Economic and Social Commission for Western Asia

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ESCWA

Developing the Capacity of ESCWA Member Countries to Address the Water and Energy Nexus for Achieving Sustainable Development Goals

Water-Energy Nexus Operational Toolkit
Resource Efficiency Module

Economic and Social Commission for Western Asia

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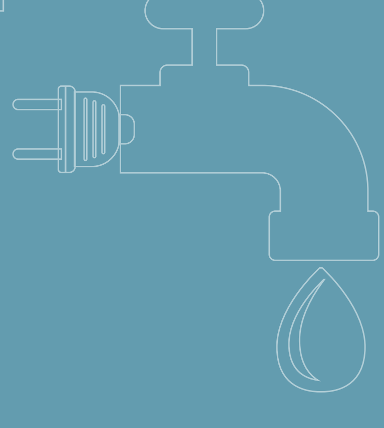

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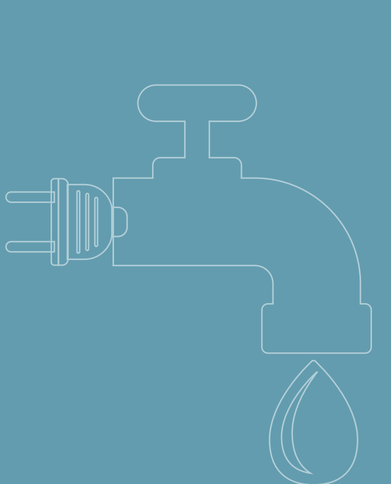
Abbreviations and explanatory notes

AD	Anaerobic digester
AFED	Arab Forum for Environment and Development
AMI	Advanced metering infrastructure
bbl	Oil barrel
BNR	Biological nutrient removal
BOD	Biochemical Oxygen Demand
BTU	British thermal unit
BWRO	Brackish water reverse osmosis
CAGR	Compound annual growth rate
CAPEX	Capital expenditure
CBNG	Coalbed natural gas
CDMA	Code division multiple access
CDP	Carbon Disclosure Programme
CEO	Chief Executive Officer
CHP	Combined heat and power
COD	Chemical oxygen demand
CP	Centrifugal pump
CSS	Cyclic steam stimulation
DAF	Dissolved air flotation
DEWA	Dubai Electricity and Water Authority
DO	Dissolved oxygen
DR	Demand response
dw	Dwelling
EIA	United States Energy Information Administration
EIP Water	European Innovation Partnership on Water
EOR	Enhanced oil recovery
ERD	Energy recovery devices
ESCWA	Economic and Social Commission for Western Asia
EWS-WWF	Emirates Wildlife Society - World Wildlife Fund
FAO	Food and Agriculture Organization of the United Nations
FE	Final effluent
FGD	Flue-gas desulfurization
FO	Forward osmosis

GCC	Gulf Cooperation Council
GDP	Gross domestic product
GHG	Greenhouse gas
GJ	Gigajoule
gpf	Gallons per flush
gpm	Gallons per minute
GSM	Global System for Mobile Communications
GTF	Global Tracking Framework
GWh	Gigawatt hour
GWRC	Global Water Research Coalition
HVAC	Heating, ventilation and air conditioning
IEA	International Energy Agency
IM	Intelligent water metering
inhab	Inhabitant
kgoe	Kilogram of oil equivalent
kg/s	Kilogram per second
ktoe	Kiloton of oil equivalent
kWh	Kilowatt hour
LC	Local currency
LNG	Liquefied natural gas
MED	Multiple-effect distillation
MENA	Middle East and North Africa
MF	Microfiltration
MGD	Millions of gallons per day
MJ	Megajoule
MSF	Multi-stage flash distillation
mWh	Megawatt hour
N	Nitrate
NF	Nanofiltration
NORM	Naturally occurring radioactive materials
OAPEC	Organization of the Arab Petroleum Exporting Countries
OECD	Organisation for Economic Co-operation and Development
OPEC	Organization of the Petroleum Exporting Countries
OPEX	Operational expenditure
P	Phosphorus

PPP	Purchasing power parity
RE	Renewable energy
RO	Reverse osmosis
SAGD	Steam-assisted gravity drainage
SAR	Sodium adsorption ratio
SCPG	Specific consumption of power generation
SDG	Sustainable Development Goal
SE4All	Sustainable Energy for All
SS	Suspended solids
SWRO	Seawater reverse osmosis
tCO_2e	Ton of CO_2 equivalent
TDS	Total dissolved solids
TFC	Total final consumption
toe	Ton of oil equivalent
tph	Ton per hour
UF	Ultrafiltration
UNEP	United Nations Environment Programme
UV	Ultraviolet
VFD	Variable frequency drive
VSD	Variable speed drive
WAG	Water-alternating gas
WAS	Waste-activated sludge
WWTP	Wastewater treatment plant
W4EF	Water for Energy Framework
$\$_{2000}$	US dollar at constant value for the year 2000



Introduction

The United Nations Economic and Social Commission for Western Asia (ESCWA), as part of its efforts to help member countries find an integrated approach to the Sustainable Development Goals (SDGs), is implementing a United Nations Development Account project to develop the capacity of member States to examine and address the water and energy nexus.

To achieve this, ESCWA is using two parallel and complementary tracks. The first targets high-level officials into ministries of water and energy who will be trained on how to incorporate the nexus in policies and strategies at national and regional levels by means of a regional policy toolkit. This is comprised of seven modules based on priorities identified during an intergovernmental consultative meeting in 2012.[1] The seven priorities, which were endorsed by the ESCWA Committees on Water Resources and on Energy, are the following:[2]

a. Knowledge and awareness-raising;
b. Increasing policy coherence;
c. Examining the water-energy security nexus;
d. Increasing efficiency;
e. Informing technology choices;
f. Promoting renewable energy;
g. Addressing climate change and natural disasters.

The second track targets water and energy service providers by means of three technical interventions addressed through an operational toolkit made up of the following three stand-alone modules:

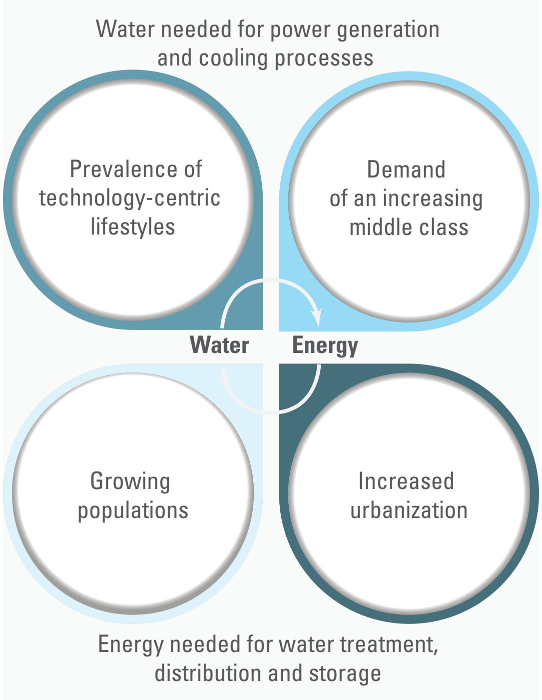
a. Resource efficiency: To improve efficiency during the production and consumption of water and energy resources and services;
b. Technology transfer: For water and energy considerations when pursuing the transfer of new technologies regionally;
c. Renewable energy: To assess costs and benefits related to applying renewable energy technologies in the region.

Each module will be discussed in one of three regional technical workshops, which will bring together participants doing similar work in different sectors.

Background

The water-energy nexus, on the one hand, refers to the relationship between the water used for the production of energy, as a renewable resource for hydroelectricity production, and the energy/electricity generation process itself. On the other hand, it refers to the energy consumed in the extraction, treatment, distribution and disposal of different types of water (for example, drinking water and wastewater) (see figure 1). It must be clarified, however, that this system is generally not a closed circle. For instance, the water treated with the use of energy may not necessarily go on to aid in the energy production process but may rather be used as a source of potable water in households. Nevertheless, water and the generation and use of energy are all interconnected to a certain extent.

Figure 1. The water-energy nexus illustrated



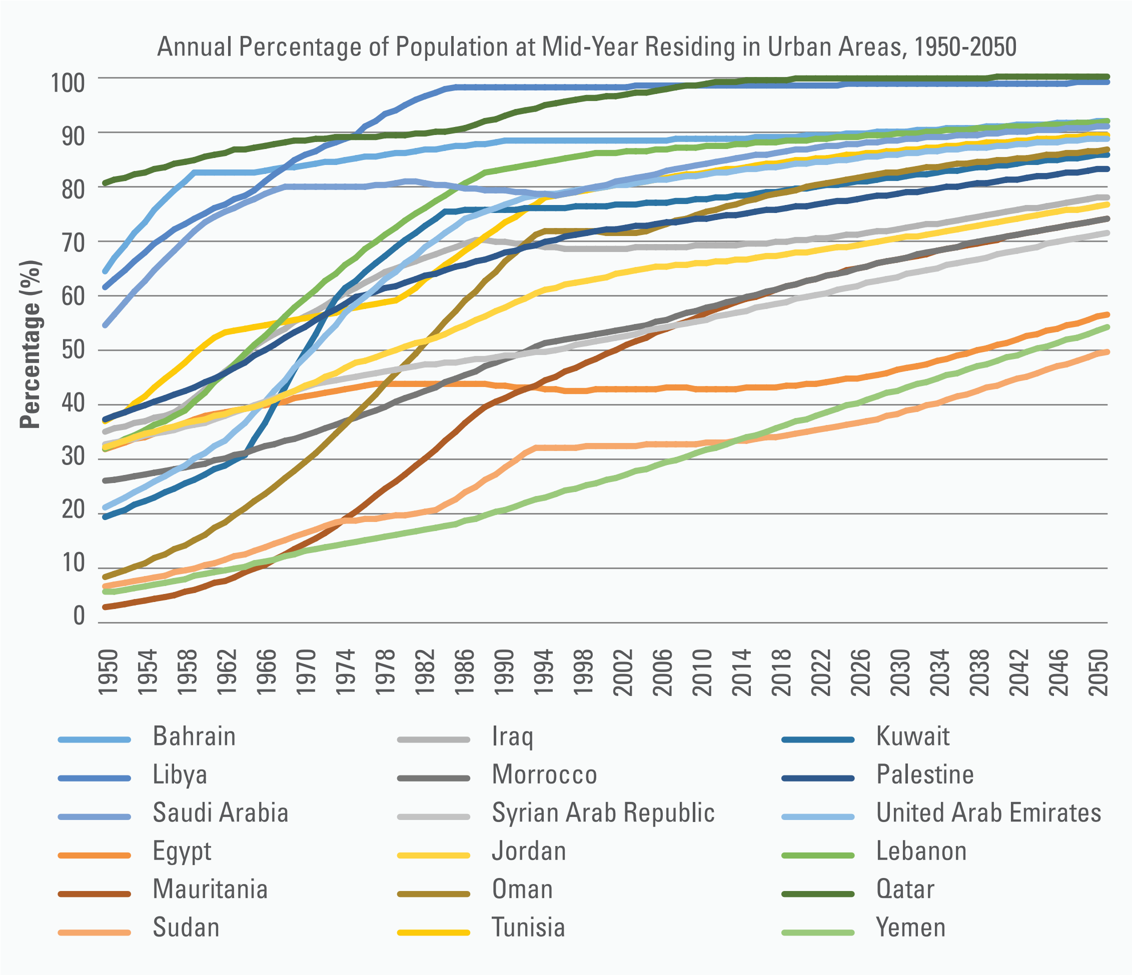
Source: Created by authors.

The water-energy nexus is a subject, which has received much attention in the recent past, as mankind expects to have infinite development in a world with finite resources. This has significant ramifications on our water and energy resources and thus the water-energy nexus. Figure 1 shows some of the factors (shown in green boxes) leading to increased water and energy demand. These factors are true on a global scale. For example, population growth means growing demand for resources.

Over the next forty years, urban areas, particularly those in the developing world, are expected to "absorb all of the population growth".[3] Furthermore, most of the population growth expected in urban areas will be concentrated in the cities and towns of less developed regions. Having such large populations in such small areas of our planet puts much strain on water and energy resources. For instance, urban settlements are known to be the main source of point-source pollution; if urban wastewater is combined with untreated industrial waste, it can be even more hazardous.[4] Such contaminated water requires more energy-intensive processes in order to be treated, adding intricacies to the water-energy nexus. Additionally, urban lifestyle leads to increased consumption of water-intensive foods[5] with large urban populations relying mostly on external entities for their resources.[6] These changes affect the transportation and distribution of water and energy resources, increasing the complexities facing the water-energy nexus. In fact, in a 2015 report, urbanization was identified as a drive for such issues as the "failure of critical infrastructure" and water crises.[7] This urbanization is also linked with a rising middle class, whose income growth is generally a strong drive for the demand for such resources as water and energy.

These growing income levels also go hand in hand with greater access to and interaction with technology, also in developing countries. In fact, Internet and mobile technology have rapidly

Figure 2. Population at mid-year residing in urban areas for ESCWA member countries (percentage)



Source: Created based on data from UNDESA, Population Division, 2014.

become a fixed part of daily life for many people in developing countries; and mobile phones in particular have become almost ubiquitous in many countries.[8] This increasing prevalence of technology implies increasing demand for electricity, thus once again raising demand for water resources.

