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REVIEW ARTICLE

The application of water–energy nexus in the Middle East and North Africa (MENA) region: a structured review

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Abstract

Water plays an important role in power generation, fuel manufacturing, and processing. This has been valid for several decades, but lately, primarily due to climate change, the limitations and insecurity related to water energy connections have become more prominent. The article is a quantitative review study conducted to evaluate the water–energy nexus in the Middle East and North Africa (MENA) region. Information about the review was generated from online databases by using keywords such as water–energy nexus, MENA region, Power Generation, Fuel Manufacturing, Energy-intensive, Energy Management Decisions, and Desalination Systems. Drip irrigation in Morocco played a vital role in the water–energy nexus for resource conservation and their better utilization. From the findings, it was revealed that distorted coupling with a relatively low reliance on freshwater energy systems has a high reliance on conceptual water and energy production systems. For Saudi Arabia, extraction and desalination of groundwater are projected to be up to 9% of total annual electricity use. Policymakers should consider energy implications for water-intensive food imports and possible water demand restructuring. This would lead to more coordinated water and energy management decisions. A comprehensive evaluation in some cases promotes the reuse of water and improvements in the agricultural sector rather than the development of energy-intensive and expensive desalination systems. One of the limitations for water–energy nexus in the MENA region is its unintelligible patterns for policy and decision-makers, and this quantitative review can be a major advancement in this regard. This study also highlights the use of water as an energy production source as well as the energy that is being utilized in water treatment and processing and their interrelationship. Cohesive and strategic tactics can lead technology's research and development to reporting local issues of water and energy issues. Improving and participating models and data will better assist scholars, decision-makers, and the community. This water–energy nexus study mounts relevant challenges and areas of improvement for future research.

Keywords Power generation · Fuel manufacturing · Energy-intensive · Energy management decisions · And desalination systems

Introduction

Globally, the relationship between water and energy has attracted an interesting scientific debate based on the demand increase and interconnections between water and energy commonly called the 'water–energy nexus' (Lange 2019). Water–energy nexus (WEN) is associated with the effective integrating of water and energy reserves to address a wide variety of planning, implementation, and optimization challenges for mechanisms that include both resources. Water and energy interconnections are complicated, and they have both impacts on each other. Even though the nexus method has garnered global attention in recent decades, there is still a significant gap in understanding that must be filled if a true revolution is to be reached. The evolving characteristic and occurrence of numerous contradictory energy–water requirements, as well as the diverse interconnections between multiple sources and sinks of energy and water, have a significant impact on prediction even within water–energy nexus, especially given that connected choices are heavily influenced by the preferences of the numerous different stakeholders associated.

Water requires energy, and energy demands water, and the two have become mutually dependent. These linkages have

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tremendous implications for economic development, human life, and well-being. Because energy and water are essential resources for life, they contribute to both sociological and financial growth. Water and energy are inextricably linked since energy is required for water and water is required for energy indefinitely. Energy is used as water treatment and supply, whereas nearly all energy generation methods involve significant amounts of water. In the next few years, the interconnection of water and energy will accelerate with profound impacts on both energy and water stability. As a result of financial, population, and environmental issues, each resource faces increasing demand and restrictions in many areas of the world (Wang and Zimmerman 2017).

Conventionally, per person, energy supplies are plentiful, but a small (or at least not very well comprehended) responsiveness of the economy to shifts in natural frameworks (Fan et al. 2019). However, from the past few years, there is an upsurge of energy need to integrate the planning of energy and water systems with a dramatic surge of population's understanding within regional climatic conditions and hydrological cycle (Fan et al. 2019). In Fig. 1, interlink of water and energy in different departments and fields illustrates the incorporation of water in energy production and utilization of energy in water production which will be further explained in this article. Water is essential in the development and implementation of energy, as demonstrated by the hydropower dam. Energy is necessary to deliver water to communities, clean both potable and sewage, and extract water. Water is required for proper cooling, discharge, refining, processing, and other activities in the fuel and energy manufacturing sectors. Variations in the groundwater table and flow have a significant impact on the quantity of energy generated by dams. Enough water is required for biofuel processing or fossil fuel extraction. In the same way, energy in the form of power is utilized for wastewater treatment, salt removal from seawater.

Current scenario of MENA region

MENA region includes countries like Iran, Iraq, Algeria, Egypt, Bahrain, Israel, Kuwait, Libya, Jordan, Morocco, United Arab Emirates Lebanon, Saudi Arabia, Oman, Yemen Qatar, Tunisia, and Syria. The area of MENA comprises less than 2% of the earth's freshwater with about 6% of the world's inhabitants (Al-Otaibi 2015). Currently, the MENA region is regarded as one of the highest food stability declining regions in the world. Furthermore, poor cross-resource productivity and human insecurity have also been raised over the past decades (Eken et al. 1996). The MENA region especially the Middle East is among the limited water zones on the earth with an estimated water supply of 1200 m^3 per year. The estimated region's population increase is about 1.8% and yet 80% of sustainable water supplies are being considered wasted only with an estimated supply of water for each individual, which is around 1200 m^3 per year and with a population increase of 1.8%, and about 80% of all sustainable water supplies are wasted in that country. Approximately, 60% of the inhabitants in this region now live in severe or extremely elevated water demand rate, while worldwide average water demand is around 35% and currently higher than 70% of the region's Gross Domestic Product (GDP) in places with a high-water constraint or a very increased water stress rate, which would be 22% on average globally (Bank 2008, 2017; Sowers et al. 2017). The level of energy utilization is directly proportional to the level of financial growth. As a result, understanding the course of action of the link between energy expenditure and capital development is critical in defining the sensible energy policies of MENA nations, which have the world's most valuable oil and natural resources. These developments intersect with nothing but a swift shift to sustainable and non-conventional water supplies with unclear cross-cutting and sectorial repercussions. The poor governance with wide disparities

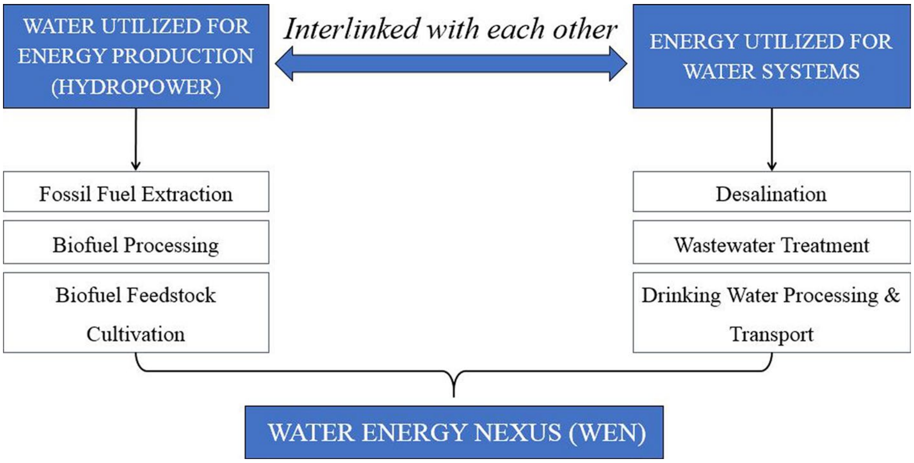


Fig. 1 Water and energy interrelationship

in executing the MENA region in any field is compounded by the absence of strategy cohesiveness (Ahmed and Azam 2016). These circumstances demand integrated water, electricity, land, and biomass monitoring, as well as effective utilization in all sectors. Such interconnected interventions would improve human, water, energy, food protection, ecological, and climate stability. In the MENA region, where numerous limitations, such as inadequate stimuli, restricted vision, skills, and expertise to direct technology growth and investment, lead to this difficulty by that: This is especially challenging in the MENA region, where several constraints, such as insufficient stimulus, limited vision, skills, and experience to guide technological innovation and investment, contribute to the problem (Ahmed and Azam 2016).

In the MENA region, rapid urbanization, economic expansion, and water requirements are the basic need of the region, but natural boundary of resources usage is further aggravated. Similarly, present construction paths are contributing to a decline in the capital base and rising shortages, combined with inefficient management activities. Previous findings have shown that MENA is being influenced primarily by climate change that limits rainfall patterns and rises in temperature, and the intense water shortage (Droogers et al. 2012). Power demands were higher than the local potential to be self-sustainable in food production in this area with the highest water shortage in the world (Droogers et al. 2012). Changing climate, socioeconomic expansion, shifting consumption patterns, increased residential and industrial water demand, and population expansion are the main reasons behind water shortage. Water resource exchange and potential have been highlighted because of increasing water shortages. For example, pressure on agricultural production to fulfil regional food safety regulations has a direct influence on water demand (Zaidi et al. 2018). A comparison methodology gives insight into different challenges to water supplies around MENA from the socioeconomic to the growth and nature (Hoff 2011).

Although a plethora of water–energy study work has been done within the region, however, only hand full has captured water–energy study holistically. To close this gap, this paper discusses the interrelation of energy and water with special emphasis on the MENA region and highlights the various policies, and regulations adopted by MENA countries. Furthermore, the paper addresses challenges and opportunities for innovation in the water–energy nexus domain. It also seeks to establish the direction and amount of the energy utilization growth link to make alternative legislation recommendations for these nations to achieve better economic expansion outcomes. Additionally, the paper discusses how energy is utilized in water and wastewater treatment, processing, and distribution, as well as how water is consumed in the extraction of fossil fuels, coal generation, and biofuel production. This analysis provides a comprehensive and quantitative assessment of water network power utilization and use of water at a state scale in the region of MENA. Furthermore, we discuss the broader problems of water sources and their energy consequences including the climatic changes for future planning using the quantitative findings. The article further explains the utilization of energy in renewable and non-renewable resources and offers solutions as to how natural resources can be conserved for the present and future generations.

Limited availability, variability, and unpredictability in water resources are now more prevalent throughout the Middle East and North Africa (MENA). Since water and energy are intertwined, water resource availability and predictability can have a direct impact on energy operations. We cannot expect the future will be the same as the past. These are significant problems that must be addressed.

