive and environmental aspects. Such an integrated approach can be achieved through creating regional cooperation and community through which the future well-being of MANA societies will be secured.

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