All the above is definitely true for ESCWA member countries, which already face fast-growing rates of urbanization, as can be seen in figure 2 that shows the change in the annual percentage at mid-year of the population residing in urban areas of ESCWA member countries from 1950 to 2050. Mid-year population refers to the "arithmetic mean of the population on 1 January and the population on 31 December of a year" and is used in the calculation of annual rates.[9] The percentage of population at mid-year residing in urban areas is, for all ESCWA member countries, expected to reach an average value of 80 per cent by 2050 (currently, already 75 per cent of the population in most countries is urban). In other words, by 2050, the urban population in the Middle East and North Africa (MENA) region alone will reach approximately 560 million.[10]

Table 1. The top 33 water-stressed countries in the world by 2040

Rank	Name	Score (All Sectors)
1	Bahrain	5.00
1	Kuwait	5.00
1	Qatar	5.00
1	San Marino	5.00
1	Singapore	5.00
1	United Arab Emirates	5.00
1	Palestine	5.00
8	Israel	5.00
9	Saudi Arabia	4.99
10	Oman	4.97
11	Lebanon	4.97
12	Kyrgyzstan	4.93
13	Iran	4.91
14	Jordan	4.86
15	Libya	4.77
16	Yemen	4.74
17	Macedonia	4.70
18	Azerbaijan	4.69
19	Morocco	4.68
20	Kazakhstan	4.66
21	Iraq	4.66
22	Armenia	4.60
23	Pakistan	4.48
24	Chile	4.45
25	Syrian Arab Republic	4.44
26	Turkmenistan	4.30
27	Turkey	4.27
28	Greece	4.23
29	Uzbekistan	4.19
30	Algeria	4.17
31	Afghanistan	4.12
32	Spain	4.07
33	Tunisia	4.06

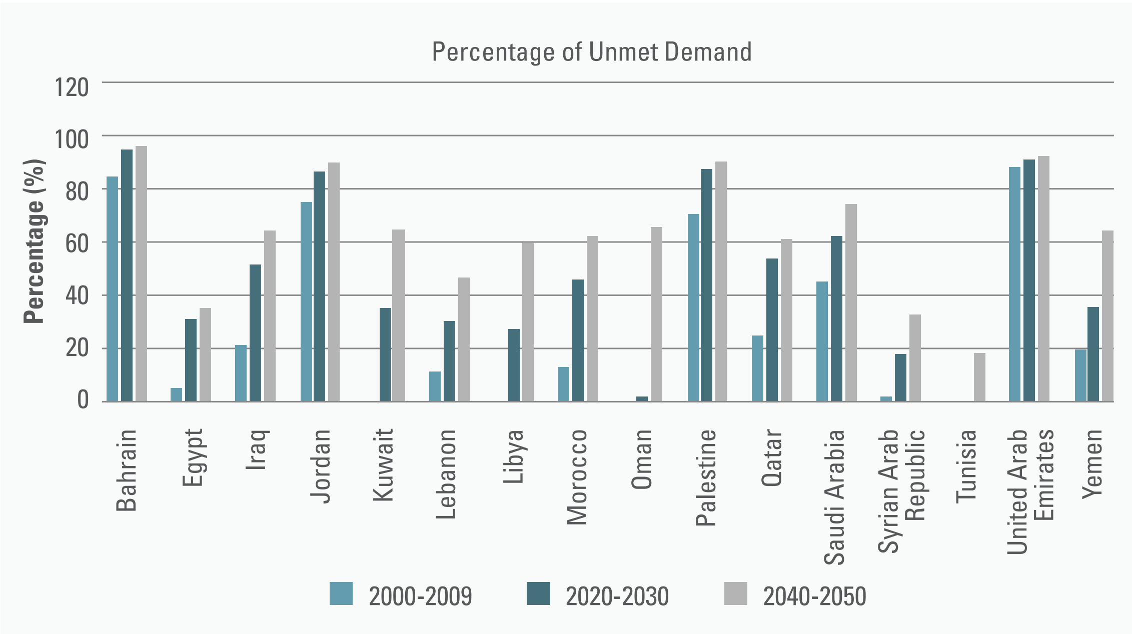
Note: "5.00" is the highest stress score possible.
Source: Created based on data from Maddocks, Young and Reig, 2015.

Similarly, water and energy demand in ESCWA member countries is quite high, in addition to these countries having scarce water resources. The situation is only expected to deteriorate as demand levels increase. For the MENA region, water shortages are projected to increase by 43 km^3/year from 2001–2010 to 2041–2050, even under the most positive climate scenarios.[11] Table 1 shows the forecasted list of top 33 water-stressed countries in 2040. Water stress is defined as the "ratio of total annual water withdrawals to total available annual renewable supply".[12] Five of the eight countries with the highest predicted stress level are ESCWA countries; and 15 of the 18 ESCWA member countries (highlighted in table 1) are included in the list.

Table 1 is further supported by Figure 3 , which shows both actual and forecasted levels of unmet water demand in certain ESCWA member countries. The forecasted values have been obtained as a result of an average climate projection model.[13] In all countries, the percentage of unmet demand is rising consistently. With respect to the MENA region as a whole, from 2001-2010 until 2041-2050, this increase in unmet demand is due to an increase in demand by about 50 per cent while supply will only increase by 12 per cent (as per the average climate change projection).[14] In some cases, such as Oman, the rise in unmet demand is expected to be drastic. As regards the connection between the water-energy nexus and climate change, increased water use means increased energy demand, which leads to more greenhouse gas emissions. The latter, in turn, contributes to elevated earth temperatures and consequently to greater water use and the vicious cycle continues.

In terms of energy consumption, as an example, the countries of the Gulf Cooperation Council (GCC) are expected to see an increase in energy consumption of more than 200 per cent from 2000 to 2020.[15] Additionally, by 2040, total energy consumption in the Middle East and Africa is expected to increase to 61.8 quadrillion Btu and 44.0 quadrillion Btu, respectively. These values represent average annual percentage increases in energy consumption from 2012 to 2040 of

Figure 3. Unmet water demand in selected ESCWA member countries (percentage)



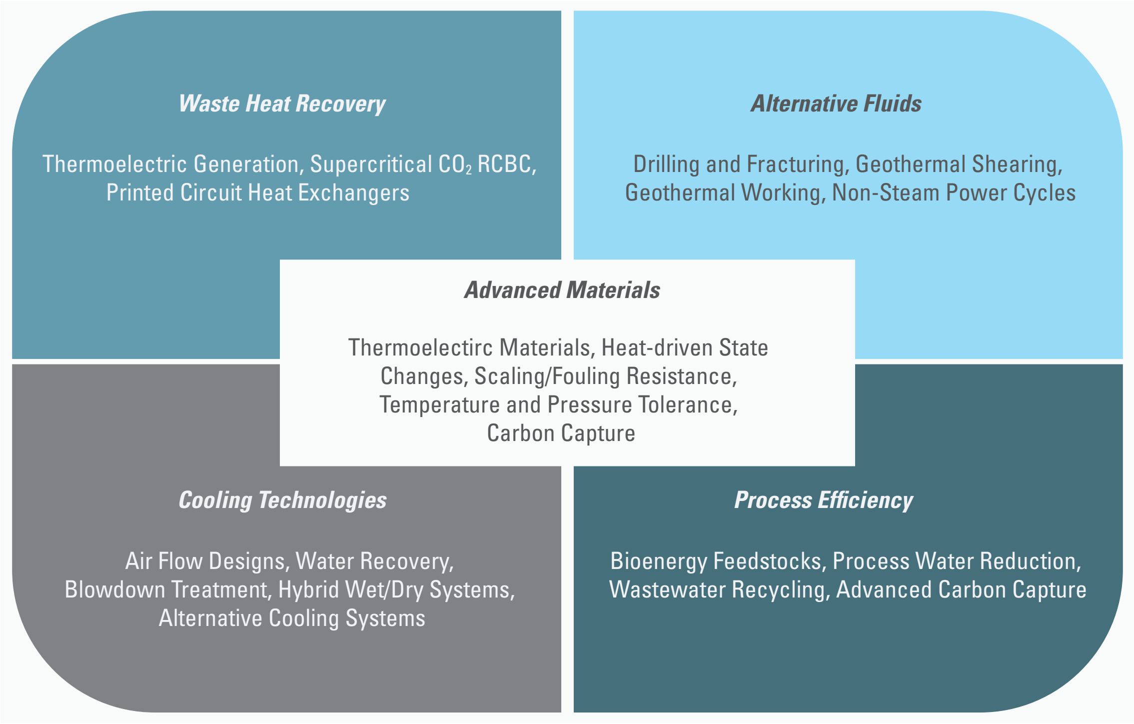
Source: Created based on data from Immerzeel et al., 2011.

2.4 and 2.6 per cent for the Middle East and Africa, respectively. These values are significantly higher than the forecasted average annual percentage increase in energy consumption for the world for the same period, which is only 1.4 per cent.[16] Therefore, this greater increase in energy consumption for the MENA region, as compared to corresponding values for other regions of the world, points out how important the improvement of energy efficiency is for the countries of the ESCWA region.

Water and energy efficiency are therefore key to a water and energy-secure future for the countries of the ESCWA region. The Middle East is already considered by some to be the least water-secure region in the world[17] and with such phenomena as global warming and climate change taking place, the situation will definitely not improve on its own. Furthermore, when considering water and energy, securing one depends on the other; and both water and energy efficiency must be pursued simultaneously through a holistic water-energy nexus approach.

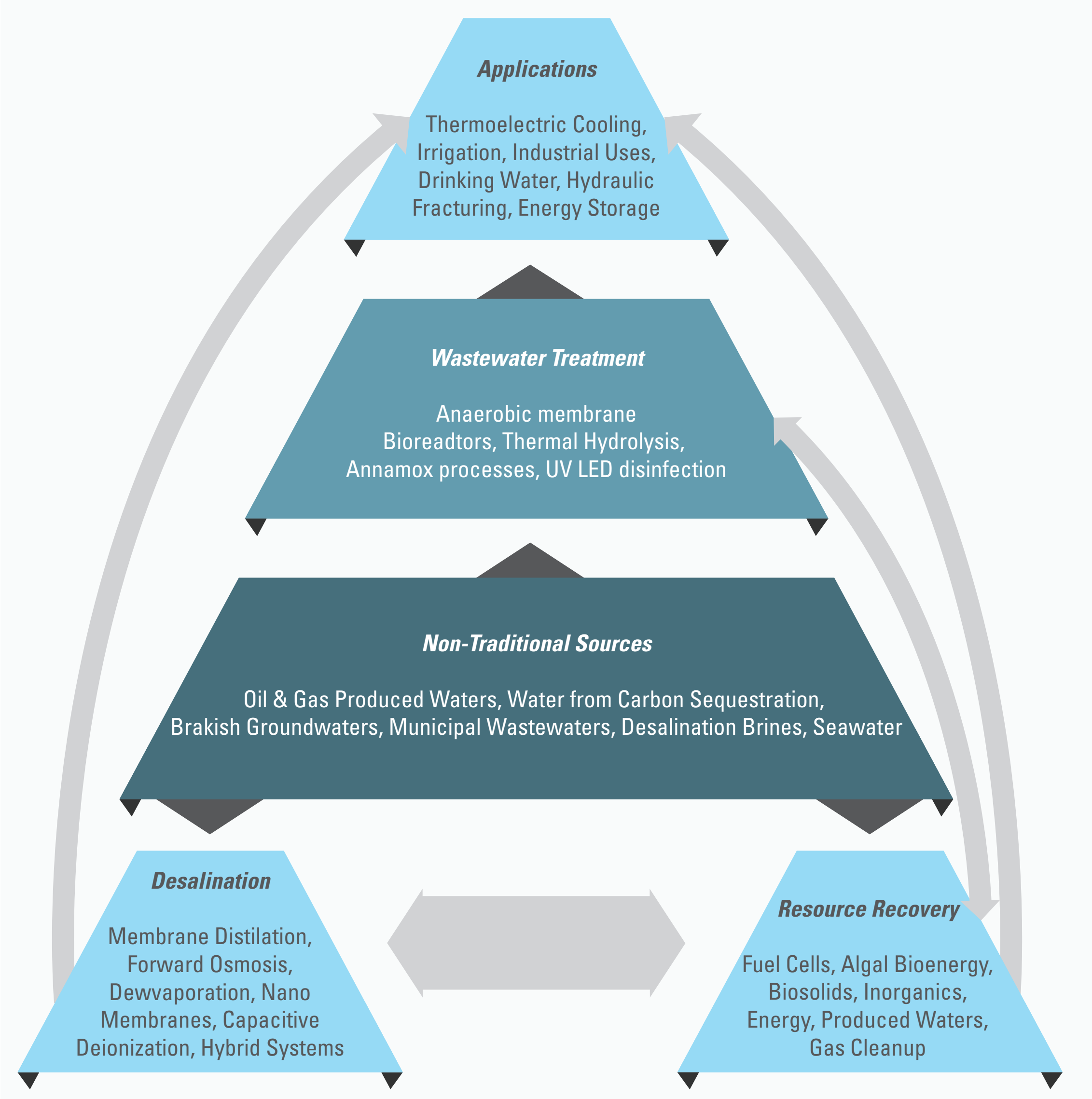
The water-energy nexus was presented in figure 1. However, it encompasses several subtopics, some of which are shown in detail in figures 4 and 5. Figure 4 shows the problem/opportunity spaces faced while using water for energy production while figure 5 shows the problem/opportunity spaces in energy issues for and caused by water. These spaces have been grouped in terms of different technological types (in the case of figure 4) and different process types (in the case of figure 5). The strategies mentioned in figures 4 and 5 not only address technologies/processes that are already being widely implemented by the global water and energy sectors, but also mention technologies that are in their infant stages of commercial implementation. This toolkit focuses primarily on the better established technologies as they have greater relevance to ESCWA member countries due to their particular climatic conditions and the industries, which these countries tend to have.

Figure 4. Representative problem/opportunity spaces in water for energy



Source: Created based on data from Bauer et al., 2014.

Figure 5. Representative problem/opportunity spaces in energy for and from water



Source: Created based on data from Bauer et al., 2014.

Objectives

The primary objective of this toolkit is to strengthen the capacity of ESCWA member countries to achieve an integrated and sustainable management of water and energy resources, thereby contributing to sustainable development. This toolkit focuses on improving the technical capacity of government officials who manage or oversee the provision of water or energy services in ESCWA member countries. It provides them with technological strategies by means of which they can integrate water and energy nexus considerations into their operations, activities, and projects.