Water is being used in every step of the energy and electricity production process. Energy is needed to obtain, convey, and supply high-quality water for a variety of human applications, as well as to treat waste fluids before they are released into the environment. Factually, water–energy nexus has been reflected on a technology or regional basis. At countries of MENA region, water and energy systems have been managed, advanced, and structured independently. These drifts may cause challenges along with some opportunities as well.

The objective of the study is to conduct an extensive review on water–energy nexus in the MENA region. The objectives of this article are to highlight the methods, strategies, and technologies in MENA region and the interrelation between energy and water. The article discusses a case study of drip irrigation in Morocco and the application of solar energy in Jordan. Moreover, the different types of nexuses of different region especially water–energy nexus of different regions are summarized and their respective relationship has been drawn. In the best of the knowledge, there is no review study found in the literature of this stage on MENA region.

The rest of the review is conducted as follows: "Methodology"Section describes the methodology for conducting this quantitative review. "Need of water–energy nexus (WEN) in the context of MENA and Relationship between water and energy"Section discuss the need and relation of water–energy nexus, respectively. "Water utilization in water–energy nexus (WEN)"Section describes the water utilization in water–energy nexus. Section Energy for water describes the energy for water concepts w.r.t different technologies. Section Energy and wastewater sectors describes the energy and wastewater relationship that how the energy can be produced from wastewater. "Case study of applying renewable energy (solar) in Sahara forest in AQABA (JORDAN)"Section describes the case study regarding adopting of renewable energy technologies to improve water–energy nexus. Hydropower opportunities in MENA region to extract energy. "Hydropower opportunities in the water and wastewater sectors"Section represents the hydropower opportunities in water and wastewater sectors. "Energy strategy for the water and wastewater sectors"Section describes the energy strategy for water and wastewater sector. "Case study of adopting drip irrigation in Morocco"Section describes the case study related to drip irrigation system to utilize the wastewater. "Energy challenges and opportunities for water–energy nexus"Section describes the energy challenges and different case studies to overcome these challenges. "Linkages of technological development with nexus aproach"Section describes the linkages of technological development in improvement in water–energy nexus. "Conclusions and future recommendations"Section describes the different types of nexuses of other region and especially water–energy nexus of other regions w.r.t most and least dominant regions.

Methodology

Figure 2 shows a brief flowchart for methodology adopted to carry this review study. This study is carried out by exploring the literature with start from current scenario of MENA region including economic activities of region and need for water–energy nexus and interlinked relations are discussed. Then, role of water utilization and energy to water and water to energy concepts are elaborated. By supporting the water to energy concepts, the hydropower opportunities are discussed, and some case studies of different regions are presented. Then in second last stage, the challenges and issues regarding water–energy nexus are summarized. In last step, different types of nexuses and especially water–energy nexus with respect to different regions across the world are summarized.

Need of water–energy nexus (WEN) in the context of MENA

In metropolitan areas of MENA, around 66% need for water has been raised. The Gulf Cooperation Council states have higher urban development ratios, i.e., in Saudi Arabia 84%, in United Arab Emirates (UAE) 87%, and in Qatar almost 99% (Zolfaghari and Jariani 2020). Likewise, 91% of the Jordanian population lives in urban areas and 89% of the Lebanese population residing in city centers. The MENA, a mega-city of almost 21 million inhabitants, is considered the most populous city in Cairo, Egypt. (Weinthal and Sowers 2020). Lack of multifactorial understanding of water–energy nexus and low consideration of resource conservation are implying pressure on available resources in the wake increasing demand. A few variables are driving MENA's intense growth, including rural-to-urban movement, demographic growth, and relocation by war. The recycling of oil costs against benefits and large influxes of worker expatriates in all sectors, such as building projects, banking, education, and service providers, led to rapid urbanization in oil-exporting countries. These factors have contributed to the enhancement of stress on water and energy natural resources in the MENA region. Therefore, several measures have been put in place to invest in large-scale water infrastructures to enhance city-level water availability for drinking and regular use in urban areas. Water is comparatively increased per capita usage, and municipal infrastructures have high dissipation costs and constrained recycling or reuse of water (Hamiche et al. 2016a).

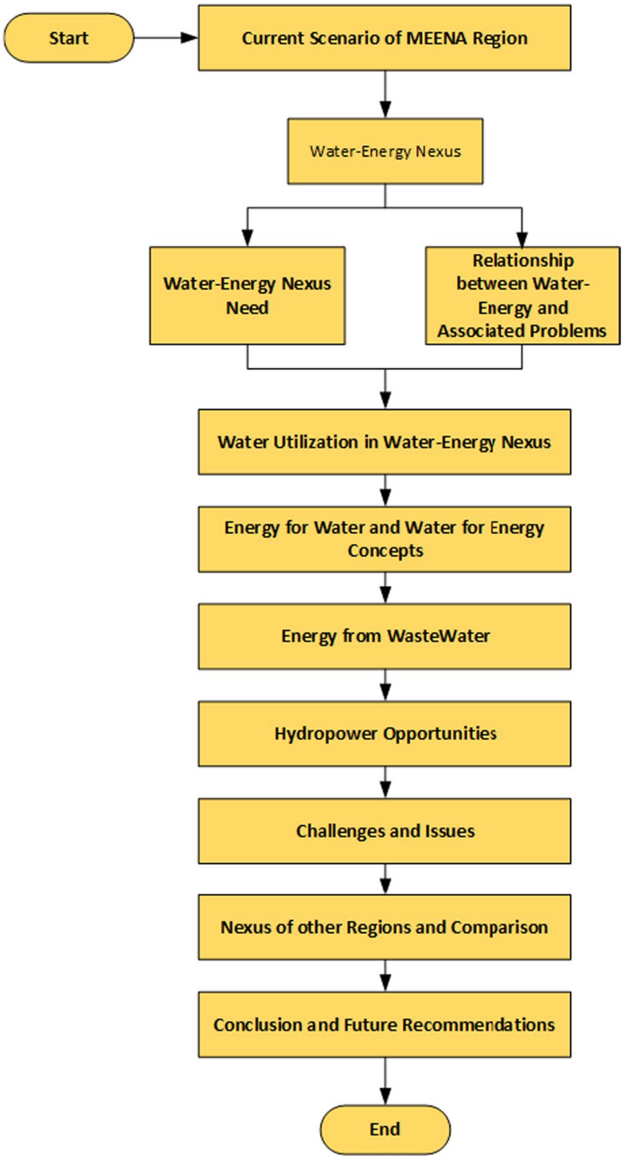


Fig. 2 Flowchart diagram for adopted methodology for conducted review study

The MENA's rising dependency on desalination underscores the need of good administration of the water linkage, with consequences for energy and water stability. Desalination power subsidies dissipate sustainability, recycling, and treatment opportunities, while absurdly cheap water tariffs are maintained (Mekonnen et al. 2015). Energy consumption during desalination influences the water–energy nexus. In the light of increased energy consumption and rapid urbanization, cities in MENA have become huge partners in implementing energy transformation strategies. Currently, two-thirds of the water production from saltwater desalination in the region comes from thermal desalination using fossil fuels, with the remainder coming from membrane-based desalination that primarily relies on power generated from natural gas. Overall, the Middle East and North Africa (MENA) account for about 90% of the thermal energy required for desalination globally, driven by the United Arab Emirates and Saudi Arabia. Most of the aggression in MENA disputes throughout the past decade has surged in the areas of Syria, Yemen, and Libya (Keulertz et al. 2016).

Relationship between water and energy

The primary methods for the analysis of the water–energy nexus include case studies, accounting, life cycle assessment, economic models, econometric models, and multivariate statistical analyses (Dai et al. 2018). Water and energy are interdependent and stringently connected (Fayiah et al. 2020a). Macro-level findings are employed to attain a comprehensive view of water–energy nexus (WEN) in a provided area while simultaneously dealing with interlinkages of water and energy. Consequently, more complex than conventional water and energy networks may be included in a broad water–energy nexus (Hussey and Pittock 2012). In the commercial, residential, and industrial sectors, water–energy nexus is significant. Heat treatment and pumping water consume considerable amounts of energy, whereas cooling systems consume significant amounts of water. Water is also employed in the generation of fuels.

The uncertainty stems largely from the existence of systems that intake water and generates energy concurrently (or vice versa). The connections and synchronization between highly integrated water and energy systems are a major priority in a water–energy link (Weinthal and Sowers 2020). Eventually, it identified a link between energy and water use as an integration of water-mediated systems. They have used this technique for practical nexus networks at diverse urban, domestic, and international sizes through input assessment and ecological network interconnections (Dai et al. 2018).

The whole categorization structure in Fig. 3 illustrates the basic flow pattern mostly from the environment, the water source, and initial electricity as well for final consumers, in the water and power generation sectors. In the identification of the possible links between water and energy, this study divides the functions into 'Manufacturing,' 'Transport,' and 'Utilization.' The division of 'Energy' covers environment-focused aspects including primary and supplementary energy, large-scale power generation, excess water demand, and desalination. The criterion 'Utilization' includes components comparable to final consumers like water and electricity retail, wastewater processing, implanted development, and application consumers. The segment of 'Transportation' involves electricity transfer and utilization, and water and wastewater collection (Hamiche et al. 2016b).

Water and energy problems in MENA region

Earlier research findings evaluating the entire MENA region revealed a significant shortage of water (Watkins 2006). In MENA, a continuous development is seen in population, urbanization, and quality of living development. Thus

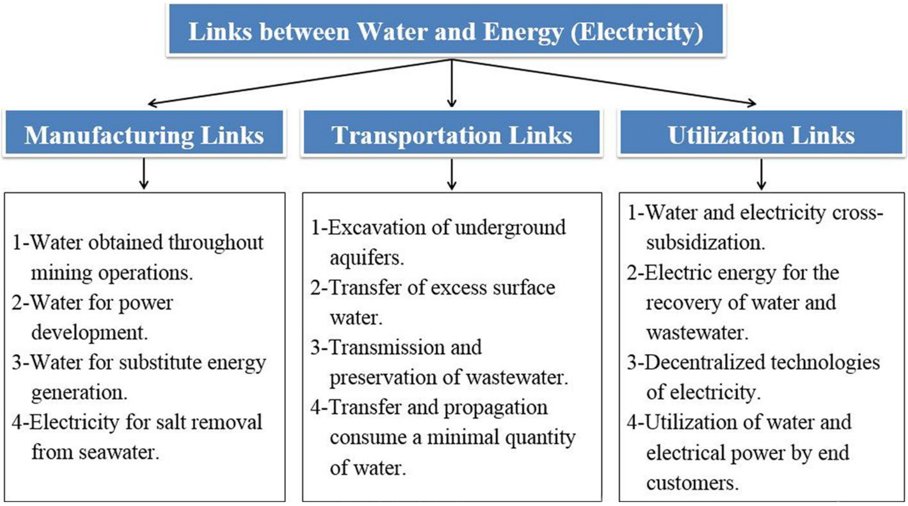


Fig. 3 Basic flow pattern from environment, water, and other energy sources

referring to UN projections, 64% and 76% more people are projected in North Africa and Western Asia by 2050, respectively, than in 2005 (Watkins 2006). The requirement for energy and water is forecasted to expand and substantial investments should be made in developing new supply sources of water and the production of electricity (Farid et al. 2016). The associations between energy and water mechanisms are thus crucial to understand so that the most efficient and effective framework of infrastructures can be implemented (Bahri 2008a).

This analysis provides a comprehensive and quantitative assessment of water network power utilization and use of water at a state scale in the region of MENA. Furthermore, we discuss the broader problems of water sources and their energy consequences including the climatic changes for future planning using the quantitative findings.

Water utilization in water–energy nexus (WEN)

Water is utilized mainly in two fields of the energy sector, namely the generation of fuel and electricity. These operations could incorporate multiple techniques with very different criteria for water consumption. It is essential to identify between water extraction and usage in the discussion of water usage in energy generation (Lange 2019). Water is converted into a different state with usage so that it could not be implemented later in the region's yearly hydrological cycle for other applications. For example, this might have evaporated or disposed of after it is contaminated (as is often the case when oil is being manufactured), like in the terms of thermal cooling (Mielke et al. 2010). Cooling, storing, improved recovery of oil, and hydraulic fracking are all uses of water in the energy sector. The Rankine cycle, which generates thermoelectric power, relies heavily on water. The water system uses energy as well, especially for pumping and cleaning public water and wastewater. The outflow of water is driven by thermoelectric cooling, whereas the water demand is dominated by agriculture (Fayiah et al. 2020b).

Water for oil extraction and refining

It has been indicated the water expenditure of a variety of transport fuels on a gallon-per-kilometer basis for production, mining, processing, and refining. Particularly irrigated feedstock has roughly two orders of intensity the greatest life-cycle water utilization. Water utilization for primary extraction, subsequent water removal, and improved tertiary recovery is a major part of the life cycle consumption and drainage of petrol and diesel. All biofuels and petroleum-based fuels must be refined with some water (Wu and Peng 2011).

Although the processing of corn ethanol in a dry facility requires nearly threefold the quantity of water as oil is refined per mile, refining is an essential component of the natural life cycle of oil–water use. Since more fuel is generated nationwide than ethanol, the national total amount of oil refining water usage is higher. For instance, in UAE major portion of its primary energy supply is generated from natural gas reservoirs, which is almost 81.5% (Gaies et al. 2019).

Fuel extraction and production in MENA region

Due to major differences induced by the introduction of various technologies and methods, broad varieties of values occur. This wide range of water requirements must be implemented in energy planning. The processing of maize ethanol, for example, compared to shallow gas and oil, has very high water demands. Promoting biofuels may have a negative impact of increasing water use to minimize oil imports and carbon dioxide emissions (Mielke et al. 2010; Gerbens-Leenes et al. 2009).

Water is required for transportation fuel generation and refining. Water is used and produced during the extraction of fossil fuels, for example. Hydraulic fracturing fluid, generated water, and flow-back all have a life cycle that can be managed to reduce the amount of freshwater needed, disposal, and environmental impact. Petroleum biofuels and fuels entail water removal and intake over their life cycle, involving mining, growing, and processing (Fayiah et al. 2020b).

The procedures of oil manufacturing and refining are particularly important for MENA countries that require the utilization of water. In customary oil extraction, the utilization of water is not substantial. However, advanced techniques for enhanced oil recovery (EOR) may be fairly water-intensive. Considerable amounts of water are utilized as heat and condensation water in the refining process (Harto et al. 2010).

Fuel refining and processing in MENA region

Oil, uranium, and natural gas both need refinement before they could be utilized as fuels, requiring large quantities of water. Unfortunately, fewer than 5% of the world's available oil supplies are of similar standard. A few of the highest performing crude oils are extracted in northwest Pennsylvania, in the region of Bradford, and the term Pennsylvania crude is often regarded as a quality benchmark for crude oils. Internationally, ancient deep crudes are occurring in Morocco (Zhang et al. 2016). Calculations reveal that perhaps the energy industry does not presently place stress on Jordan's water resources, according to low levels of local oil cultivation and export, as well as the types of electric power plants (Gaies et al. 2019).

Fuel storage and transportation

Water is utilized for the shipment of coal via slurry, pipelines of finely grounded coal combined with water, and for the testing for leakage energy pipelines. The fuel in the storage tank has been under pressure and can flow spontaneously to the surface. A water pipe where the liquid lies under the oil pushes that to the surface or a gas cap push where a gas bubble drives it down onto the surface may become the operator accountable for oil flow. Settled output happens as oil needs to be drained out of the field (Zhang et al. 2016).

Emissions control

Due to the significant rise in global refining capacity in MENA region, operation planning and general optimization have become powerful components for the refining sector. Environmental restrictions and the threat of climate change, on the other hand, are forcing the refinery industry to reduce emissions of greenhouse gases. According to the findings, MENA region should undertake strategies to minimize pollution while also stabilizing productivity development. Increasing the share of renewable energy in comparison with non-renewable energy sources is one of these policies. Almost all thermo-electronic systems release sulfur, mercury, particulate matter, carbon dioxide, and other contaminants. These processes also consume huge volumes of water (Zhang et al. 2016).

Water for electricity generation

In the power industry, as questions about water consumption emerge as a non-negligible element in the cost of electricity (COE), the water footprint of energy production arises. This could occur due to the following circumstances:

1. *Operational costs* Water or waste disposal costs are an unacceptable portion of the electricity prices leveraged.
2. *Construction costs* Legislation or shortage of water compels operators to invest in more expensive infrastructure. (For example, a dry or hybrid cooling device, a discharged water treatment structure, etc.)
3. *Capacity Factor* Water-related problems lead to plant shutdowns (both due to the shortage of cooling water and due to fear of non-compliance with the rules on the released water temperature during heat waves).
4. *Thermal efficiency* The manufacturer is forced to install an efficient cooling system which in impact increases fuel demand per electricity unit and increases COE.
5. *Permitting delay* The use of water entails delays in the construction of plants, prolongation of shortage, and growing COE (Mittal 2010).

Since expense and revenues of the power plant rely on several (and at times difficult to achieve) parameters. Sometimes a qualitative economic assessment is not of much help to figure out when and why the use of water is relevant in the power sector.

Water used in thermoelectric generation systems

For cooling purposes steam is being used in turbine exhaust, water utilization in Thermoelectric Generation System wherein steam is utilized in the power of a turbine is quite considerable (Borgomeo et al. 2018).Those kinds of techniques can produce hot air from non-renewable sources (including fossil fuels like coal, oil, and gas), biofuels (often including wood or effluents), solar and geothermal energy (Averyt 2011).

Three main cooling systems are available: open loop (further classified as once-through cooling), closed loop, and dry loop. In open loop, cooling water would be drained and then released back to its generator at elevated temperatures. For this purpose, water is sometimes taken from a lake, dam, aquifer, or sea to cool steam and then restored to the origin at extremely high temperatures (Madden et al. 2013). In closed-loop systems, warm water allows the atmosphere to lose evaporation. Power plants are then cooled in by evaporating cooling water. A cooling tower or a refrigerating pool is used to pump water in a closed circle. In water-constricted locations in which the intensity between consumers is high, power plant water usage is becoming an important issue. It eliminates just a portion of the volume that systems once do; however, more or all of it absorbs (Macknick et al. 2012). In dry cooling, air is used for heat removal with small consumption of water. If the supply of the water is not limited, water cooling is generally preferred, because the cost of capital and thermal efficiency is lower (Macknick et al. 2012).