Though the nexus is governed through an institutional or policy response,[18] its implementation relies on technical interventions, which may render the process and resource

Ain Beni Mathar Integrated Thermo Solar Combined Cycle Power Plant, Morocco © Philippe Roos - https://www.flickr.com

use more efficient and effective.[19] The successful implementation of these technologies is only possible through access to comprehensive information about the technological options available so that more informed decision-making can take place. It is this toolkit, which aims to provide this information.

The current water-energy nexus operational toolkit aims to assist in building capacity for exchange and collaboration across disciplines based on a common language and set of assessment tools, techniques, and indicators for pursuing resource efficiency at the operational level, for instance during investment planning, the operation and maintenance of water and energy utilities, and irrigation schemes. It contains guidelines for the entities responsible for water and energy services, and reviews and reinforces appropriate data collection procedures to monitor energy and water production. All of these findings and analyses are based on consumption statistics reflecting the water and energy cycles. Consequently, the toolkit describes the key performance indicators used in the water and energy industries. After all, it is such statistics obtained through the monitoring of consumption patterns and the resulting analysis using established indicators, which enable long-term planning and a more efficient management of national natural resources. For this planning to be effective, the collected data and statistics must be sufficient to allow the strengthening of analytical capacity, thus facilitating evidence-based policymaking and policy assessment in the interrelated fields of water and energy. Consequently, this toolkit seeks to provide steps, which may be followed to ensure the robustness of data monitoring and collection procedures.

Technologies to improve water efficiency

When considering water efficiency improvement strategies, the approach being implemented can broadly be classified into two categories: One focuses on using technologies, which operate more efficiently and the second focuses on water reuse so that a smaller footprint is achieved even with regular process efficiencies. It must be noted here that there is a difference between water treatment and water reuse. Water treatment ensures that the output water can be returned to the environment. For water reuse, the treated water must be purified to such a level that it can be used in industry, agriculture, and even as potable drinking water.[20] Table 2 shows the different sectors where water can be reused, along with the particular type of use in each sector. For each reuse category, the water treatment needed is also shown. The more sensitive/critical the area of reuse, the more elaborate the treatment required to obtain a product of greater purity.

Table 2. End use of recycled water and minimum treatment

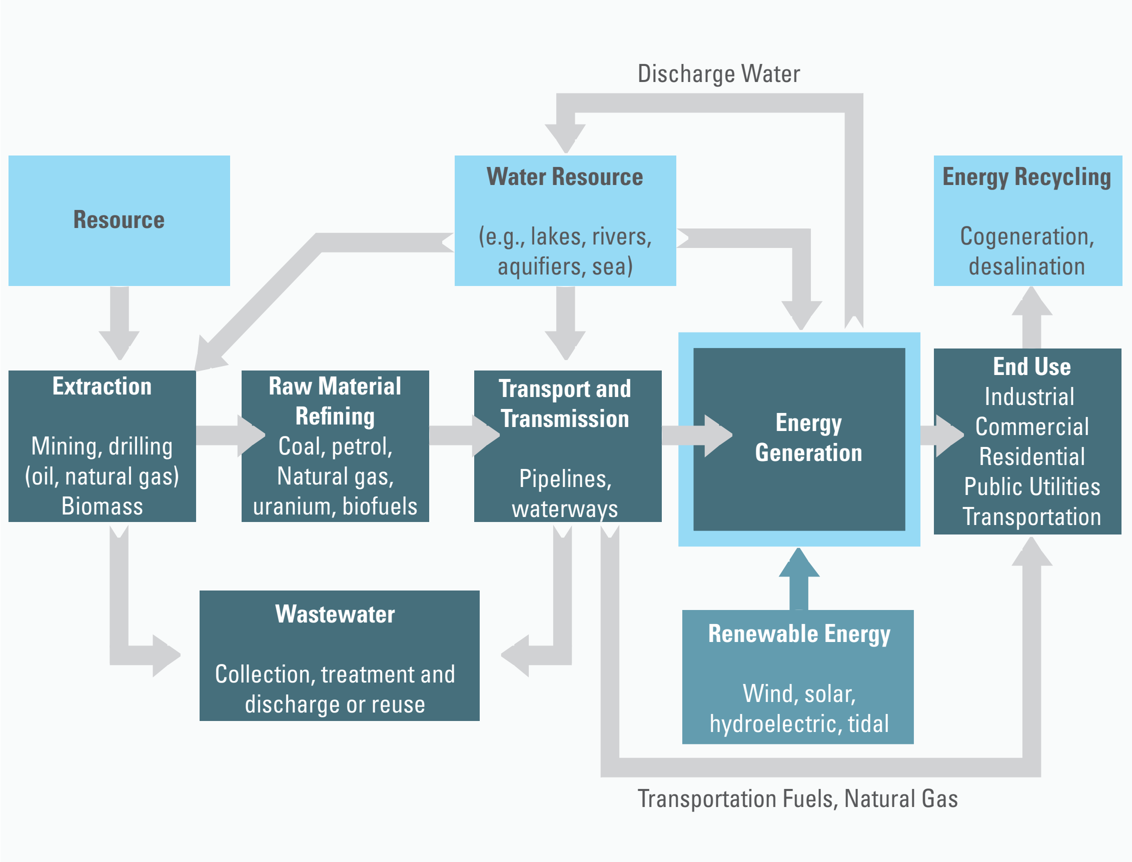
Reuse Category	Description	Treatment
Urban Reuse	Unrestricted Restricted	Secondary, Filtration, Disinfection Secondary, Disinfection
Agricultural Reuse	Food Crops Processes Food Crops Non-food Crops	Secondary, Filtration, Disinfection Secondary, Disinfection Secondary, Disinfection
Impoundments	Unrestricted Restricted	Secondary, Filtration, Disinfection Secondary, Disinfection
Reuse Category	**Description**	**Treatment**
Environmental Reuse	Create wetlands, enhance natural wetlands, sustain stream flow	Secondary, Disinfection
Industrial Reuse	Once-Through Cooling Recirculating Cooling Towers High-Quality Industrial Use	Secondary Secondary, Disinfection (coagulation & filtration could be needed) Secondary, Filtration, Advanced Wastewater Treatment, Disinfection
Groundwater Recharge	Non-Potable Reuse, Spreading Non-Potable Reuse, Injection	Primary Secondary, Soil Aquifer Treatment
Indirect Potable Reuse	Groundwater Recharge, Spreading Groundwater Recharge, Injection Augmentation of Surface Water Supply Reservoir	Secondary, Filtration, Disinfection Secondary, Filtration, Advanced Wastewater Treatment, Disinfection Secondary, Filtration, Advance Wastewater Treatment, Disinfection

Source: Created based on data from Water in the West, 2013.

Water efficiency in electricity production processes

Figure 6 shows the flow diagram on how water is used in the electricity production process. It is clear that water is needed as part of almost every step in the process, and this water requirement is essential for all conventional fuels. To illustrate the extent of the relationship between water use and electricity production, according to certain global statistics, 90 per cent of power generation is water-intensive and three quarters of all industrial water withdrawals are used for power production. Additionally, 80 per cent of global energy is produced by thermal power generation, which is responsible for 50 per cent of all water withdrawals in the United States and several European countries.[21] In fact, energy production accounts for the second largest use of water (after agriculture) and is expected to continue increasing over the next 15-20 years.[22] As a result, there is much to gain from improved water efficiency in the power sector. This is particularly true for the ESCWA member countries where improved water efficiencies would mean greater abilities to meet the water demand.

Figure 6. Flow chart of embedded water in energy



Source: Water in the West, 2013.

Figure 7. Gaps in meeting water demands of thermal power plants under low flow conditions

Note: Green dots indicate a value of 0.5-1.0 for the ratio of cooling water consumption to Q90, while red dots indicate a ratio greater than 1.0.

Source: http://wef-conference.gwsp.org/fileadmin/documents_news/understanding_the_nexus.pdf

Figure 7 illustrates where the water demands of thermal power plants cannot be met under low flow conditions. Low flow conditions are defined in terms of Q90, which is a "flow static representing the daily flow, which is exceeded or equalled 90 per cent of the time" and can be used to determine the resources available in periods of low flow or drought".[23] In the case of figure 7, in particular, the gap has been determined by the ratio of cooling water consumption to Q90. Green dots indicate a ratio of 0.5-1.0 while red dots indicate a ratio greater than 1.0, demonstrating that the demand cannot be satisfied. Even a cursory glance at figure 7 is enough to see the large number of red dots in the ESCWA region, depicting the challenges faced by thermal power plants in the region, and the situation is only expected to worsen with time unless newer optimization methods are used to improve water efficiency.

In the past, water was regarded as a low-cost resource to electricity production facilities and was used inefficiently. However, due to the rising standards and costs of wastewater treatment and the rising costs of water resources as they become scarcer in many regions, awareness has increased and a proactive approach is increasingly followed where water efficiency is concerned. Table 3 shows the amount of water needed in the energy production process for conventional sources of energy. Crude oil production can consist of up to three different phases: the primary recovery phase, involving the use of the natural pressure of the reservoir or gravity to drive oil into the wellbore (the drilled hole of the well), along with artificial lift techniques (for instance pumps) that assist in bringing the oil to the surface; the secondary recovery phase, where oil or gas is injected into the ground to displace the oil and drive it into the wellbore; and the tertiary phase, also known as enhanced oil recovery (EOR), using further techniques in order to extract even more oil. Primary recovery accounts for extracting about only 10 per cent of the resources of an oil field, secondary recovery for 20-40 per cent, and EOR for 30-60 per cent.[24] For bitumen, steam-assisted gravity drainage (SAGD) and cyclic steam stimulation (CCS) are similarly used to achieve enhanced oil recovery. It is clear that, at succeeding stages of oil recovery, water requirements tend to increase.

Table 3. Water coefficients in primary energy production

Energy Source		Water coefficient (m3/TJ)
Crude oil	Primary recovery	6
	Secondary recovery	600
Bitumen	Mining	26
	In situ SAGD	8
	In situ CSS	14
	In situ multi-scheme	32
Heavy oil		14
Natural gas liquids		6
Coal-to-liquids		53

Source: Created based on data from Xylem, 2014.

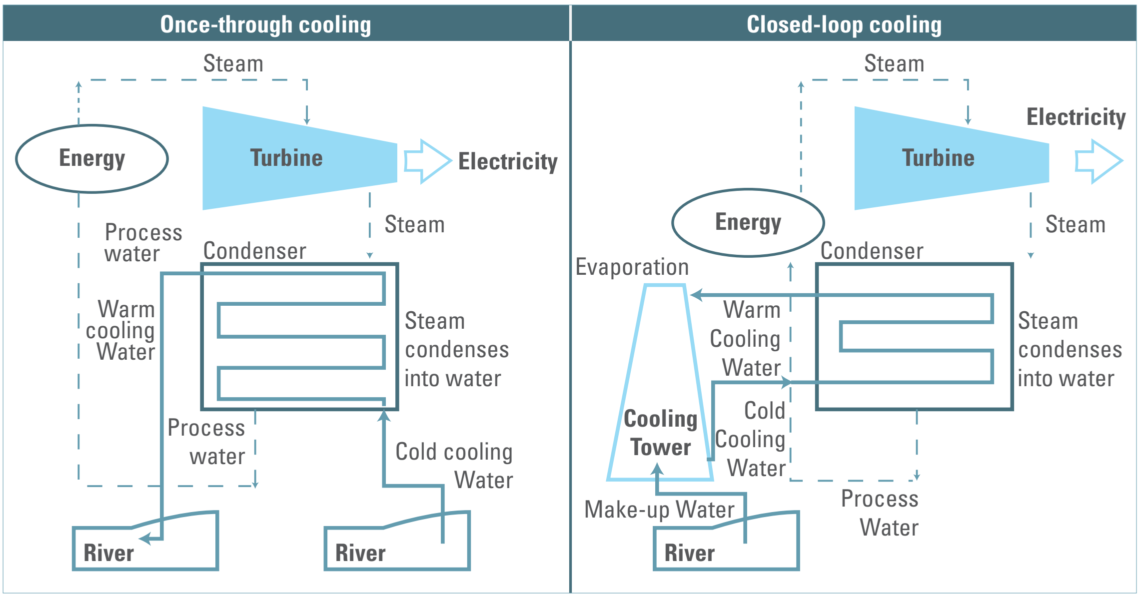
Water efficiency and cooling processes

Among the different applications for which water is used in a power plant, cooling entails the greatest water consumption. According to a publication on raw water usage for various fossil fuel plants, water used for cooling ranged from 79 to 99 per cent of total water usage; the remaining water was used for such applications as ash handling, the humidifier, the condenser and flue-gas desulfurization (FGD) at combustion-steam plants.[25] As a result, to make the electricity production process more water efficient, its cooling procedure must be improved.

There are various types of cooling, as mentioned in tables 4 and 5. Two of these cooling systems are depicted in figure 8. The closed-loop cooling system is also known as the recirculating system. The wet cooling tower is a type of recirculating cooling system commonly used in power plants. Table 4 shows the impact of each of these cooling systems in terms of various factors, such as water use and costs. Table 5 numerically describes the water use impact mentioned in table 4 for different types of power plants. It is important to note the difference between water withdrawal and water consumption. Water withdrawal refers to the amount of water, which is taken by the power plant from its water source (ocean, aquifer, and others), while consumption refers to the water, which is lost, usually due to evaporation as part of the cooling process, from the water withdrawn. As a result, the water discharged back to the water source is the difference between the water withdrawn and the water consumed.[26]

As illustrated by table 4, the once-through cooling system is intense in terms of the water it withdraws but is moderate in terms of the water it consumes and vice versa for the recirculating system. However, if we look at the numerical values in table 5, it is clear that, even when the recirculating system consumes much water, the intensity of consumption is only a fraction of the intensity of the water withdrawn by the same plant when using a once-through system. The dry-cooling system, which uses air instead of water as the cooling

Figure 8. Diagram of different cooling systems



Source: Kohli and Frenken, 2011.

medium, is clearly most efficient as far as water use is concerned but its capital cost is high, decreasing overall plant efficiency and challenging its more widespread implementation. In order to increase the water efficiency of electricity production process, a dry-cooling system should be first choice, a recirculating system second choice, and a once-through cooling system third choice. However, the system chosen for a particular plant must obviously consider local regulations, economics, and ambient conditions.

Table 4. Cooling system tradeoffs

Cooling Type	Description	Water Withdrawal	Water Consumption	Capital Cost	Plant Efficiency	Ecological Impact
Once-Through	Takes water from nearby sources, circulates it through pipes to absorb heat from the steam in systems called condensers, and discharges the now warmer water to the local source.	Intense	Moderate	Low	Most efficient	Intense
Wet Cooling Towers	Also known as wet-recirculating or closed-loop systems. They reuse cooling water rather than immediately discharging it. Usually, they use cooling towers to expose water to ambient air. Some of the water evaporates and the rest is sent back to the condenser in the power plant.	Moderate	Intense	Moderate	Efficient	Moderate
Dry Cooling	The ultimate heat rejection to the environment is achieved with air-cooled equipment that discharges heat directly to the atmosphere by heating the air.	None	None	High	Less efficient	Low

Sources: Created based on data from Electric Power Research Institute (EPRI), 2002; Rodriguez et al., 2013; Union of Concerned Scientists, n.d.

Table 5. Water withdrawn and consumed for power plant cooling (in gallons of water required per megawatt-hour of electricity produced)

	Once-through		Recirculating		Dry-cooling	
	W	**C**	**W**	**C**	**W**	**C**
Coal (conventional)	20,000-50,000	100-317	500-1,200	480-1,100	N/A	N/A
Natural gas (combined cycle)	7,500-20,000	20-100	150-283	130-300	0-4	0-4
Nuclear	25,000-60,000	100-400	800-2,600	600-800	N/A	N/A

Note: W: withdrawal; C: consumption.
Sources: Created based on data from Macknick et al., 2012; Union of Concerned Scientists, n.d.

Increasing water efficiency through decreasing waste heat

Decreasing the waste heat generated by a power plant reduces its cooling requirements and consequently its water requirements. This can be achieved by improving the efficiency of the components of the power plant system and by reusing some of the heat that would otherwise be dissipated, by having the power plants operate along with other systems, which can use their waste heat as is the case in the following three examples:

Combined power and desalination plants: These plants are able to simultaneously produce electricity and drinking water. They are also known as hybrid desalination plants. By integrating thermal electricity production with desalination, such plants are able to improve efficiency and lower the energy costs associated with the desalination process.[27] Indeed, this is important since desalination is already known to be more energy intensive than conventional water treatment processes. Waste heat from the power plant is used as a source of heat for the desalination process, which is typically multi-stage flash (MSF) distillation (a distillation process where seawater is distilled by flashing it into steam in multiple stages).[28] This system is more efficient than a stand-alone power plant and a stand-alone MSF desalination plant. Along with the substantial capital cost, a traditional disadvantage of such combined plants is the challenge of unequal water and electricity demands, which also change according to season. For example, during winter, electricity demand can decrease while water demand may stay more or less the same. In such cases, the plant would end up operating at low efficiencies. Nevertheless, for the ESCWA region, which is arid more or less all year round, such combined plants can be a good solution.[29] Some studies have claimed that it is the most cost-effective way to meet both water and electricity requirements in desert regions.[30] In the recent past, however, such hybrid plants are becoming less popular as more energy-efficient desalination processes, such as reverse osmosis, become more prevalent. In addition, decoupling electricity and water production allows for the introduction of renewable forms of energy as well as nuclear energy into the overall energy mix for the region.[31]

Combined heat and power (CHP) plants: These plants are also known as cogeneration plants. They take the heat that is produced in the electricity generation process and, instead of dissipating it as waste heat, use the heat for district heating as hot water or steam. This consequently causes a significant decrease in the cooling water requirements of the plant and helps increase overall efficiency. CHP plants can be used with any type of fuel but efficiencies vary from one fuel to another. As with the combined power and desalination plants, CHPs efficiency can be as high as 90 per cent. One of the advantages of CHP plants is that they rely on the combination of technologies, which are already widely used in commercial installations globally. In order for CHP plants to achieve their highest potential efficiency, it is important that they are located close to the site where there is demand for the heat and electricity generated; this prevents heat losses, which take place during the transportation of the heat and may otherwise lead to substantial decreases in overall efficiency. Consequently, CHP plants tend to be suitable as decentralized sources of energy, though they entail greater capital expenditure (relative to conventional power plants). However, in the long term, CHP plants are more economical due to the energy savings they achieve, though their payback period tends to be quite long. Last but not least, meeting heat and power demands simultaneously by one single plant adds more complexity to the CHP plant process.[32] Among ESCWA member countries, Saudi Arabia already uses cogeneration plants: cogeneration units are already present at the Ju'aymah, Shedgum, and 'Uthmaniyah gas plants, and new CHP facilities are being built at the Abqaiq, Hawiyah, and Ras Tanura facilities.[33] As a result of these projects, power capacity is expected to reach 6,500 MW in 2016.[34]

Increasing water efficiency using alternative water sources

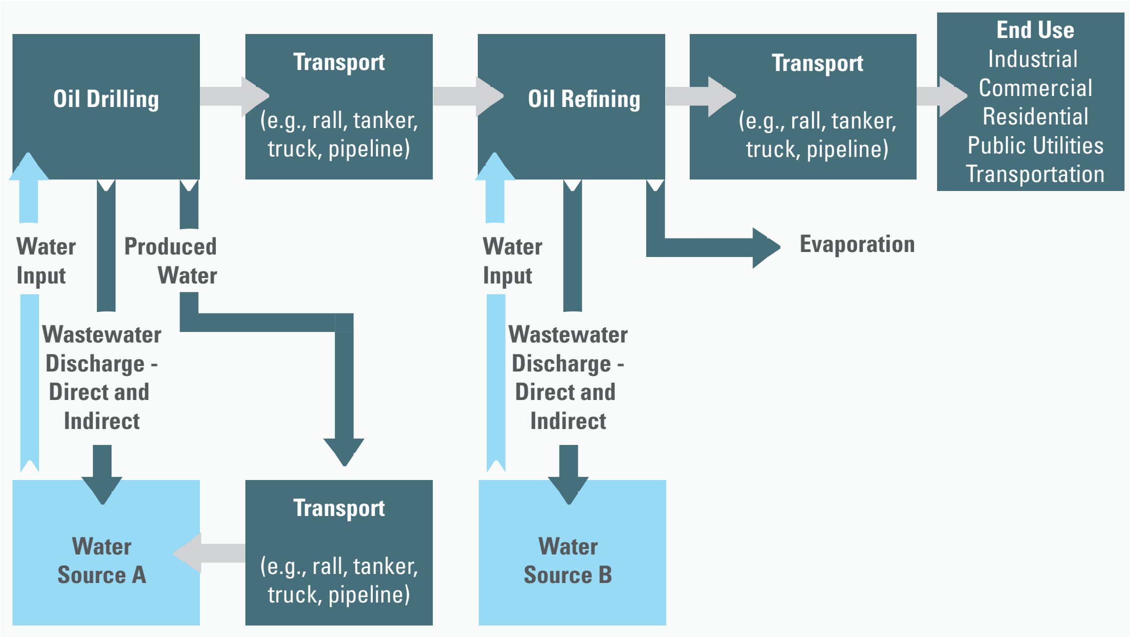
This strategy for increasing water efficiency draws on the points mentioned above regarding water reuse as well as the use of entirely new types of water, which shall help reduce dependence on freshwater resources. For instance, non-freshwater sources such as saline groundwater effluents,[35] can be used as cooling water in thermal power plants. However, the implementation of the use of such alternative water sources depends on the quality of the water and its source location (for instance, the power plant must be situated on the coast if seawater is to be used).

As concerns the reuse of water, treated wastewater also can be used as an alternative for cooling water in thermal power plants. However, before this is possible, the pollutants in the wastewater must be satisfactorily removed so that it does not damage the cooling system in any way (for instance, through corrosion). Such procedures must be carried out in accordance with local regulations, oftentimes leading to increased costs. And since many countries require that water being discharged by power plants be pretreated until at least secondary treatment standards, treating the same water to reusable levels for cooling purposes would not lead to a significant cost reduction. Since wastewater is available in large quantities in most places, especially large urban areas, treated wastewater as a source of cooling water is a reliable water source. Treated wastewater is therefore currently used for cooling purposes in more than fifty power plants in the United States, including the largest nuclear plant in the country, Palo Verde in Arizona, which solely uses wastewater to fulfil its cooling requirements.[36] This potential for the use of treated wastewater also exists in ESCWA member countries. For example, the Pearl gas-to-liquids (GTL) plant in Qatar, the largest source of GTL products in the world, has a water recycling plant, which is the largest of its kind. It treats water, which is then reused for cooling purposes and in steam production. This prevents any liquids from being discharged from the plant.[37]

Case study: The oil and gas industry

The oil and gas industry is a very important part of the economy of many Arab countries. Seven ESCWA member countries are members of the Organization of the Petroleum Exporting

Figure 9. Flow chart of oil and embedded water

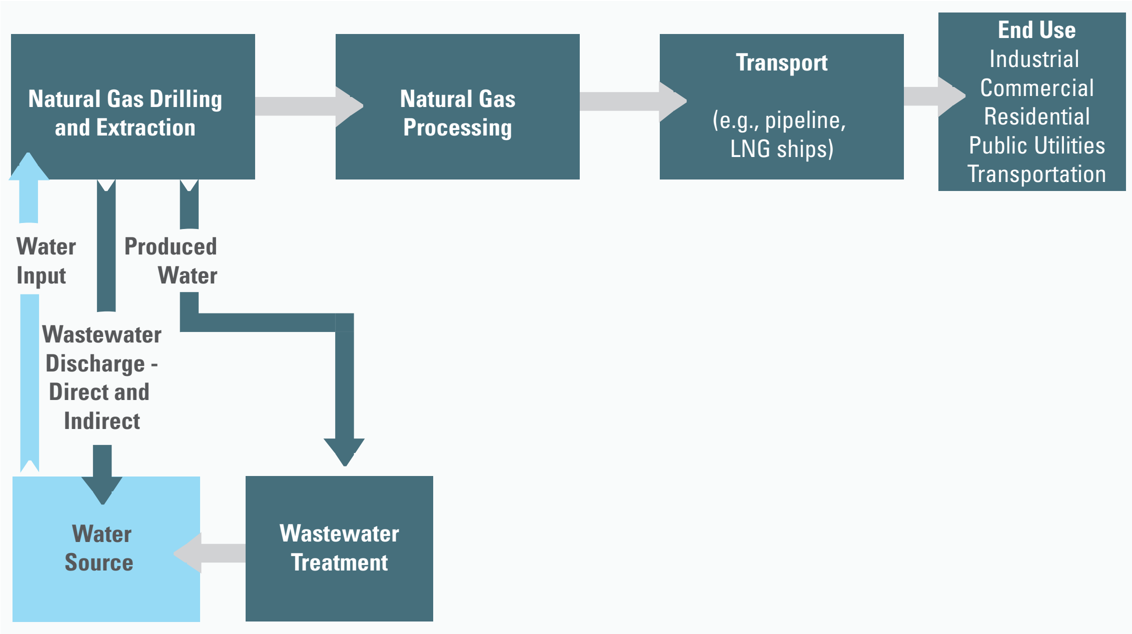


Source: Water in the West, 2013.

Countries (OPEC) and account for the bulk of OPEC's proven crude oil reserves.[38] Even in terms of exports, in 2014, the crude oil and natural gas exports of Arab countries accounted for more than 40 per cent of the world's crude oil exports and around 20 per cent of global natural gas exports.[39,40] As a result, though the oil and gas exporting countries of the ESCWA region are making efforts to diversify their economies, as of 2012, crude petroleum and natural gas represented 48.0 per cent while petrochemicals represented 2.9 per cent of the gross domestic product (GDP) of the GCC.[41] In addition, in the recent past, as oil prices have fallen significantly, the economies of the oil-producing countries of the ESCWA region have been hit substantially. Nevertheless, as mentioned by Amin H. Nasser, President and Chief Executive Officer (CEO) of Saudi Aramco, at the recent 2016 Annual Technical Conference and Exhibition of the Society of Petroleum Engineers in Dubai, "oil's central position, especially in heavy transport and petrochemicals feedstock, will remain solid and central for years to come".[42] In fact, the oil and gas sector in the Gulf region continues to expand along with an increase in petrochemical projects.[43] This expansion in energy investment is expected to reach up to $900 billion by 2021 according to an Arab Petroleum Investments Corporation report.[44] The importance of the oil and gas industry to the ESCWA region is thus evident. Mr. Nasser also mentioned that the industry must learn how to better deal with difficult times from the financial perspective while simultaneously continuing to improve efficiencies.[45] This toolkit seeks to facilitate the improvement of efficiencies.

Water is used in upstream oil and gas exploration and production for such purposes as injection water for wells and the recovery of crude oil and gas.[46] Indeed, water-based fluids can be required in the wellbore drilling and stimulation stages. During the drilling of the actual well, water-based fluid is used for various procedures, including "lubricating the drill bit, circulating the drill cuttings out of the hole, containing formation fluids and facilitating the operation of sophisticated formation evaluation tools".[47] The downstream segment of the oil and gas industry includes processes related to refining and petrochemical production, and water is used mainly to supply boilers and cooling circuits and for some oil refining processes.[48] As an example of

Figure 10. Flow chart of natural gas and embedded water



Source: Water in the West, 2013.

water use for drilling (which is one of the main application areas of water in the oil production process along with oil refining), in the United States, drilling vertical wells has been reported to use an average of 77,000 gallons of water with an additional 310,000 gallons to hydraulically fracture the well while drilling horizontal wells was reported to use an average of 130,000 gallons with an additional 2,700,000 gallons for hydraulic fracturing.[49]

Natural gas tends to be liquefied to decrease its volume, thereby facilitating its transport and storage as liquefied natural gas (LNG). As part of the liquefaction process, water is mainly consumed for process cooling at the liquefaction plants and for revaporization heating at LNG receiving terminals (where LNG is turned back into gas). These processes may result in significant water discharge streams.[50] Water is also required by the amine system, which removes carbon dioxide and hydrogen sulphide from the feed gas. For this purpose, a portion of the water requirements of the LNG plant must be met by water, which meets specific criteria in terms of cleanliness and chemical composition.[51] Though water consumption rates for such processes can vary considerable,[52] an industry benchmark of 30,000 m^3 of water per hour has been specified for systems open-rack vaporizers, which use seawater to heat and vaporize the LNG.[53] This has relevance for the Arab countries where, due to arid conditions, sea water is mainly used to meet water requirements. Since the water requirements in the LNG plant/processes primarily feed cooling and heating systems, especially concerning refrigeration cycles and sometimes power cycles,[54] measures taken to improve water efficiencies are assumed to be similar to those of other oil and gas processes where water requirements due to cooling are also substantial.