Cooling systems used in thermoelectric generation systems According to Abbass et al. (2018), freshwater is primarily inadequate in the MENA region in once-through cooling systems (OTF), with Egypt as an exception. Steam turbine generators and brackish water (OTB) also consume seawater. In Egypt, the OTF cooling systems account for 25% of the overall installed configuration and only account for 0.006% of the total water drawn (Abbass et al. 2018). There is a significant amount of freshwater cooling in three other MENA countries. In Turkey, 0.4% of power generation capacity is represented by OTF systems; 5% and 7% are in Iraq and Syria. Renewable energy consumption is small

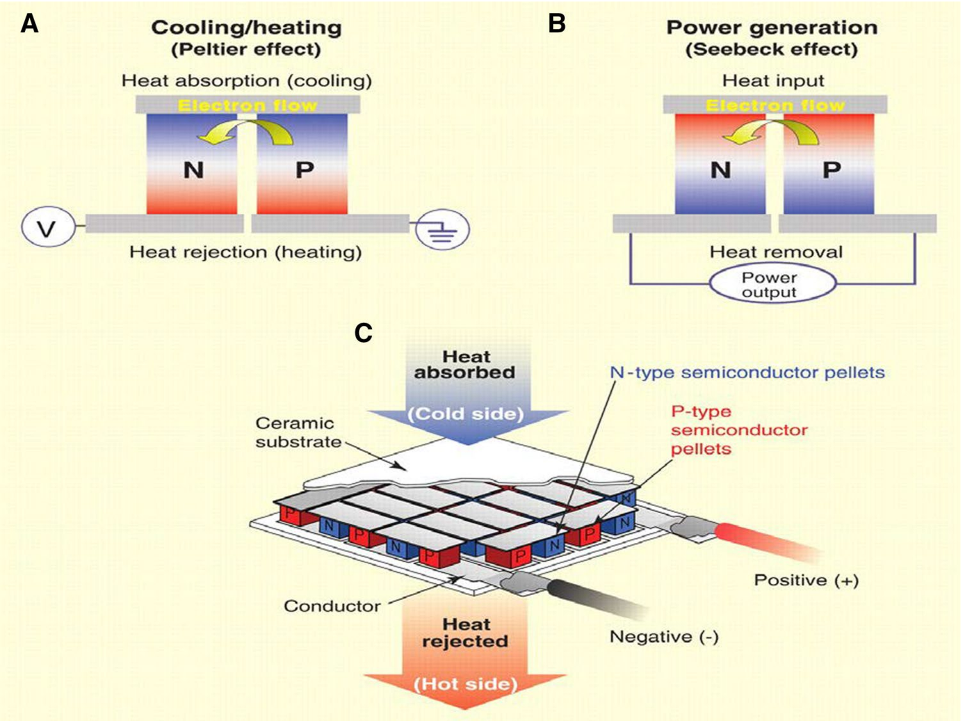


Fig. 4 Water-cooling systems in thermo-electric generator

in the majority of the MENA countries (Hutson 2000). The water-cooling systems are shown in Fig. 4.

On the other hand, Zarei (2020) argued that the cooling systems in electrical power plants accounted for 39% of freshwater intakes and 3% of freshwater usage in the USA in 2015. The electricity output depends relatively weakly on freshwater cooling in MENA; the system is not closely linked to the existence of freshwater (Zarei 2020). It is to be considered in the Arab Peninsula of the MENA region since these countries do not have major freshwater sources. Nevertheless, the reliance on energy production in freshwater countries with an abundance of freshwater traditionally in Iraq, Turkey, Iran, and Egypt is also small (Torcellini et al. 2003).

Water utilization for electricity production in MENA region

The two most popular kinds of plants are steam turbines (STs) and gas turbines (GTs). Hydropower plants (HYs) are also a substantial part of the power generation mix in Egypt, Iran, and Turkey. Steam turbine plants are the most significant regarding water use. GT plants do not use cooling water, which is mostly due to large dams' evaporative losses and water usage in the hydropower systems. The hydroelectric water utilization was measured with the proportion of the whole quantity of surface water consumption to renewable energy (Tan and Zhi 2016). According to the decreased estimation, all countries experience fluctuations at or below 0.1% (of 1429 gal/MWh). The approximate limit (6882 gals/MWh) shows a loss of between 0.5 and 0.7% to Morocco, Syria, Egypt, and Turkey. In many nations, apart from Turkey and Egypt that have wide barriers, the lower approximation can be expected to refer to higher consumption (Cunha et al. 2017). The electricity capacity usage in the MENA region is shown in Fig. 5.

Energy for water

The overall energy implication for water varies markedly based on geospatial, physicochemical, and technical aspects. Energy is required for the drainage (e.g., for pumping of groundwater), for restoration (e.g., for saline wastewater treatment and then reuse), for dispensing (for example, transmission of water over lengthy piping systems and densely populated supply structures), for use (example for commercial, domestic, and irrigation applications), and for preventing the usage of heat water (Abbass et al. 2018).

Depth of the well (alongside injecting equipment), transport and other variables such as pipeline length, pipeline size, and elevation changes affect energy utilized by water transport and influence the configuration of underground water drilling (Abderrahman 2001). Demand of electricity utilization is incessantly escalating with the population and urbanization.

Electricity consumption in the water sector depends on supply and distribution, wastewater treatment, removal of salts from seawater, and transfer and reuse. Varying water

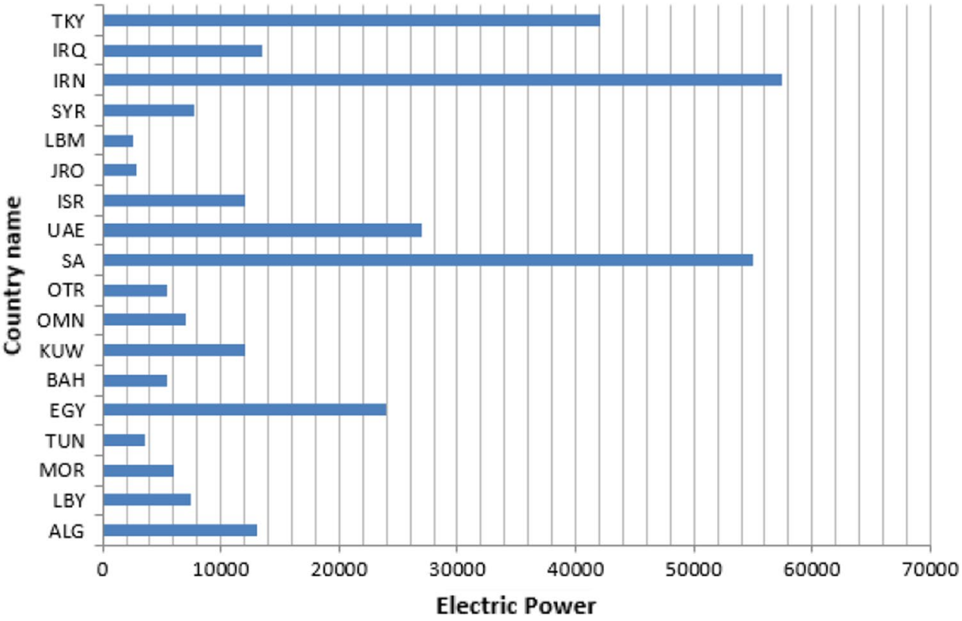


Fig. 5 Consumed electric power per country in MENA region

sources necessitate different levels of treatment. High-salinity water, such as seawater or effluent from certain gas and oil production, requires special treatment. Sometimes wastewater carries substantial amounts of volatile organic content as in municipal wastewater which needs a lot of energy (Hancock et al. 2012). Whenever more atypical forms of water are utilized, the energy demands will rise overall. Desalination can use up to 100 times more energy as treating freshwater. Pumping can also have a variety of energy intensities, based on the situation. The energy needed for pumping is mostly determined by the change in elevation (Hancock et al. 2012).

Energy for water pumping, treatment (desalination and distribution)

Dams and reserves

Current existing and new reservoirs cover the landscape across the MENA region for water supplies, floods are caught, and unpredictable river flows are regulated, and drainage flows are provided during the year. Large dam development is among the most extensive and challenging water–energy infrastructures in the world. Dams have been developed as a tool for encouraging industrial growth and supplying hydroelectric electricity. They also serve to control seasonal water levels, avoid floods, and offer additional storage to be used throughout dry seasons (Adamo et al. 2020). Dam building also leads to people displacing their land and cultural sites, wetlands are destroyed by floods in water bodies, natural flow shift is changed, evaporation and depletion of water are enhanced, transfers of sediment to downstream deltas are decreased, and interdependence between upstream and downstream consumers is impaired (Coffel et al. 2019).

The analysis of past studies reveals that the dam would only be able to function at full capacity throughout the few months of the rainy seasons (Lange 2019). Egypt is extremely concerned regarding the current timeline for filling the GERD (Grand Ethiopian Renaissance Dam) tank, as this would lead to lower downstream levels as the reservoir is being filled. With temperatures increasing across the Nile Basin due to global warming, leading to enhanced occurrence and length of hot and dry years, increasing cooperation, and monitoring systems may be needed for environmental disruptions. Dams may therefore cause conflict between states, but they may also enhance conditions for dam maintenance coordination. Given the significant differences in water delivery time and space in the MENA, officials have cooperated in massive water distribution schemes to move water from water-rich to water-poor zones. The transportation of farm water and the provision of potable water demanded vast and costly energy inputs (Kaniewski et al. 2012).

Groundwater pumping

Various sources of water often need specific intensities of processing. In general, water treatment with high salinity like saline water or water generated from petroleum or gas management, with significant amounts of degradable matter, for example, domestic wastewater, has an elevated level of energy demand. Thus, the related energy needs will typically increase as more non-traditional water forms are used (Hancock et al. 2012).

In Morocco, Bahrain, Iran, Jordan, Lebanon, Libya, Oman, Saudi Arabia, Tunisia, the UAE, and Yemen, groundwater tends to be the main resource (expected to contribute to over 50% of total region withdrawals). About 84% of the water collection is generated on the Arabian Peninsula, while 8% of the water supply is desalination. Since the raising of water below the soil surface requires more power a surface source gravity transport, many of these countries would likely use massive quantities of energy to access the water (Damerau et al. 2016; Salem 2007).

Data concerning good depths were required in an attempt to achieve an estimated initial order of intensity of energy expenditure for underground water required to pump. The energy required to elevate the volume of groundwater obtained in two very different countries was ascertained by incorporating a pumping efficacy of 70% and significantly decreased well depths (Salem 2007). Excessive extraction of groundwater to augment rained irrigation was necessary for the expansion of harvesting in semiarid and arid areas of MENA characterized by low and irregular rainfall. As somewhere else in the world, post-colonial MENA states have subsidized energy rates to encourage social welfare, thereby encouraging the fast start of motorized pumping and tube technologies to reach seed-soil at low cost (Endo et al. 2017). Depending on heavily controlled energy may have contributed to extensive erosion and contamination of groundwater in the MENA, as well as unprecedented agricultural development. As a result, seawater has infiltrated into renewable coastal aquifers, and both coal and natural groundwater sources have been depleted. Subsidized power has enabled wealthy farmers to pump enormous amounts of groundwater, while displacement from rural areas has contributed to a reduction in conventional terracing and rain-fed agricultural production. Groundwater extraction has consumed 28% of the country's total electricity and fuel consumption. As a result, groundwater resources across the world have been over-extracted, causing substantial friction between cities and villages hinterlands (Weinthal et al. 2017).