Figures 9 and 10 show the flow of processes during oil and natural gas production, respectively, and include information about the involvement of water at the different stages of the processes, supporting what has been mentioned above. While figure 6 illustrates the water intensity of electricity production, figures 9 and 10 prove that electricity production using oil or natural gas as a fuel is also water intensive.

Hydraulic fracturing, also known as fracking, is another process through which oil and gas resources are obtained. A high-pressure water mixture is directed at shale rock in order to release the oil or gas, which the latter contains. Having been employed increasingly in the recent past, fracking has attracted quite a bit of controversy due to the water use, which it entails. Fracking has increased the competition for water in some of the most water-stressed areas in the United States.[55] Though it is certainly more water intensive than using energy resources, such as coal and the primary recovery of oil, fracking need not always be the most water-intensive option; the amount of water required for the fracking process can vary significantly from one type of shale to another and from one well to another.[56] Among Arab countries, Tunisia, Egypt, Saudi Arabia, and Jordan have plans to extract shale gas, while others, such as Oman and Algeria, have already begun fracking operations.[57,58,59]

Water efficiency in the oil and gas industry can be improved by better water and wastewater management. Using trucks to transport water between different locations, such as extraction sites and wastewater wells, can be inefficient from the cost, safety, and environmental perspectives. Such processes may be improved by using pipelines, onsite treatment, and reusing wastewater and produced water. Whether or not produced water is reused, injected or discharged depends on various factors, such as geology, location, field maturity, location, available technologies, the relevant economics, and even environmental and social factors. Along the same lines, the particular technology used for water treatment depends on several factors. Table A1 in the annex provides a comprehensive reference of advantages, disadvantages, and applicability of different water treatment technologies in the oil and gas industry.

Once a plant starts reusing produced water, operations are facilitated through, for example, the implementation of remote monitoring and control systems that enable the automated management of water resources in real time.[60] What is more, recycling water can help overcome the challenge of uncertainties in water supplies. More water-efficient systems enhance water security and thus the overall resilience of oil and gas sector operations. They are becoming more prevalent in the oil and gas sector as policies on water use are become more stringent. As an example, advanced ultraviolet (UV) and ozone technologies are being implemented to prevent wastewater from fouling. Similarly, waterless fracking, which uses gases instead of water, is also being experimented with.[61]

Table 6. Water required and recovery assessment for various oil recovery technologies

Recovery Technology	Injection water (gallons water per gallons crude oil)
Primary recovery	0.2
Secondary water flooding	8.6
EOR steam injection	5.4
EOR CO_2 injection	13
EOR caustic injection	3.9
EOR forward combustion/air injection	1.9
EOR micellar polymer injection	343.1

Source: Created based on data from Xylem, 201

EOR: The primary, secondary, and tertiary recovery of oil has already been discussed. Table 6 goes into more detail by providing information on the quantities of water required by different types of EOR (tertiary recovery) processes. Clearly, primary recovery is least energy intensive. Even though tertiary recovery is known to be water-intensive, it can be, in some cases, less water-intensive than secondary recovery depending on the type of recovery selected.

EOR is broadly classified into three types: thermal recovery, gas injection, and chemical injection. As shown in table 6, steam injection and forward combustion/air injection are considered to be types of thermal recovery, CO_2 injection is considered to be a type of gas injection, and caustic injection and micellar polymer injection are considered to be examples of chemical injection. All these methods of EOR mentioned in table 6 are considered to have high values for the incremental recovery they provide. This is not

Table 7. Limitations of various EOR processes

EOR process	Limitations
Miscible gas injection	• Very sensitive to heterogeneity • Poor vertical sweep owing to large density difference from water • Reservoir pressure must be greater than minimum miscibility pressure • Excess gas production
WAG injection	• Operationally more complex • Oil may be trapped in pores by water if too much water injected
Polymer flooding	• Well injectivity owing to higher viscosity of injected water • Loss of polymer by adsorption • Costly due to large volumes of chemicals required • May not be feasible in hot reservoirs or with saline water
Alkaline surfactant polymer flooding	• Complex to design, requiring analysis of oil, water and rock chemistry as well as geological heterogeneity • Costly due to large volumes of chemicals required • May not be feasible in hot reservoirs, carbonate reservoirs or with saline water
Low-salinity water injection	• Mechanism not fully understood • Possible dilution of injected low-salinity water by in situ brine
Polymer gel treatments at injection wells	• Only works where high-permeability thief zone is isolated from other oil-bearing zones • May not be feasible in hot reservoirs, carbonate reservoirs or with saline water • Potential production of H2S by sulphate-reducing bacteria in reservoir
Deep reservoir flow diversion	• Only works for water injection • May not be feasible in hot reservoirs, carbonate reservoirs or with saline water

Source: Created with data from Muggeridge et al., 2013.

true for other types of EOR processes, such as those mentioned in table 7. For example, polymer flooding and low-salinity water injection are considered to provide only low incremental rates of recovery while water-alternating gas (WAG) provides very high rates of recovery.[62]

Table 7 deals with the limitations of different EOR technologies. Such factors need to be considered when deciding which EOR technology to adopt along with factors, such as incremental recovery, water requirements, and costs (such as capital costs and the cost of drilling additional wells).[63] For example, chemical injection is typically not a popular EOR technology due to the significant costs of chemicals (for example, surfactants) it employs.

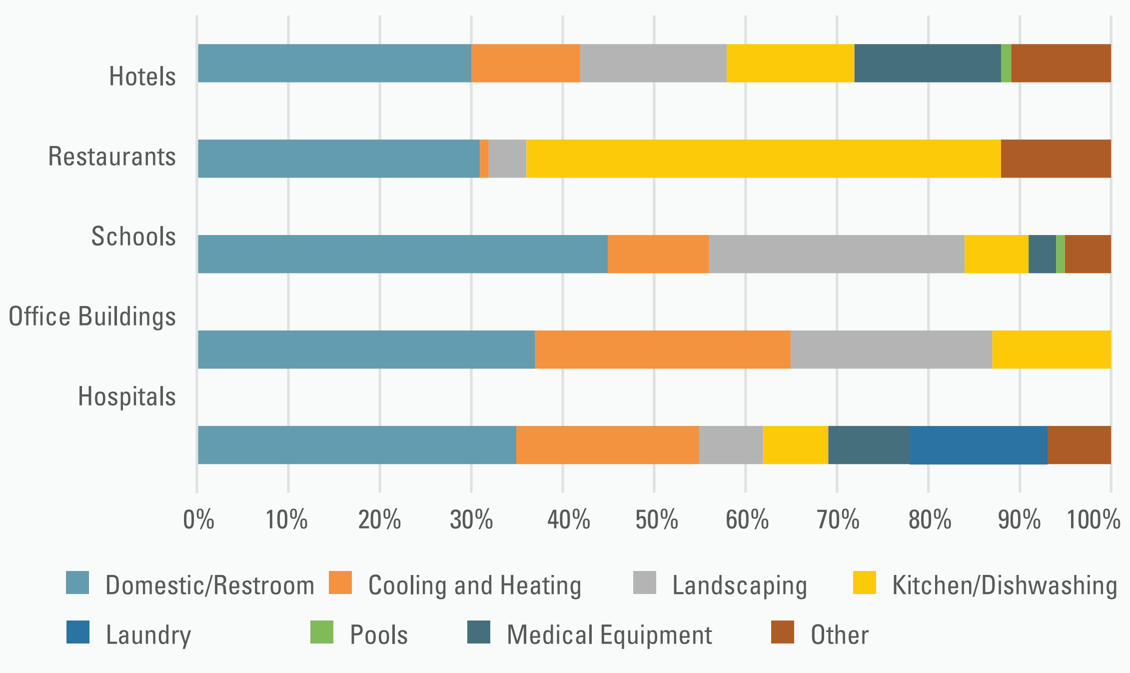
The term *consolidation practices,* used in the oil and gas industry, refers to the consolidation of operations related to well development so that they are performed for several wells at the same time. This enables a more efficient use of resources,

Table 8. Benefits and drawbacks of consolidation practices

Consolidation	Advantages	Disadvantages
Multiple well pads	• Requires less roads and infrastructure, leading to a smaller disturbance per well and reduced overall production footprint • Can eliminate disturbance in particularly sensitive areas • Reduces drilling and completion time, which reduces rig rental costs • Reduces need for service crews, decreasing traffic (and associated emissions) and operating costs • Increases efficiency of hydrocarbon recovery from the chosen reservoir	• Higher concentration of surface disturbance and waste generation • Batch processing of multi-well pads requires all wells on the pad to be drilled and completed before the results of the first well are known, delaying the start of production
Centralized staging/ storage	• Reduces truck traffic, which reduces wildlife harassment, air emissions and road damage • Reduces number of storage tanks needed per well site, reducing well pad size requirements • Facilitates reuse of materials; reduces fresh water usage	• Increases concentration of waste generation
Consolidated production facilities	• Reduces truck traffic, which reduces wildlife harassment, air emissions and road damage • Reduces number of storage tanks needed per well site, reducing well pad size requirements • Facilitates reuse of materials; reduces fresh water usage	• Surface disturbance concentrated to smaller area

Source: Created based on data from Intermountain Oil and Gas BMP Project, n.d.

Figure 11. End uses of water in various types of commercial and institutional facilities



Source: Created based on data from EPA WaterSense, 2016.

including water. Examples of such consolidation processes are provided in table 8 along with their advantages and disadvantages. These processes are multiple-well drill pads (advanced drilling procedures enabling the drilling at multiple locations in a single reservoir so that several wells can be drilled at once), common corridors (all roads, pipes, utility, and transmission lines being located in common corridors to reduce construction requirements) and centralized staging and storage (both input materials and output products being stored in centralized locations).[64] Anadarko's Completion Transport System has won awards for the savings it was able to achieve as a result of consolidation practices. For instance, it was able to decrease the need for fresh water by approximately 2 million oil barrels (bbls) by recycling about 80 per cent of completion fluids.[65]

Water efficiency in the industrial, commercial, and institutional sectors

Water efficiency improvement technologies in the industrial, commercial, and institutional sectors are primarily related to the type of buildings and to the equipment, which these buildings contain. To clarify the areas where most water efficiency gains can be made, it must be understood where exactly most water is used. Figure 11 shows the end use of water in different commercial and institutional entities.

There is indeed much room for improvement in the industrial, commercial, and institutional sectors as far as water efficiency is concerned. The minimum estimate of potential savings from increased water efficiency in the industrial, commercial, and institutional sectors of

California would be sufficient to fulfil the annual water requirements of the whole city of Los Angeles (both residential and non-residential applications).[66] Table 9 provides information on the different water and energy-saving technologies available for the sectors mentioned above.

Table 9. Potential water and energy-saving technologies available in the industrial, commercial, and institutional sectors

Area of improvement	Water efficient technology	Water and energy savings potential	Additional savings and information
Commercial landscaping	• Xeriscaping • Smart controllers and sensors	• Xeriscaping reduces water use by 50 per cent or more • Smart controllers cut 20-40 per cent of annual water use	Reduces dry-weather runoff and waterborne contaminants; can improve the appearance of the landscape
Cooling towers	• Conductivity controller • pH controller	• Conductivity controllers save 800,000 gallons (two acre-feet per year) • Up to 80 per cent potential water savings depending on the usage and facility	Upgrading one cooling tower can save significant amounts of money in water and sewage costs (up to $4,000 in the United States); pH controller reduces chemical costs; overall reduction in wastewater bills
Commercial faucets	• Low-flow faucet aerators (0.5, 1.0, and 2.2 gallons per minute (gpm))	• Reduces faucet water flow by 30-50 per cent (range is based on aerator type and faucet use) • Low-flow aerators reduce the energy costs of heating faucet water by up to 50 per cent	Faucet aerators cost less than $5 on average, making them very cost-effective
Showerheads	• Low-flow showerhead (2.0 and 2.5 gpm)	• 2.5 gpm flow can save 2 gallons per shower • 2.0 gpm flow can save 3.5 gallons per shower	Low-flow showerheads can be purchased in bulk quantities for low cost ($5-12 each in the United States)
Toilets	• Ultra low-flow toilets (1.3-1.9 gallons per flush (gpf) • High-efficiency toilet (1.28 gpf)	• Can save 15,000 gallons per year depending on the facility • Can save up to 19,000 gallons per year	Overall reduction in wastewater
Urinals	• High-efficiency urinals (0.5 gpf or less) • Waterless urinals	• Can save 20,000 gallons of water per year • Can save 45,000 gallons of water per year	Overall reduction in wastewater

Area of improvement	Water efficient technology	Water and energy savings potential	Additional savings and information
Commercial kitchen dishwashers	• Water-efficient commercial dishwasher	• Reduces water and energy use by 25 per cent per year	Payback period for installing small efficient commercial dishwasher can be significant (between one and four years in the United States). Larger flight-type machines even have a much longer payback period.
Commercial kitchen pre-rinse spray valves	• Water-efficient pre-rinse spray valve (1.6 gpm or less)	• Saves up to 50,000 gallons of water per year (26-80 per cent less water and energy consumption compared to standard valves)	Replacing a traditional pre-rinse spray valve that is used roughly three hours per day with a water-efficient pre-rinse spray valve can save 180 gallons of water per day and decrease water and energy costs (up to $1050 per year in the United States)
Medical equipment	• X-ray film processor water recycling equipment • Steam sterilizer retrofit	• Reduces annual water use by as much as 98 per cent • Saves 45 to 50 gallons per hour (60 per cent) per sterilizer	X-ray processor retrofit saves on utility bills each year ($600 in the United States). Steam sterilizer retrofit also achieves cost savings ($2,500 per sterilizer per year in the United States)
Clothes washers	• High-efficiency commercial clothes washers (common-area laundries) • Water efficient washer extractors (on-premise laundries) • Tunnel washers (industrial laundries)	• Can reduce water consumption by 35-50 per cent and achieve energy savings of up to 50 per cent • Can reduce water consumption by up to 40 per cent • Can reduce water consumption by 30-60 per cent	More efficient washers can reduce energy bills by up to 50 per cent and water and sewer costs by 35-50 per cent. High-efficiency washers require 50 per cent less detergent.

Source: Created based on data from Cohen, Ortez and Pinkstaff, 2009.

A number of strategies may be employed to increase water efficiency using devices already installed in industrial, commercial, and institutional buildings:

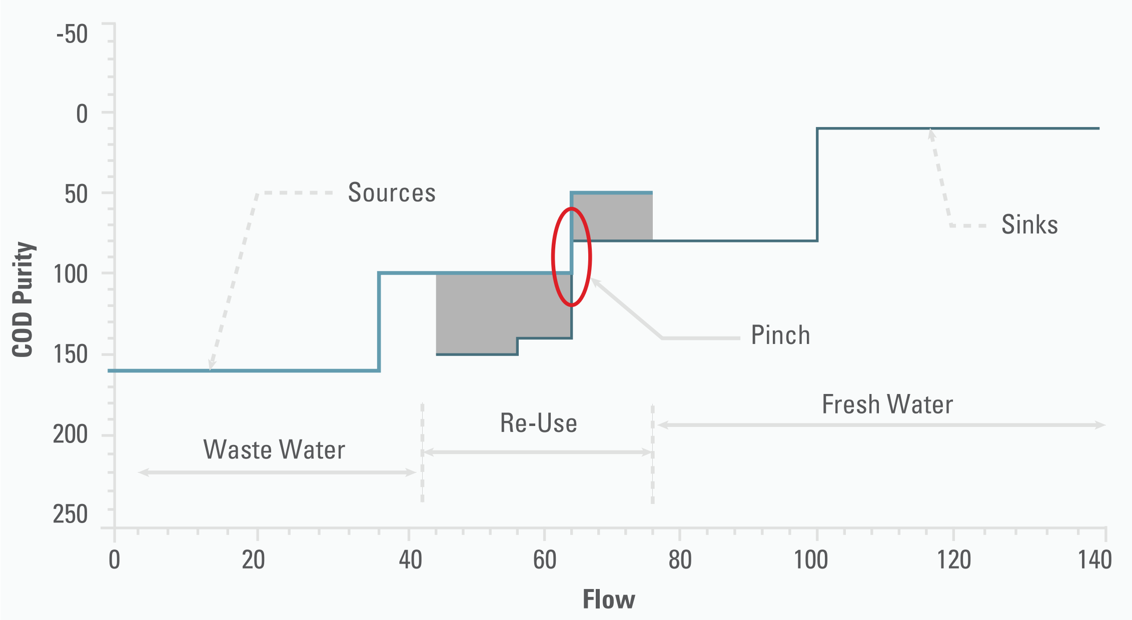
- Rinse cycles in industrial and food processing facilities can be modified to facilitate water savings, for example, by reducing the rinse time and water flow rate and by reducing the number of rinse cycles;
- Wastewater from production processes can be used to clean air scrubbers;
- Products of food and beverage processing can be disinfected with ozone instead of water;
- Automatic shut-off valves can be used on process equipment to stop the water flow when production stops;
- Water can be used in the first rinse of a batch of fruits and vegetables that has been previously used in the final rinse of the previous batch.[67]

Another possible strategy to increase water efficiency in the industrial, commercial, and institutional sectors is to use water storage tanks with two independent cells, each accommodating half of the tank's overall capacity. This arrangement enables the water from one cell to be held in the other cell during regular maintenance. Thus, this large portion of water does not need to be drained and the maintenance process becomes much more water efficient. Another strategy is to design the internal water distribution network of a building with clearly independent sectors depending on area of the building they belong to and the type of water consumption they entail. Such a network could consist of one sector per floor, one sector for the heating, ventilation and air conditioning (HVAC) system, one sector for the common areas, and so on. Each sector would then be equipped with its own water flow meter to specifically measure only its water consumption. This would help provide an understanding of water use trends in the different sectors while assisting in the identification of possible water leaks in the building.[68]

Pinch technology is a well-known energy and material flow analysis tool, which helps to optimize industrial processes while simultaneously increasing their energy and water efficiencies and limiting waste. This technology was originally used to improve thermal efficiencies, thereby saving energy at chemical process industries. It has also been used to address water and wastewater minimization by identifying potential process modifications, which can increase water savings and decrease water discharge.

In a pinch technology process, a flow sheet of the entire water system is first drawn up, displaying all the locations of water input and output. A water balance accounting for the various water sources and sinks in the system can therefore be analysed. Contaminants present in produced water, which may hinder its further use are also identified along with the limits for these contaminants at the different steps of the system. The determination of these parameters is followed by data collection and analysis. The multidimensional pinch analysis can then be used to determine optimum matches between different sources and sinks. This enables greater reuse of the water and thus improves water efficiencies. Water savings of up to 60 per cent have been reported as a result of the use of this technology.[69] Figure 12 shows a generic example of purity profiles used as part of pinch analysis. It illustrates water quality (water purity on the y-axis) and water quantity (water flow on the x-axis). Examples of relevant units of flow are measured in kilograms per second (kg/s) or tons per hour (tph). The chemical oxygen demand (COD) is an indication of contaminants in the water.

Figure 12. Purity profiles used as part of pinch analysis



Source: Kumana & Associates, 2011.

Water efficiency in households

With regard to improving water efficiency in households, the technology that may be used here is similar to that used in the bathrooms and kitchens of commercial and institutional buildings. However, there are some differences due to the different scales of operations. In general, water-efficiency technological solutions recommended for households include water-efficient fixtures and appliances or water-reuse technology. Landscaping options encourage people to plant primarily drought-tolerant grasses in their yards. Swimming pools can be covered when not used to prevent water loss through evaporation. Using dishwashers, when fully loaded, is much more efficient than washing dishes manually.[70]

Greywater recycling systems

Water can be reused in households in the form of a greywater recycling system. Such a system can be expanded and used in industrial, commercial, and institutional buildings as well. However, its successful application depends substantially on the potential uses of wastewater at the facility and the types of wastewater it generates. As a result, this toolkit reflects on the general example of a household greywater recycling system, which may easily be expanded for application in office buildings. In such a system (see figure 13), rainwater or greywater from showers, washbasins, and laundry operations may be used for watering lawns and gardens, washing clothes, and flushing toilets. It must be noted though that greywater reuse in toilets tends to require the installation of extra pipes, a storage unit, pumps, and a simple treatment unit. It is therefore much easier to build such reuse systems into a household under construction as opposed to integrating them into existing infrastructure later on. In addition, smaller scale greywater reuse systems, using the greywater from washbasins directly to flush the adjoining toilet, are gaining increased attention. Such systems include water disinfection and filtration processes, small water storage tanks, contrary to greywater recycling systems for a complete household, can easily be integrated into already existing installations.[71]

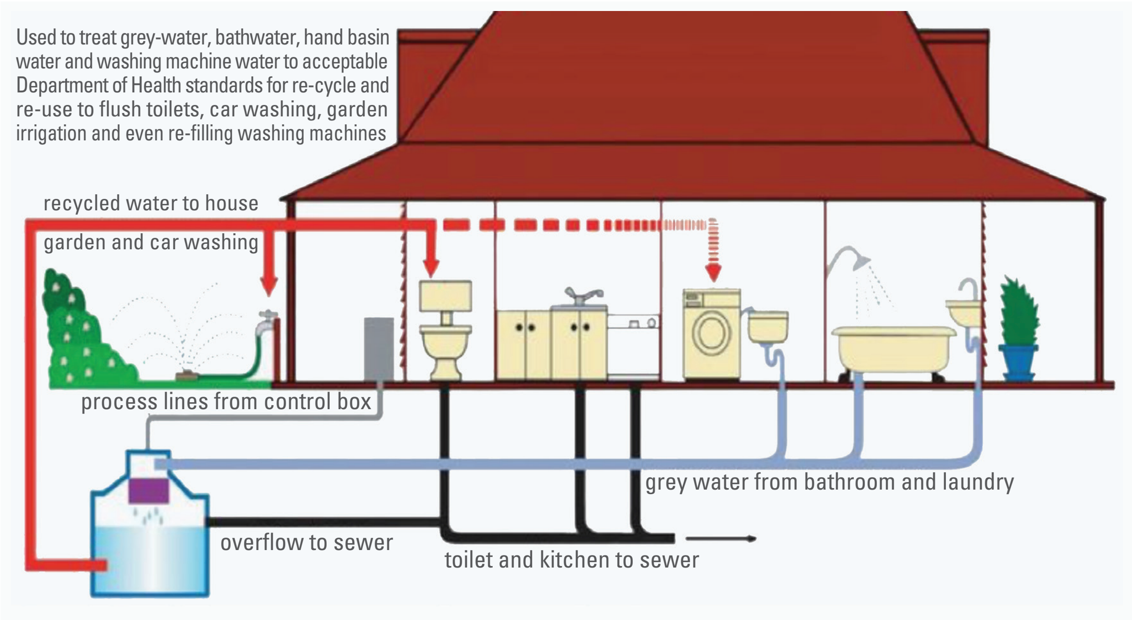
Water efficiency in water production and distribution systems

Water efficiency and irrigation

The water efficiency of irrigation for agricultural purposes depends substantially on the type of irrigation. Pressurized water application methods, such as sprinklers and microirrigation are considered to be the leading water saving irrigation technologies.[72] Moreover, the process of controlled drainage may be employed to decrease freshwater use since it enables agricultural water needs to be partially fulfilled by capillary rise from shallow water tables.[73] Additionally, partially treated water may be used for applications, such as growing vegetables and fodder for livestock through irrigation, thereby facilitating water reuse.

In order to optimize the irrigation process with respect to water use, below ground irrigation systems should be given priority over above ground systems as evaporation losses can be avoided in this way. Adjusting the irrigation process in response to variations in soil moisture content and local weather data further improves water efficiencies. This can be achieved to some extent with the use of an automatic irrigation controller, which also has the advantages of reduced costs and labour.[74] Other water-efficient irrigation technologies include efficient sprinkler heads (for instance, rotary spray heads) and rainfall shut-off devices (which help conserve water by turning off the irrigation system in rainy weather). Rainfall shut-off devices are inexpensive and can easily be retrofitted to almost all systems.[75] In order to maintain the water efficiency of irrigation procedures, the equipments involved must be regularly maintained to detect any faults in the system and ensure that parameter values (such as water flow rates from the drip nozzles) function well and provide the best performance to the overall system

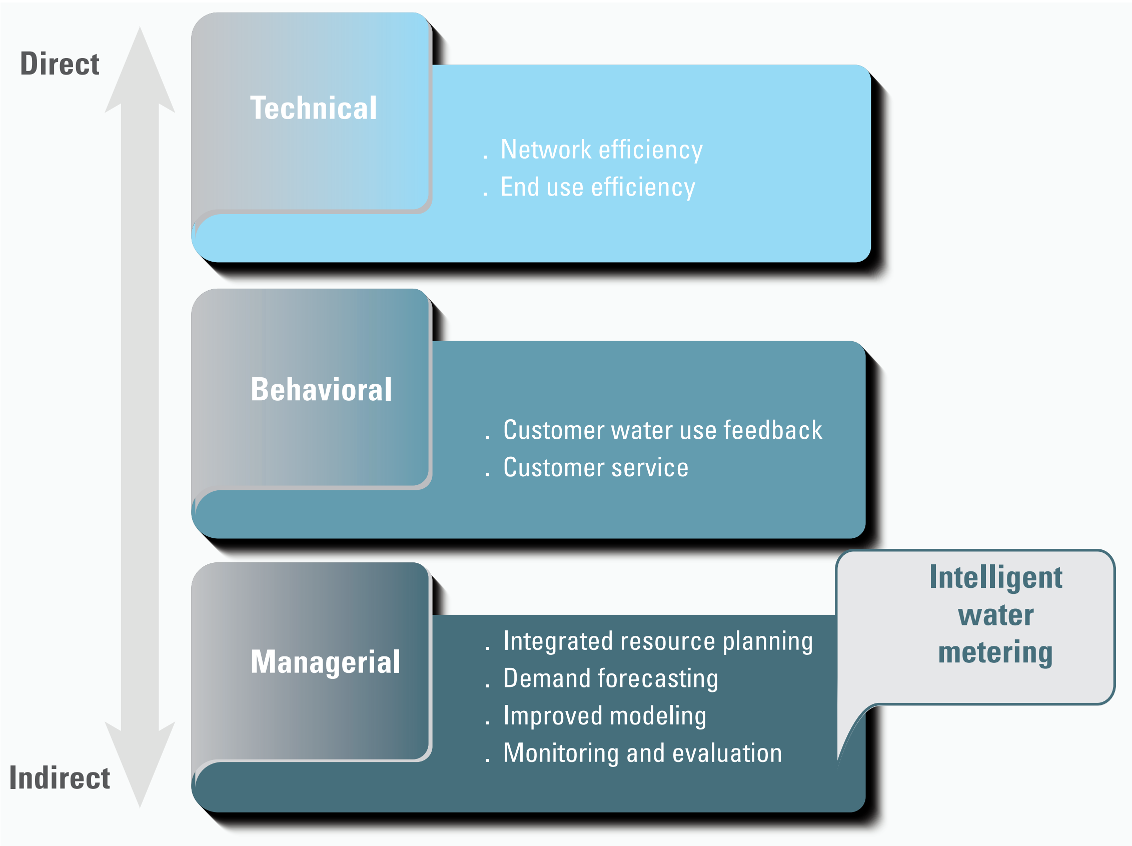
Figure 13. Schematic diagram of a greywater recycling system



Source: Tanked Australia, 2007.

during any disturbance. This is true for all water distribution systems. Such control and maintenance can be facilitated through intelligent systems as will be discussed in section 2.4.2. South Africa and Spain, among others, already apply such systems. In South Africa, an innovative decision support programme named Water Administration System is being used for irrigation projects where water has been supplied to clients in the required volumes and at the requested times through rivers, canal networks, and pipelines. Water losses have consequently decreased by up to 20 per cent, yielding annual water savings of about 41 million cubic meters. Similarly, in Spain, a centralized control system has been used, which improves water efficiency by monitoring the operations of pumping stations and the opening and closing of flow-regulating valves, performing surveillance of wells, locating failures in the system, accounting for volumes of water delivered to different irrigators, and so on.[76] According to their needs, farmers can program the activation and deactivation of irrigation to their farms by opening and closing the flow-regulating valves and monitoring pumping stations and wells (since the irrigation requirements of the 1,700 farmers participating in this system must be addressed simultaneously through using the pumping stations and wells).[77] This guarantees that water is supplied to the farms as required, preventing wastage. By locating failures in the system, water leakages can be prevented; and by accounting for water delivered to different farms and comparing these values to requested values, any faults in the system can be detected and remedied before too much water is wasted.