Desalination

The process of desalination consumes major energy proportion, followed by large-scale water imports and increased demand for treatment of wastewater (and higher treatment levels). By 2040, the consumption of energy is projected to rise by 80%. However, there are substantial energy-saving opportunities in the water sector if both commercially usable energy conservation and energy recovery capacity are utilized in the water sector (Mannion 2007).

A significant part of the water system in the Arab Peninsula is now covered by water desalination. Based on many proposed projects, this is projected to increase in the upcoming. Table 1 shows a variety of different technologies with varying energy demands are being established for the desalination of seawater. Multiple-effect distillation (MED), reverse osmosis (RO), and multi-stage flashing (MSF) are some of the popular applications. In RO, water diffuses by a selective membrane, removing the accumulation of each salt (like NaCl), which is then released as salt or waste (Damerau et al. 2016).

Electrically driven reverse osmosis

Electricity-driven RO can eliminate other larger organic pollutants as well. Through MSF, water is moved through several chambers of dissolved salts at corresponding lower pressures. The water is evaporated (flash), and the vapor is concentrated afterward. MED seems to be a thin film precipitation method in which vessel solvent is evaporated within the next vessel and hence generates another evaporation radiant heat. Throughout the years, energy compliance (for both heating and electronics) has increased and the performance improvements have been substantial in RO applications in particular (Council 2008).

MENA was 17.9 m^3 million per day, with most of the desalination capabilities in GCC (Gulf Cooperation Council) countries (Saudi Arabia, Bahrain, UAE, Qatar, Kuwait, and Oman). It is primarily based in the Arab Peninsula and has the highest availability of MSF factories. RO-based treatment plants are nevertheless prevalent in Egypt, Israel, and Algeria, and their proportion in the GCC countries is

Table 1 Table showing different desalination technologies used and their energy consumption (Huttner 2013)

Technology used for desalination	Source of energy used	Electricity consumption (kWh/m^3)	Heat consumption (MJ/m^3)
Multi-stage flashing	Thermal	3–5	233–258
Multiple effect distillation	Thermal	1.5–2.5	233–258
MED–TVC	Thermal	< 1.0	233–258
Reverse osmosis	Electrical	3–5	No heat energy required
MF/UF/NF	Electrical	3–5	No heat energy required
Electrodialysis	Electrical	3–5	No heat energy required

predicted to increase over time. The annual desalination water volume by country is estimated for each type of process, assuming all desalination plants operate year-round with their full capacity (Lattemann and Höpner 2008). Desalination produces over 1.6 billion m^3 of water each year, with the United Arab Emirates desalinating approximately 13% of wastewater for clean water (Zekri 2020).

Cost required for desalination Energy requisites for desalination consideration for 33–50% of the total cost of desalination, while the progression of MSF technique has considerably reduced unit water costs over the last 40 years, and possibilities for long-term price declines in both MSF and MED methodologies are most probable to arise through elevated energy restoration mostly from brine outlet. Furthermore, with exception of MSF, which has achieved its technical maturity, MED technology possesses the prospects for further technological innovation (Huttner 2013). Figure 6 shows the estimation of costs in percentages utilized in different desalination technologies like MSF, MED, and RO.

Energy for wastewater collection, treatment, and reuse

Using volume information on treated wastewater, this was projected that all wastewater was subjected to secondary treatment, including an activated slot procedure in which bacteria are supplied with oxygen, and organic dissolves. Nevertheless, in the case of Egypt, only primary treatment has been expected to be used. For primary treatments, the

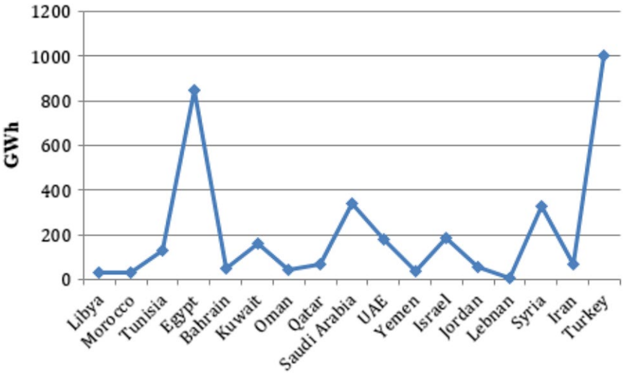
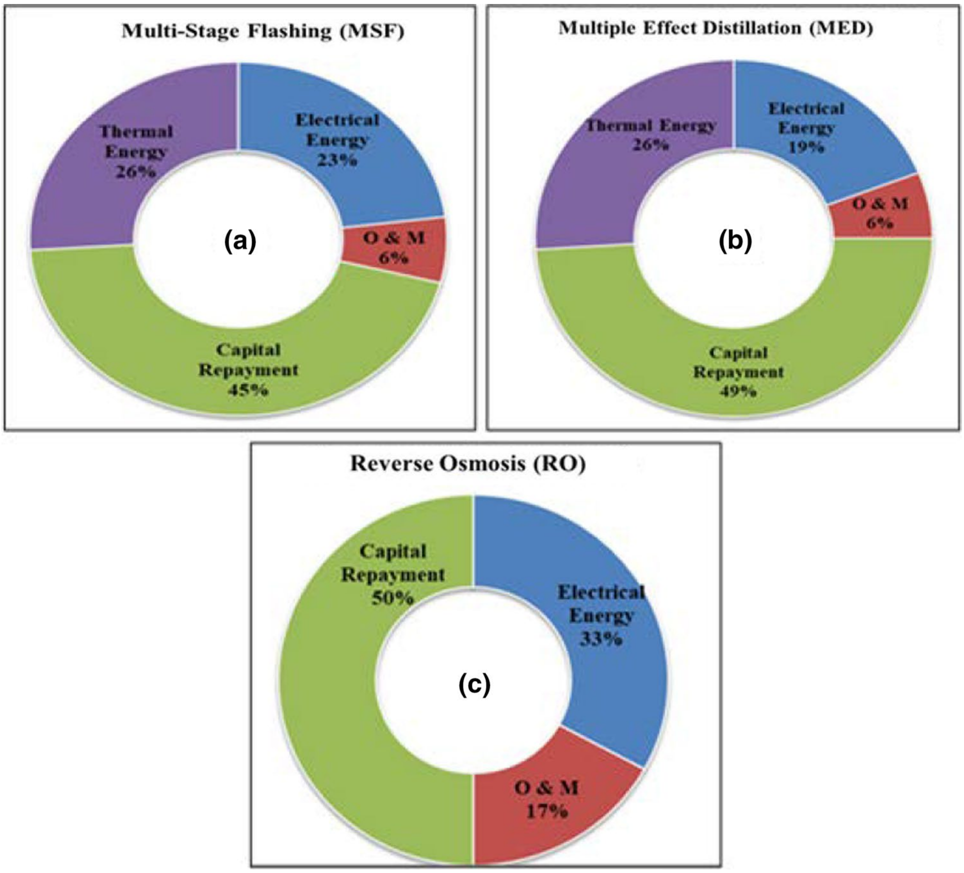


Fig. 7 Energy required for the wastewater treatment in MENA region (Tabakovic and Poci 2012)

Fig. 6 Percentage of cost utilized in **a** MSF, **b** MED, **c** RO



energy intensity range of 0.1–0.3 kWh/m^3 has been assumed and 0.272–0.58 kWh/m^3 was estimated for secondary (activated sludge) (Siddiqi and Anadon 2011).

Figure 7 illustrates a pattern of energy utilized by different countries for wastewater treatment. The widest fractions of wastewater from manufacturing and domestic sources are provided by Egypt and Turkey. As shown in the above figure, their approximated power expenditure of most of treating wastewater seems to be even higher as compared to numerous different regions of MENA. Nonetheless, as multiple countries have published details for different years, the data must be approached carefully. For example, the recorded data are for 2019 in Egypt and are for 2020 in Turkey. In 2019, Egypt was recorded to consume 67.9 billion kWh of electricity (Zarei 2020).

The quantity of wastewater treated is amounted to be 2971 million m^3, and the total number of electric powers utilized (subject to pre-treatment) could even vary from 0.4 to 1.3% of its total energy cost. The reduced amount is 0.4%; scope would be much likely to be similar to its real scenario (Lange 2019). The total volume is 44.4 km^3, and the quantity of wastewater created (13.2 km^3) in the MENA region demonstrates that about 30% is returned to the network as wastewater. Under-reporting of the volume of wastewater created, a lack of relevant data, or water loss or sewage penetration into groundwater are all possible causes of such low yield. Untreated wastewater amounts to 7.5 km^3 per year, accounting for 57% of total wastewater produced in MENA nations. Approximately 83% of wastewater is used for agriculture, with urban and pre-urban farmers cultivating a range of crops, the majority of which are grown using partially distilled, diluted, or untreated wastewater (Abu-Madi and Al-Sa'ed 2009).

Energy efficiency in the water sectors

The direct and substantial effect on energy usage can also be demonstrated on water quality measures (Putra et al. 2020). The graph demonstrates the allocation of groundwater extraction among crop production, manufacturing, and household divisions in MENA countries. Yet Gulf Cooperation Council (GCC) countries with significant water deficits commit the largest proportion of their water to agriculture. This is interesting to note. As a result, a substantial effect on water utilization could be achieved by switching the utilization of water away mostly from the farming industry (Zeitoun et al. 2010).

Water management for runoff and storm water

Fluid management in oil and gas operations can help to avoid unintended leaks into the ecosystem. Water quality problems can also be caused by several other streams of runoff. Storm water from gas and oil building sites is a main source of surface water pollution. Expanded biofuel feed cultivation can result in agricultural runoff, which can pollute water sources with poisons, fertilizers, and silt. Passive methods are commonly used to manage runoff in agriculture. Technological improvements that enabled widespread usage of annual energy crops such as woody crops and switchgrass could minimize erosion and nitrogen requirements. Optimum management practices have proven to be a successful technique for conserving water quality and attaining other sustainable development in both forestry and agricultural sectors (Fayiah et al. 2020b). Uranium and coal mining can cause acidic mine drainage by exposing metal sulfides in tailings heaps. Regulating water flows and cleaning wastewater is the traditional treatment. Coal slurry, which is made up of sludge from coal washing, is stored in well-kept storage tanks. Breach of earth retaining walls happens when storage pits are not adequately built or managed. Consequently, ash is often disposed in landfills, which allow harmful particles to leak into groundwater (Bennett 2007a).