Figure 14. Hierarchy for water efficiency strategies



Source: Created based on data from Boyle et al., 2013.

Intelligent water metering systems

Intelligent metering systems employ "smart meters" in order to improve water and energy efficiencies. Such systems are increasingly being used around the world, where they are leading to substantial water and energy savings. For example, a study conducted by Intelligent Energy Europe, in which buildings from various European countries took part, reported water savings of 1-39 per cent (United Kingdom), 1-82 per cent (Austria), and 5-49 per cent (Denmark) and electricity savings of 0.5-40 per cent (United Kingdom), 2-80 per cent (Austria), and 0-27 per cent (Denmark).[78] Though results can vary greatly, it is evident that considerable improvements can be achieved. In general, it is estimated that energy savings of up to 30 per cent can be achieved as a result of combining intelligent metering with the behavioural change of the occupants of a building.[79] Unfortunately, information on savings is not easily available for the countries in the ESCWA region where intelligent metering systems have been used but this does not mean that such technology has not been applied in the region or that it does not have potential there. As of 2013, the countries of the Middle East could be divided into those, which still had not begun the introduction of these smart meters (for instance, Jordan and Lebanon), and those which were in the pilot phase of adopting such technologies (for instance, Saudi Arabia, and Qatar). Amongst the latter, the United Arab Emirates stands out as a frontrunner. By 2013, Abu Dhabi had already completed its first phase of smart meters implementation for both electricity and water[80] and the United Arab Emirates is still leading in this area. At the end of 2015, Dubai Electricity and Water Authority (DEWA) was intending to reach an installation rate of more than 200,000 smart meters in Dubai by 2016; and by 2020, that number was supposed to reach more than one million smart meters, with all mechanical and electromechanical meters expected to be replaced in Dubai.[81] A factor, which has been of relevance in the slow implementation of intelligent metering systems, especially in the Gulf countries, is the reluctance of authorities to change tariffs for utilities. However, low oil prices and governmental efforts to restructure their tariff schemes for water and electricity should provide impetus to the implementation of intelligent metering technology.[82]

Intelligent water metering (IM) (see figure 14) is a water-efficiency strategy, which has the potential to transform, and is already transforming, urban water management and to act as a tool for demand-side management. In 2009, for example, 18 per cent of all intelligent metering projects in the global water and energy industry were intelligent water metering projects.[83] However, the uptake of the technology has been slow due to such reasons as the low unit cost of water and high costs of technology.

IM "embraces two distinct elements; meters that use new technology to capture water use information and communication systems that can capture and transmit water use information as it happens, or almost as it happens".[84] The backbone of IM is therefore the advanced metering infrastructure (AMI), which consists of meters at the client end and communication links between client and service provider.[85] IM can monitor water consumption both locally and remotely, reducing labour costs (in addition to more controlled costs, in general) in addition to water savings and waste reduction, which explains its advance amongst utilities worldwide.

The information feedback provided by IM makes it an important tool for decision-making. The fundamental processes by which the IM system is bound are shown in table 10 along with their descriptions. It is therefore clear that IM is a data-intensive system. The parameters in table 10 "provide a framework to assess the opportunities provided by IM

Table 10. Processes of an intelligent metering system

Parameter	Measurement	Transfer	Processing/ analysis	Feedback
Mode	Water meter and data logger technology combinations used to capture information about water consumption. Residential intelligent metering typically uses displacement meters which generate a pulse signal after a set volume passes through the meter.	Means by which data is transferred from meters to utilities, customers and back. Data is transferred from the data logger via broadband, cable or wireless (e.g., radio, GSM, CDMA). May be fully remote or require near range collection (e.g., "drive-by" download).	Means by which a utility/third party stores (e.g., data servers) and manipulates (e.g., end-use analysis software package) water use data. Implications for third party access.	Method by which data is provided to customers for interpretation, e.g., postal bill, e-mail, Web interface, smart phone application. Behaviour change may/may not ensue.
Frequency	The specified time intervals at which (i) water use is recorded by the meter/between number of pulses; and (ii) data from the meter is collected by the data logger, e.g., 15 min intervals.	How often data is sent or collected by the utility/ third party, e.g. daily, half hourly, "real-time". Will vary depending on the type of meter, e.g., pulse versus interval.	The frequency at which water use information is used to update utility operations (e.g., for pressure management).	The frequency at which water use information is communicated to the customer (e.g., quarterly, monthly, daily, real-time, etc.).
Resolution	The granularity of water flow detected by a water meter (e.g., L/pulse). Determined by the purpose, capabilities and settings of the water meter. Resolution of the recorded data by the data logger, e.g., L/15 min (frequency of measurement, above).	Resolution of data remains unchanged, though quality of data (complete/ partial) may suffer from disruptions to transmission process.	Data may be aggregated or manipulated to analyse trends (e.g., leak assessment; end-use analysis).	The level of detail of information provided to the customer, such as usage per unit of time and/or end use breakdown. Comparative framing and benchmarking may aid legibility and comprehension. Content and framing should be informed by behaviour change theory, information about target audience and tailored to the mode in question.

Notes: CDMA: Code Division Multiple Access; GSM: Global System for Mobile Communications; both are technology platforms for mobile/ cellular telephones.
Source: Created based on data from Boyle et al., 2013.

through an enhanced understanding of how and when water is used".[86] Furthermore, Table 10 lists different hardwares and softwares that provide the infrastructure of IM systems.

There are several different metering technologies, which use different principles to capture and record water use data. These technologies may be broadly classified into four categories: Displacement meters, velocity meters, compound (or combination), and electromagnetic meters. Displacement (also known as mechanical) meters are inexpensive and known to be accurate at low to moderate water flow rates. Since electromagnetic flow meters have no moving parts, they are well-suited to monitor flows with debris or contaminants, which could damage a displacement meter.[87] In some instances, new meters need to be installed while in others, older meters may be retrofitted as part of the IM system.

In Australia, trials for the IM technology have been carried out. One such trial reported annual savings of 900 million litres or a 12 per cent decrease in water use,[88] manifesting the potential of IM. However, there are challenges to its large-scale implementation, including the processing of such large amounts of data at a single time and the challenges associated with making supply meet demand. Nevertheless, this market is growing rapidly and smart water metering is expected to lead to cumulative investments worth $7.8 billion by 2020 in Europe alone.[89]

Technologies to improve energy efficiency

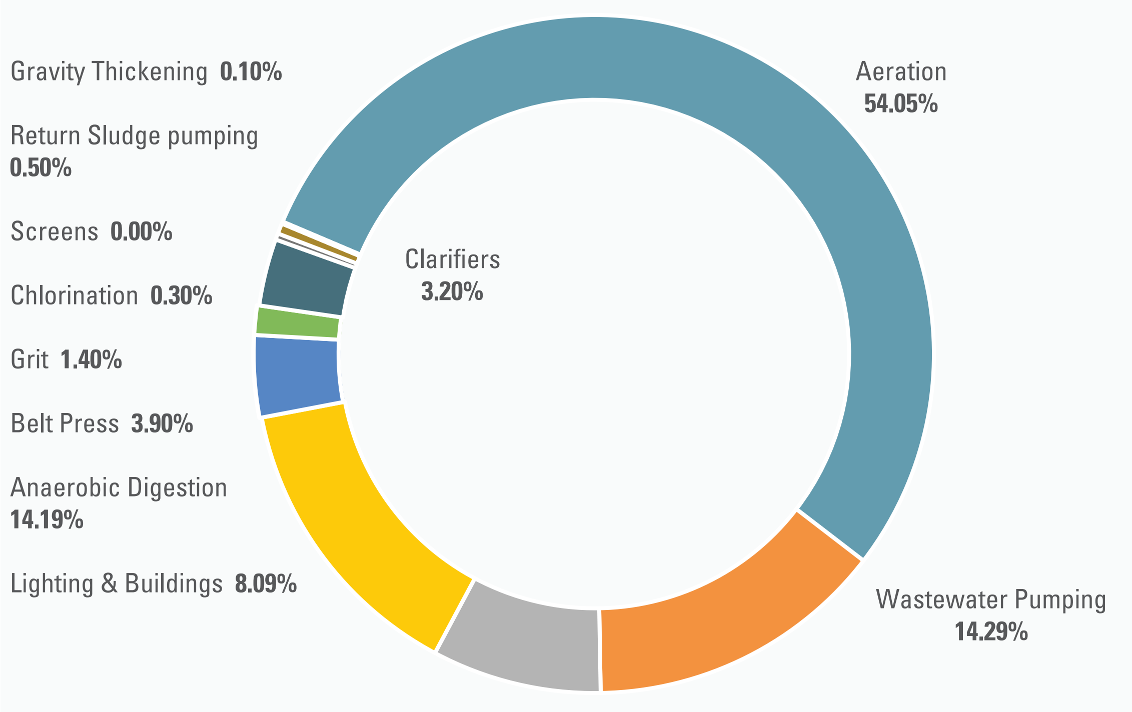
Due to water-energy nexus, the strategies recommended for water efficiency in section 2 of this toolkit would naturally lead to energy efficiency as well. Along the same lines, strategies mentioned in this section would help in reducing water requirements. The ESCWA region is especially dependent on processes like desalination for its water needs, which tend to be energy intensive. Moreover, the energy consumption rates per capita of

Table 11. Energy management opportunities in the water and wastewater industries

Energy efficiency and demand response	Emerging technologies and processes	Energy recovery and generation
• Strategic energy management • Data monitoring and process control • Water conservation • High-efficiency pumps and motors • Adjustable speed drives • Pipeline optimization • Advanced eAeration • Demand response	• Odor control • Membrane bioreactors • Deammonification sidestream process • Water reuse • Residuals processing • Microbial fuel cells • LED UV lamps	• Cogeneration using digester biogas • Use of renewable energy to pump water • Recovery of excess line pressure to produce electricity

Source: Created and grouped based on data from Reekie, 2013.

Figure 15. Percentage breakdown of typical wastewater system energy consumption (percentage)



Source: Created based on data from Darwish et al., 2016.

countries in the region, such as Kuwait, Qatar, and the United Arab Emirates are among the highest in the world.[90] As a result, energy efficiency technologies are urgently needed in the region.

Table 11 shows different management opportunities for energy. Some of these, such as water reuse, have been discussed extensively in section 2. These measures are applicable in a variety of sectors. Those which are of greater relevance to the ESCWA region and are more established technologies will be discussed in the remainder of section 3.

Energy efficiency in water and wastewater treatment

Energy consumption of water and wastewater treatment plants (WWTPs)

Figure 15 depicts energy consumption in a wastewater treatment plant.[91] It illustrates where the efforts of the management must be directed if the most substantial improvements in energy efficiency are to take place. These areas of improvement have to do with aeration, wastewater pumping, anaerobic digestion, and lighting and buildings.

Table 12 mentions various types of commonly used WWTPs along with their unit energy consumption. It is clear that as the capacity of the plant increases, the unit energy consumption decreases, though the decrease has been most pronounced for the trickling filter pant. It is also clear that as treatment options become more advanced, they require

Table 12. Unit electricity consumption in kilowatt hour (kWh)/cubic meter for wastewater treatment by plant size and type of treatment

Treatment plant size (cubic meters per day)	Trickling filter	Activated sludge	Advanced wastewater treatment	Advanced wastewater treatment nitrification
3,785	0.479	0.591	0.686	0.780
18,925	0.258	0.362	0.416	0.509
37,850	0.225	0.318	0.372	0.473
75,700	0.198	0.294	0.344	0.443
189,250	0.182	0.278	0.321	0.423
378,500	0.177	0.272	0.314	0.412

Source: Created based on data from Darwish et al., 2016.

greater amounts of energy. Therefore, as per the extent of purity required in the treated water, a type of treatment can be chosen, which has the lowest energy consumption while providing that level of cleanliness.

Table 13 provides the energy intensities for different plants already in operation throughout the world and lists the different characteristics of the plants. The plants are listed in order of increasing capacity. As the capacity increases, the electric energy intensity decreases; the only exception is the 85 millions of gallons per day (MGD) advanced wastewater plant using biological nutrient removal (BNR), whose electric energy intensity has increased despite its large capacity, which is due to the advanced wastewater treatment it employs to remove nitrogen and phosphorus from the water being treated.