Energy and wastewater sectors

Over the last 100 years, MENA region has not been able to emulate economic and social reforms with the necessary organizational and operational improvements in the water sector to deal with water constraint. They stick to the solutions geared toward Western water-rich countries (Zekri 2020). Various amendments done include water reallocation from villages to cities and from agricultural sector to industrial sector, irrigated land freezing, groundwater authorizing and tracking, wastewater reuse for farming purposes, tertiary wastewater treatment, cost recovery for treated wastewater, and sufficient availability of drinking water (Bennett 2007a). Various energy sources being employed in MENA for water and wastewater sectors are discussed as follows:

Non-renewable energy sources

Renewable energy does not seem to be the sole class of sustainable energy sources addressed in the MENA sector. MENA has long been renowned as a region rich in non-renewable energy resources such as natural gas and crude oil. Numerous countries of MENA have been trying different non-renewable energy resources to supplement the region's water resources and compensate for the region's gradually dwindling energy reserves (Siddiqi and Anadon 2011).

Nuclear energy

The UAE had already developed the lead function, with 5.6 GW under development including the first one among four anticipated reactors prepared for 2017. Nuclear power generation was a subject for varying research findings (Ahmad and Ramana 2014). Many MENA nations, including Tunisia, Kuwait, Israel, Jordan, Egypt, Tunisia, Libya, Algeria, and Morocco, have demonstrated nuclear ambitions according to World Nuclear Association. However, after the incident at a Nuclear Power Station in Japan in 2011, Kuwait, Oman, and Qatar no longer operate nuclear power, and some of the public's opposition to nuclear power is retained in some MENA countries just like Jordan, for example. In most nations, tertiary wastewater treatment is minimal, with the exception of oil-rich countries, where tertiary or even quaternary processing is the norm. In coastal areas, the environmental expenses involved with the dumping of secondary treated water are extremely obvious (Ramana and Ahmad 2016).

With Algeria operating two experimental reactors in Algeria for two decades, Morocco, Tunisia, and Algeria are continuing to show a focus on nuclear power and generation. Regardless of national agendas, nuclear energy faces numerous challenges in the MENA region, especially enhanced capital expenses that regularly accelerate with the time when formation and construction are postponed due to a lack of communication and cooperation of large nuclear reactors with limited nationwide electricity grids. The carbon-free baseload power sources available in MENA nations to respond to rising demand for electricity and water, integrate well with government established energy networks, and availability to needed government funding in selected situations are potentially important benefits of nuclear technology. The likelihood of improved system monitors and safety control when running nuclear power plants, as well as the establishment of more close alliances with countries having nuclear power plant distribution capability, is less apparent but still important possibilities on nuclear energy production in the MENA countries (Nakhle 2016).

Coal energy

There are no MENA countries with significant coal reserves, and so, excluding Morocco and Israel, coal played a small part in the MENA energy system. Morocco depends on coal for roughly 32% of its electricity output (Shaffer 2011).

Subcritical coal-fired power generation accounts for about 80% of global coal-fired power and is considered decreased efficacy (around 25–37%) and an extreme source of pollution (Zarei 2020), while the most adopted type of coal-fired electricity is among the lowest preferred options in the latest power capacities, despite the importance of resource efficiency and environmental issues. MENA countries other than Morocco and Israel are now developing coal-based power production according to this pattern. By 2022, Egypt is preparing to add 12.5 GW of coal-fired energy into its mix, and by 2025, Jordan is aiming to produce 5% of its coal power (Corbeau et al. 2016; Matar et al. 2015). Because hazardous metals cannot be eliminated at the elevated temperatures of coal power plant boilers, wastewater stream generally has very high content of dangerous metals that aggregate in coal ash (Zarei 2020).

Liquefied natural gas (LNG) and water–energy nexus

In growing its national natural gas reserves, several MENA states are facing the challenges of making it one of the most desirable LNG markets in the world. While only 1% of global LNG demand was in the MENA area in 2013, that number is expected to expand to approximately 6.5% of the world's demand by 2025 (Griffiths 2017a). While the push toward imports of LNG by Net Oil, such as Egypt, Jordan, Lebanon, and Morocco, LNG imports are also becoming essential to the energy policies of various geographic major oil-exporting regions, such as the UAE. LNG import is also a major source of energy. Saudi Arabia also considers importing LNG when seeking to boost domestic resource production. The dramatic decline in world LNG prices in previous years and the surplus LNG supply up to 2020 allows for the regions of MENA to fulfill short-term energy needs through LNG imports. LNG is a strategic draw (Griffiths 2017b).

Renewable energy sources (hydraulic, solar, wind, geothermal and bio)

For MENA markets, the restructuring of domestic pricing systems to reflect the relative economic importance of each energy technology is the most powerful tool in promoting renewables. Providing that the international price of gas and oil, the high degrees of fossil fuel dependence of MENA economies, and the competitive location advantage for renewable energy advancements (such as solar) in many MENA countries, even without clear policy instruments and subsidies to renewable energy in Europe, the financial impact of renewables can be seen on a cost-induced basis. Increasing the margin to create new inequalities and economic losses by the use of cost-reflective prices as the key predictor of the market forces, rather than policy led goals and rewards, helps markets absorb renewable energy where economic efficiencies arise, thus impeding markets wastage of resources in situations with no benefit for renewables (El-Katiri 2014).

Solar and wind energy

Besides, MENA countries possess renewable power technologies including waste to energy, in addition to solar and wind energy (Hawila et al. 2012). In provincial renewable energies, however, these resources should play a more restricted role concerning solar and wind energy. Much of its area's hydraulic reserves are distributed in Algerian, Tunisia, Israeli, Lebanon, Iran, Morocco, and Syria. The region's hydrological resources and built capacities constitute the largest portion of the world. However, in these countries, hydroelectric resources are almost fully exploited, except in Iran (Fragkos et al. 2013).

In Iran (1.04 GW), Morocco (464 GW), and Iraq (240 GW), pumping storage facility (PSH) has been installed to support such countries with energy storage capacity that enables the widespread use of intermittent solar and wind resources. Dubai also announced a plan to combine 250 MW of PSH with solar energy, the first of its kind in the GCC (Griffiths 2017b).

Geothermal energy

In MENA energy processes today, geothermal energy has no significant role, with Israel alone having 23 MW of geothermal potential used for direct heating. Nevertheless, Algeria, Morocco, Saudi Arabia, and Yemen have geothermal sites over 200 °C at 5000 m and therefore may theoretically use geothermal energy to generate electricity. Low geothermal temperature heat can also have area desalination and district cooling applications. The energy obtained can be employed for wastewater treatment (Loutatidou and Arafat 2015).

Case study of applying renewable energy (solar) in Sahara forest in AQABA (JORDAN)

Switching to clean fuels decreases the reliance, critical for combating climate change on imports of crude oil and greenhouse gas productions. The implementation of sustainable energy for the seawater desalination and the aeration of greenhouses in advanced processing structures will increase the supply of water, maximize crop yields, and produce vegetation, fish, grassland regeneration, forestation of the desert.

Opportunities of WEN nexus in Jordan

The interconnected development system for the Sahara Forest program utilizes extensively existing natural resources notably solar power and saltwater, to increase water supply and crop production distribution thereby creating new job opportunities. The water requirements for food processing are 50% fewer than most greenhouses utilizing the hydroponic method and moisture in the air.

Alternatives for operational and financial nexus

The Sahara Forest Project incorporates several core innovations, including power generation using solar panels (PV or CSP) freshwater generation, coastal desalination with renewables, seawater-cooled food-processing greenhouses, and greenhouses outdoors rushing. The primary players that gain from this kind of interconnected development mechanism are the water business, which desperately needs an improvement in irrigation water, and subsistence agriculture, which depends on supplementary desalinated water to sustain and enhance agricultural development. It also includes Jordanian and foreign public and local government stakeholders with no civil society participation.

Framework arrangements for Jordan water–energy nexus

Up to now, the Sahara Forest project is on a pilot stage, along with the first 1-hectare and one greenhouse in Qatar starter and a bigger 3-hectare launch station, and two greenhouses in Jordan. All those pilots are assisted by the Norwegian Climate and Environment Government, the Norwegian foreign ministry and the European Union, and international organizations. The proposal is being or will be revised by national strategies, agencies, and financing.

Steps involved in analysis and supervision

Multi-sectorial strategy formulation and contributions required to build the projects involve collaboration between the water and energy sectors, while local partners, private corporations, and investors actively participate in this. In Jordan, certain processes of collaboration and participation are currently in existence. Given the focus on the economic benefit of the enterprise, as the project is upgraded, public–private collaborations are considered the applicable market and management model. The circumstances for upgradation (water usage mainly in low-lying areas along the sea, to prevent energy-dependent rolling) include 50 MW of CSP, 50 hectares of greenhouses hiring more than 800 people, and sequestering more than 8000 tons of CO_2 per year.

Hydropower opportunities in the water and wastewater sectors

Water could be used by hydropower systems to produce electricity. In power plants, evaporation from large reservoirs is the key element of power use. It is worth pointing out that the reservoirs are typically multi-functional and therefore the deterioration of water (Because of massive storage) could not necessarily be associated solely along with contribution for electricity generation, for example, storage for agriculture or household usage and electricity generation. In water production, the future of hydropower largely hinges on the influences of climatic change on accessibility and volatility of hydroelectricity supplies (Skaggs et al. 2012). The

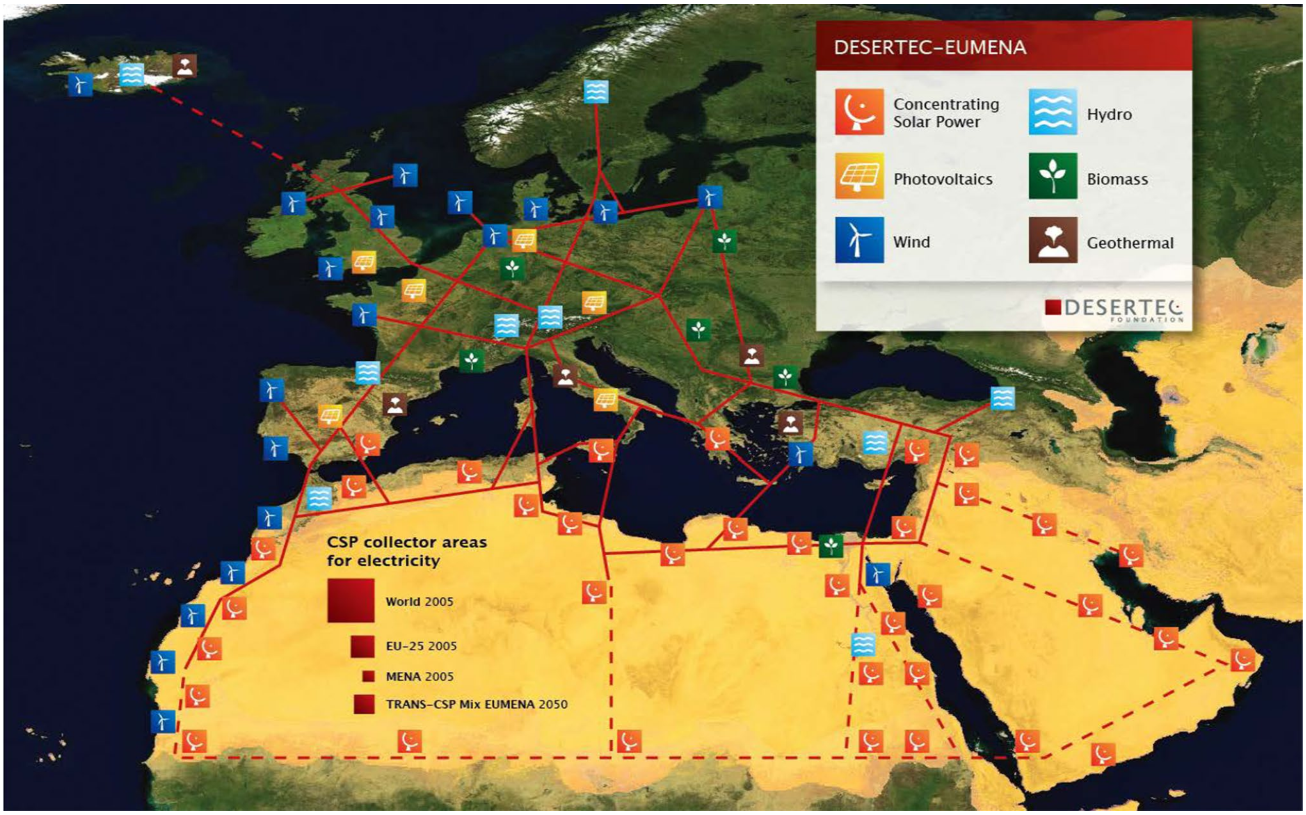


Fig. 8 Hydroprojects in MENA region

common hydroprojects within MENA Region are shown in Fig. 8.

When employed in water management projects and drainage pollution, environmental concerns from large-scale hydroelectric projects such as impacts on migratory passages of the aquatic life and threat of floods do not occur. In wastewater treatment, hydropower can increase the quantity of dissolved oxygen in the treated effluent. Additionally, structural restrictions to hydropower generation at specific sites do not exist when used in the water and sanitation sector. Forecasting the consequences of climate change on water supplies is far from straightforward. The dependability of hydropower at a certain site is mostly determined by the net head and treated stream regime available, which generates enough electricity to make the investment feasible (Paish 2002). Either another head or the flow should be substantial to modify a hydropower system. In hilly terrain, mountain range treatment infrastructures will likely provide a considerable amount of energy with relatively low costs and short repayment periods. Variations in rainfall patterns will affect temperature and land use alterations, resulting in differences in evaporation, transpiration, and water use. The precipitation form will assess how quickly the hydrological reaction to developing precipitation is. Watershed planning may become an increasingly important strategy for mitigating climate change; rather than being a by-product for specific purposes, water management must be permitted as a sustainable land use (Bennett 2007b).

Energy strategy for the water and wastewater sectors

Energy strategy for water sector

Depending on our evaluation, we recommend that this concern is expanded to include the energy repercussions of water-intensive crops in several MENA countries also. Could not only locally water savings be made by planting water-intensive crops, but also energy savings are made by can water drainage by deep aquifers. In countries with extensive surface waters and gravity-feuded canal systems, the energy influence by reduced agricultural withdrawals may not be very high. Nevertheless, energy-intensive groundwater withdrawal (and even desalination in the UAE) in many MENA countries is a significant source of water. This can have major energy impacts from a decrease in agricultural water use. In practice, reducing energy consumption by reduced groundwater drainage cannot be easy without measuring and tracking wells. However, at some points, the potential for major energy consequences may be sufficient to provide creative and realistic solutions (by the use of agricultural water) (Council 2008).

Energy strategy for wastewater sector

Agriculture uses over 83% of processed wastewater, whereas urban and pre-urban farmers rely on treatment, dilution, or untreated wastewater for the majority of their crops. Countries have used various treatment strategies for wastewater. Most wastewater produced in Bahrain, for example, treatment of municipal wastewater sludge and tertiary techniques with much lower than 10% being treated in Iran, Lebanon, Morocco, and Libya (Bahri 2008b).

Wastewater recycling has many advantages. The environmental advantages involve reducing water supplies contamination and vulnerable reception systems and managing saltwater infiltration by recharging groundwater (Ibrahim and Alola 2020). The reuse of wastewater also has financial value through the provision of significant supplementary water quantities and the preservation of freshwater resources. It also supplies irrigation with essential nutrients in the water and decreases demand for synthetic chemicals (fertilizers and insecticides). Additional jobs and export goods are other socioeconomic benefits. As trace and pathogens in mineral and natural wastewater are a danger to population health, repurpose by appropriate management of wastewater for the reuse intended (Qadir et al. 2010).

Case study of adopting drip irrigation in Morocco

Implementing drip irrigation in the agricultural sector will improve water quality and consumption of electricity. Under some circumstances, this can reduce total water and energy expenditure for agriculture. Drip irrigation's relatively high water and energy efficiency, on the other hand, will encourage farmers to improve their manufacturing, expand their irrigated acres, and accept more rebounding (rebound effect) water-demanding crops. Drip irrigation also decreases the water distribution flows to aquifers accessible to other uses by reducing surplus water consumption. Although localized conservation, the water pressure may stay high or can even arise at the basin or national level. Besides that, it is not clear whether new technology can be equally beneficial for all farmers and whether it can reduce inequities.

Opportunities of nexus in Morocco

Water and energy efficiency can be increased in terms of productivity of agriculture, gross margins, and food security. Other co-benefits may be achieved in principle; however, this tends to depend on increased water and energy efficiency which leads to a reduction in total consumption. These co-benefits could typically involve elevated environmental flows, increased climatic resilience, mitigation, and other economic-wide nexus prospects, such as water reuse to other sectors, including hydroelectricity and water.

Alternatives for operational and financial nexus

Advanced irrigation utilizing pressure irrigation could even significantly raise the productivity of water and energy use. Consequently, in exchange to decrease cumulative water and energy usage, these operational nexus approaches must be complemented by effective policies, legislative, and supervisory metrics.

Framework arrangements for Morocco water–energy nexus

To guarantee that improved efficiencies transform into true water and energy conserving somewhat less than to produce overuse and rebuilding impacts, effective legislative action, policies, organizations, and regulations are necessary. All such circumstances also contain water emergent phenomenon regulation, limitation of the number of new sources, and evaluation and revision of pricing structures and incentives. Failure to do that may well create the difficulties already present worse with drip irrigation. Current standardization knowledge transfer and technical support for farmers must be expanded and stepped up.

Analysis and supervision of nexus

It must be routinely tracked and analyzed (i.e., through a nexus context) the impacts of emerging drip irrigation systems, the possible impacts of up-scaling at groundwater levels should be modeled and the findings and lessons drawn must be conveyed to producers, decision-makers, and legislators to enhance adoption and put it into the proper legislature.

Energy challenges and opportunities for water–energy nexus

There are a variety of technical obstacles and potential for solutions across the water–energy system at various scales. These include technological solutions, as well as analytical tools, for water–energy nexus. To begin with, the volume of water needed for thermoelectric cooling can be significantly reduced. To achieve this, enhancing the plant's energy efficiency is a favored approach for reducing dissipated energy. This could be achieved by employing power cycles with better theoretical efficiency and/or waste heat recovery. Ensuring that water from cooling towers is captured and reused can also help. Finally, advances in cooling technology can minimize water use, albeit there are energy efficiency trade-offs if dry cooling is used instead of wet cooling. Second, as the MENA's oil and gas industry expands, reuse of produced water will become increasingly significant. A large portion of the water utilized in the extraction of non-traditional gas and oil reserves is eventually pumped deep underground. Disposal effectively eliminates water from the hydrogeological cycle for time periods that are pertinent to water–energy systems, and it may raise the danger of seismic activity in disposal wells (class 1 and class 2). Furthermore, a significant portion of gas and oil production takes place in very dry places, where treated water can be put to advantage. As a result, joint study on water quality and availability, air quality, triggered seismicity, and development consequences can be beneficial. Third, considering regional freshwater shortages, continuous application of new sources, i.e., brackish water, seawater, domestic and industrial wastewater, and energy production will allow energy systems and other water users more flexibility. These include direct employment of these assets, such as the creation of algal biofuel feedstock. Furthermore, sustainable practices can decrease the hazards of operations across the fuels life cycle to surface water and groundwater quality by using a variety of containment methods, monitoring systems, and management tactics. Because the rate of gas and oil development is expanding, and the intricacy of operations throughout the fuel life cycle is considerable, these indicators are very significant. As bioenergy production develops, ongoing use of agricultural and forestry BMPs, and perhaps even the innovation of BMPs for novel feedstocks, will help to conserve or improve water quality (Fayiah et al. 2020b). Irrevocably, such issues can be related to locally specified analytical tools for informed decisions like energy facility placement, water management, and technology choice.

Linkages of technological development with nexus aproach

Renewable energy linkages

According to International Renewable Energy Agency Report (Ferroukhi et al. 2015), rapid monetary growth, increasing populations, and growing prosperity are riding up call for power, water, and meals, especially in growing countries. By 2050, the call for power will almost double globally, with water and meals call for expected to growth through over 50%. The capacity of current water, power, and meals structures to fulfill this developing call for, meanwhile, is confined given the competing desires for restrained resources. The venture of assembly developing call for is in addition compounded through weather alternate impacts. From the rice fields in India to desalination flowers withinside the Middle East, and nuclear electricity flowers in France, the nexus is already posing a massive venture for enhancing water, power and meals security, a problem for policymakers today. Renewable strength technology should cope with a number of the trade-offs among water, strength and food, bringing large advantages in all three sectors. They can allay opposition through offering strength offerings the usage of much less resource-extensive techniques and technology, as compared to standard strength technology. The allotted nature of many renewable strength technology provides integrated answers for increasing get entry to sustainable strength even as concurrently improving safety of deliver throughout the three sectors.

Smart water system development linkages

Currently, many water structures are not controlled sustainably enough. Water utilities face different challenges, including infrastructure getting older and negative cost-recovery, main to a loss of finance for O&M (Operation and Maintenance). Energy is needed in all tiers of water manufacturing and distribution, from pumping and remedy to transportation. Energy prices are a top-of-thoughts problem for water utilities, irrespective of geography, length, and stage of water community efficiency. On the opposite hand, water utilities are having a difficult time to both enhance their offerings or amplify their community to unserved neighborhoods in growing countries. Smart water machine like, water remedy and irrigation systems, clever water networks, and concrete water distribution community control, allows progressed water–strength nexus withinside the region. Different tactics like artificial intelligence: machine learning; pattern recognition; and business rules, help in adopting those technologies (Helmbrecht et al. 2017).

Water–energy nexus of other regions and comparison

The water–energy nexus of few other regions is elaborated here, which will obviously help to identify the key points and to draw a comparative analysis of water–energy nexus of MENA region and other regions in the world. From the viewpoint of Europe region, EU has bold decarbonization dreams for the future, which may be very tough to obtain if the European water system turns into too confused considering that decarbonization is based on water-demanding power technology along with biofuels, carbon capture, or nuclear energy. The water area is not always as power-in depth as different industries. Despite that, the operation of the water area might also additionally provide answers for growing the ability of the European energy system (Magagna et al. 2019). The destiny recommendations on this vicinity consist of the advent of water-associated standards into long-time period strength guidelines, incorporated control of water and strength sources to help the strength gadget without affecting agriculture and water supply. More suggestions and guidelines consist of exploring the position of desalination, powered with the aid of using renewable strength, as a feasible supply of clean water, in addition, improvement and adoption of strength performance signs and goals for the water sector, research and development (R&D) in water- and strength-saving technologies. Improved facts series throughout water uses.

From the viewpoint of Asia and Pacific region, this nexus transfer faced many challenges for transforming from theory to practices, policy and management, and natural and social sciences. Due to water–energy nexus in Asia and Pacific region, the core issues are related to integrated management and security of both water and energy. This effect leads to cause a social change in the region. The detailed challenges can be summarized in the form of integration of multiple issues and sectors for production and consumption, integration of local scale to global scale. security issues of the nexus, and interdisciplinary and transdisciplinary approach for the nexus research (Taniguchi et al. 2017). The relationship between MENA and Asia and Pacific region can be elaborated based on the food nexus, which is the third stakeholder of water–energy nexus. Food security and integrated management have a triangle relationship with water–energy nexus, which cause climate change and land issues. The comparative representation of different types of nexuses and their comparison with respect to each other regions are summarized in Fig. 9 (Endo et al. 2017). The nexuses types with respect to most dominant and least dominant region are summarized in Table 2 (Endo et al. 2017).

Conclusions and future recommendations

The availability of energy (power) and water (including rivers and lakes) supports in the MENA sector varies widely with available resources. However, there are some popular patterns throughout the region including increased industrialization and development, reduced agricultural percentage of the domestic economy. All such patterns may possess significant implications for the demands of water (and resources indirectly). It is likely that for managerial trade in water footprint and sustainable growth, the transformation of water into services rather than agricultural practices will take place in some of these countries. Water utilized for irrigation is a subject to worth-consideration recycling and will

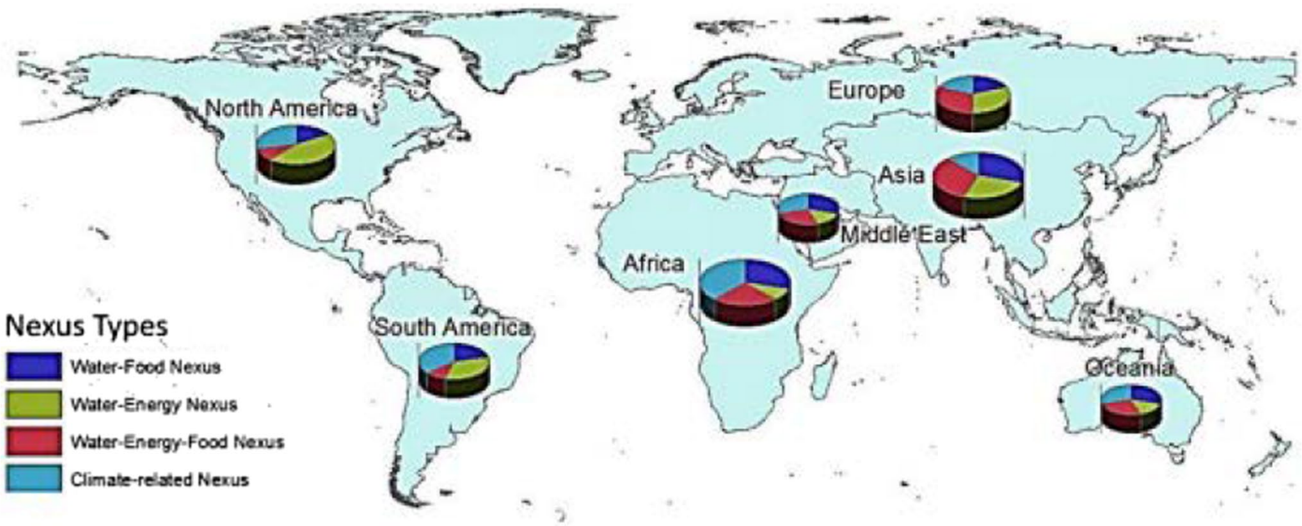


Fig. 9 A graphical representation of nexus types in different regions (Endo et al. 2017)

Table 2 Nexuses types and most and least dominant regions with respect to nexus type (Endo et al. 2017)

Sr. No	Nexus type	Most dominant region	Least dominant region
1	Water–food nexus	Asia and Africa	North America
2	Water–energy nexus	North America	Africa
3	Water–energy–food nexus	Africa and Asia	South and North America
4	Climate-related nexus	Africa	Asia

need extensive investments to convey that water for farming. Majority MENA countries are dependent on food imports, and its growth will be directly proportional to population explosion and global warming. It might require current water sources to remain sufficient (with rising populations) for some time in the future. Therefore, before investments are made into long-term energy and water infrastructure, various potential supply opportunities should be considered carefully (rather than traditionally extrapolated). Urban water demand is anticipated to rise in many countries of the MENA region, and wastewater generation will increase thereafter.

Throughout this analysis, a quantitative assessment was conducted out of the water intensity throughout MENA countries in the water supply chain of energy output and energy intensity. Water–energy nexus is crucial in this regard to avail current resources for everlasting applications. Redevelopment problems differ in the way water, and energy management is blended into wider policy economies. Further investigations of the interconnections between the water–energy nexus can assist to alleviate the difficulty of comprehending the system's links and therefore promote sustainable evolution. Conflict-affected MENA countries would have a significant effect on the human protection and growth trajectories of deciding to restore their water and energy systems. Not only technological competence but effective reuse of wastewater and improved water–energy infrastructure is needed to gain prosperity in water and energy sector. An assessment to decide infrastructural investments in water and energy, to restore ecological resources, and to mitigate emissions must be devised. In the situation of Saudi Arabia, we predict that freshwater can be accounted for 9% of total electricity consumption, while 25% of the installed power in Morocco and Egypt relies on cooling freshwater. Such high dependency will restrict the development of electricity if climate change drastically decreases freshwater rates. Even by recycling and processing of just a portion of the wastewater generated per annum, Kuwait, Qatar, Libya, and Israel would theoretically satisfy their industrialized requirement for water. Although the assumptions in this work are an initial estimate, they underline the requirement for comprehensive energy and water infrastructure growth and policy formulation by policymakers.

Given the sheer water shortage, particularly during droughts, water for the ecosystem is indeed the last priority. Water policy reforms have shown that public intervention and large spending are required to subsidize the cost of water scarcity. Without employing additional water, agricultural production will have to increase dramatically. A significant monetary portion dedicated to municipal water service tariffs should be redirected in the long term to implement the required water sector adjustments. In water-scarce countries, however, creating water usage rights and allocations is a superior strategy, and numerous MENA countries still have similar procedures in place, but they are outdated. To enable the formulation of effective, integrated resource allocation strategies, decision-makers require simplified tools that reveal constraints across nexus components. Climate change adaption solutions must be devised that are both practical and realistic. Collaborating with resources and identifying tools are key stages in removing the obstacles that prevent decision- and policymakers from comprehending the nexus.

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