Table 14 reflects the energy requirements of treatment plants with membrane systems and does not solely discuss conventional WWTPs. It further mentions the end uses of the treated water, which gives an idea of the extent of purity achieved through the treatment process. The membrane treatment tends to provide higher quality water products, which require greater amounts of energy. These membrane treatment systems will be discussed in more detail in section 3.3, which focuses on desalination.

Table 13. Typically consumed energy for several plants' capacity and different WWT processes

Treatment plant description	Electric energy intensity kWh/MG (kWh/m^3)
3 MGD membrane bioreactor for water reuse	4,910 (1.30)
6 MGD sequencing batch reactor, dried biosolids sold for reuse, UV disinfection	2,250 (0.59)
20 MGD trickling filter with anaerobic digester	1,520.9 (0.40)
85 MGD advanced wastewater plant using BNR	2,040 (0.54)

Source: Created based on data from Darwish et al., 2016.

Table 14. Energy intensity of recycled water treatment and end uses of the recycled water

Technologies Used	Energy use (kWh/MG)	End Use
	Conventional tertiary treatment	
Anthracite coal bed filtration, demineralization, chlorination	982	Irrigation, industrial use
Flocculation, direct filtration, UV/advanced oxidation	1,500	Irrigation, industrial use
Clarification, media filtration, chlorination	1,619	Irrigation, industrial and commercial use
Anthracite coal bed filtration, UV	1,703	Irrigation, industrial use
Rapid mix, flocculation, media filtration, UV	1,800	Irrigation
	Membrane treatment	
Coagulation, flocculation, clarification, UF, RO, UV/ advanced oxidation	3,220	Agricultural, industrial use
MF, RO, UV/advanced oxidation	3,680	Groundwater recharge
MF, RO, UV/advanced oxidation	3,926	Seawater intrusion barrier
UF, RO, UV	4,050	Industrial use
MF, RO	4,674	Industrial use
MF, RO	8,300	High-quality industrial use

Notes : MF: Microfiltration; RO: Reverse osmosis ; UF: Ultrafiltration; UV: Ultraviolet.
Source : Created based on data from Water in the West, 2013.

Initiatives to improve energy efficiency

There are several initiatives, which can be undertaken to improve energy efficiency in water and wastewater treatment and which are listed in table 15. This strategy of targeting the most energy-consuming processes mentioned in table 15 complements the discussion on figure 15 in this report. Along the same lines, it can be noted that table 15 pays special attention to pumping energy, which is also one of the major energy consumers at WWTPs.

Table 16 describes various initiatives, which may be implemented to improve energy efficiency at water and wastewater treatment plants. While table 15 is more specific about the area of the plant where the energy management strategy is being implemented, the strategies described are more general in nature. The opposite is true for table 16. As a result, the practices mentioned in table 16 are examples of how the strategies mentioned in table 15 can be implemented.

Table 15. Energy efficiency strategies for municipal WWTPs

Technologies Used	Energy Use (kWh/MG)
Process energy	Focus on biggest energy consumers at WWTP
Operational controls	Tailor operations to meet seasonal and diurnal changes
Quality vs. energy	Balance water quality goals with energy needs
Repair and replacement	Consider equipment life and energy usage to guide repair and replacement
Biosolids	Consider trade-offs between treatment energy and improved biosolids quality
Infiltration/inflow	Address infiltration and inflow to reduce treatment energy
Leaks and breaks	Address leaks and breaks to reduce pumping energy
On-site renewable energy	Consider opportunities for on-site generation to reduce energy purchases
Conservation	Educate the community: Less water reduces WWTP loads and energy needs

Source: Created based on data from Daw et al., 2012.

The best practices listed in table 16 are divided into three categories: General, water, and wastewater. While this toolkit concentrates on those best practices, which are technology-centric, tables A2 and A3 in the annex contain detailed information (namely, description, primary area/process, productivity impact, economic benefit, energy savings, applications and limitations, practical notes, other benefits, and stage of acceptance) on the implementation of these selected general and wastewater best practices. Table A2 discusses electric motors: Variable frequency drives applications while table A3 discusses fine-bubble aeration; variable blower air flow rate; dissolved oxygen control; post aeration: Cascade aeration; sludge: replace centrifuge with screw press; sludge: replace centrifuge with gravity belt thickener; reduce fresh water consumption/final effluent recycling; and use biogas to produce CHP.

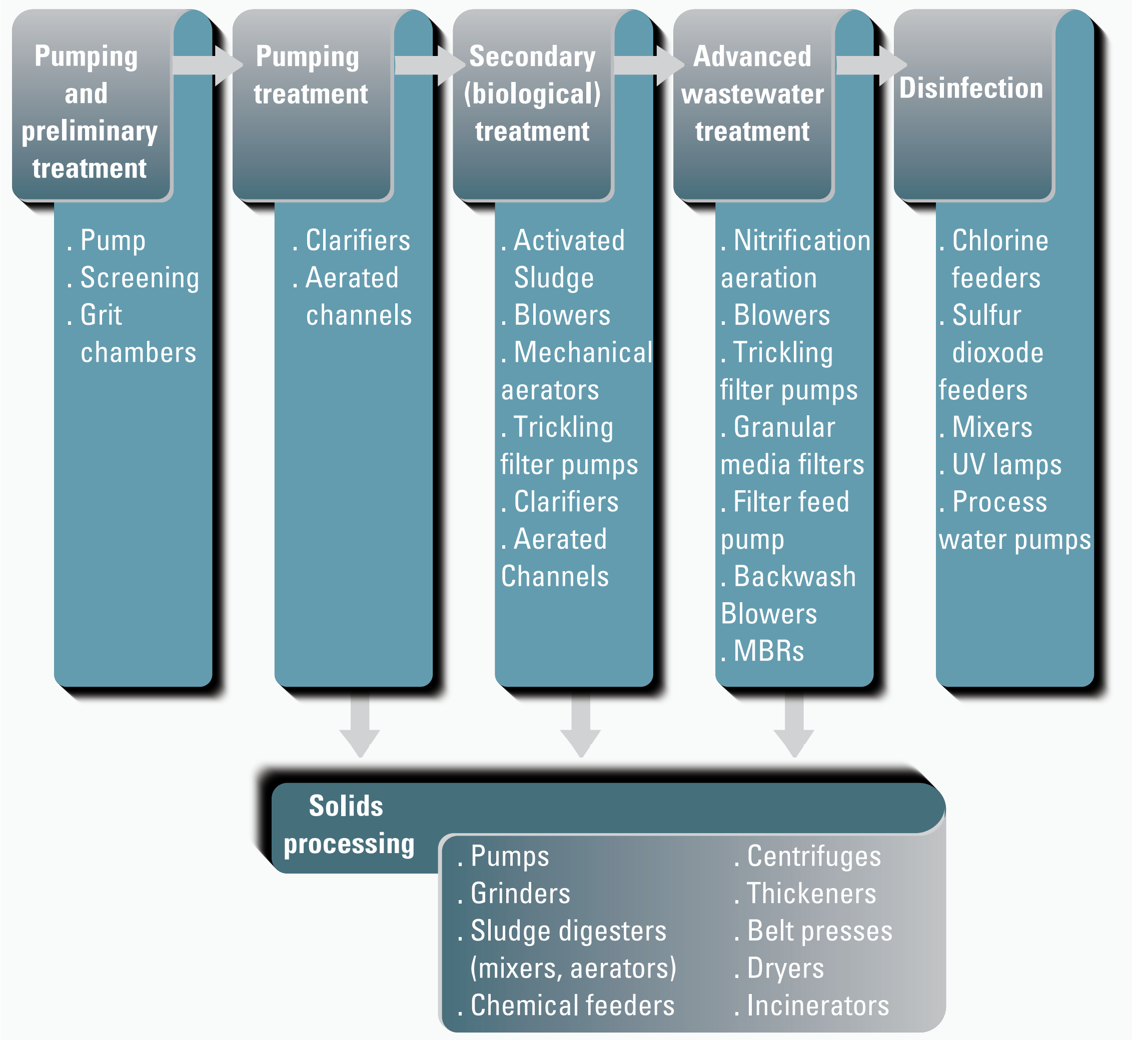
Figure 16 lists commonly used equipment in wastewater treatment and outlines the basic sequence of steps followed in the treatment process. At each step, not all the equipment mentioned is used at a particular facility. In fact, in most cases, particularly as concerns solids processing, the different equipments mentioned are alternatives, which must be chosen from. Each equipment has its particular energy footprints, which should also be considered when choosing the appropriate type of equipment. Apart from energy requirements, the selection depends on economics, intended final use of treated water, and regulatory requirements, in addition to a number of other logistical and technical factors. As an example, table 17 describes the options for solids processing in terms of their relative energy requirements. It must be noted that the energy consumption of WWTPs also depends on the quality of the influent entering the plant.[92] In addition, oftentimes obtaining a higher quality effluent and higher quality biosolids requires greater energy consumption rates, and plant designers must strike a balance between the effluent quality they need to obtain and the amount of energy they are willing to use to obtain it.[93] This is also mentioned in table 15. Table 18 shows how the level of energy consumed varies with different treatment system setups and the relationship between the effluent quality and the energy consumed in the treatment process. Lower values of the parameters of biochemical oxygen demand (BOD), suspended solids (SS), phosphorus (P), and nitrate (N) indicate better quality water. The trends goes towards greater energy consumption values at higher quality effluent levels although the type of treatment being done and, consequently, the equipment used also play a significant role in determining energy consumption values, as already mentioned.

Table 16. Best practices in water and wastewater energy management

General Best Practices	Water Best Practices	Wastewater Best Practices
• **Facility energy assessment** • **Real-time energy monitoring** • **Energy education for facility personnel** • **Comprehensive planning before design** • **Design flexibility for today and tomorrow** • **Electric peak reduction** • **Manage electric rate structure** • **Idle or turn off equipment** • **Electric motors: install high-efficiency motors** • **Electric motors: automate to monitor and control** • **Supervisory control and data acquisition (scada)** • **Electric motors: variable frequency drives applications** • **Electric motors: correctly size motors** • **Electric motors: properly maintain motors** • **Electric motors: improve power factor** • **Pumps: optimize pump system efficiency** • **Pumps: reduce pumping flow** • **Pumps: reduce pumping head** • **Pumps: avoid pump discharge throttling** • **Filtration: sequence backwash cycles** • **Ultraviolet (UV) disinfection options** • **Renewable energy options**	Integrate system and power demands Computer-assisted design and operation System leak detection and repair Manage well production and draw-down Sequence well operation Optimize storage capacity Promote water conservation Sprinkling reduction program Manage high volume users	• Operational flexibility • Staging of treatment capacity • Manage for seasonal/tourist peaks • Flexible sequencing of basin use • Optimize aeration system • Fine bubble aeration • Variable blower air flow rate • Dissolved oxygen control • Post aeration: cascade aeration • Sludge: improve solids capture in DAF system • Sludge: replace centrifuge with screw press • Sludge: replace centrifuge with gravity belt thickener • Biosolids digestion options • Aerobic digestion options • Biosolids mixing options in aerobic digesters • Biosolids mixing options in anaerobic digesters • Optimize anaerobic digester performance • Use biogas to produce heat and/or power • Cover basins for heat reduction • Recover excess heat from wastewater • Reduce fresh water consumption/final effluent recycling

Note: DAF: Dissolved air flotation.
Source: Malcolm Pirnie, Inc., 2010.

Figure 16. Commonly used processes and equipment in wastewater treatment



Source: Created based on data from Reekie, 2013.

Tables 17 and 18 have outlined different strategies to improve energy efficiency at water and wastewater treatment plants but the questions remains how effective these strategies actually are. Table 19 provides a quantitative idea of the possible energy savings from some of these strategies. The data in table 19 is a compilation of energy savings achieved from energy efficiency measures applied globally by Global Water Research Coalition (GWRC) members. The values documented in the table are estimates of unit process electrical and primary energy reduction performance as aggregated for all wastewater treatment plant types and capacities from 1-100 MGD.[94]

Table 20 provides some values for the possible energy recovery potential from such strategies, though the technologies it addresses are more complementary to the data in table 17 and the data provided is with respect to existing wastewater treatment plants. The values mentioned refer to the quantity of energy that would need to be extracted from the incoming wastewater for facility primary energy self-sufficiency (namely, the

Table 17. Processing and disposal methods of solids

Processing or disposal function	Unit operation, unit process and treatment method	Impact on electricity use
Preliminary operations	Pumping	Moderate
	Grinding	Small
	Degritting	Small
	Solids blending and storage	Small
Thickening	Gravity thickening	Small
	Flotation thickening	Moderate
	Centrifugation	Moderate
	Gravity belt thickening	Small
Stabilization	Lime stabilization	Small/moderate
	Heat treatment	Significant
	Anaerobic digestion	Small/moderate
	Aerobic digestion	Moderate/significant
	Composting: windrow	
	Aerated static pile	Small
	In-vessel	Moderate
		Significant
Conditioning	Chemical conditioning	Small
	Heat treatment	Significant
Disinfection	Pasteurization	Moderate
	Long-term storage	Small
Dewatering	Vacuum filter	Significant
	Centrifuge	Significant
	Belt press filter	Small/moderate
	Filter press	Moderate/significant
	Biosolids drying beds	Small
	Lagoons	Small
Heat drying	Dryer variations	Moderate
	Multiple effect evaporator	Significant
Thermal reduction	Incineration	Significant when used
	Wet air oxidation	Significant when used
Ultimate disposal	Land application	Small
	Landfill	Small
	Lagooning	Small
	Chemical fixation	Moderate

Source: Created based on data from Reekie, 2013.

"Gap").[95] This quantity is estimated to be 1.9-7.2 megajoules (MJ)/m^3. As seen in table 20, the range of energy savings is quite significant for many of these strategies, which is caused by the implementation of these strategies in different types of plants. Similarly, the performance of plants is influenced significantly by environmental conditions in a particular location. Therefore, energy savings obtained vary from one location to another.

Table 18. Total annual energy consumption for a typical 1-MGD system including electrical and fuel requirements

Treatment System	Effluent Quality				Energy
	BOD	SS	P	N	(1000 kWh/yr)
Rapid infiltration (facultative lagoon)	5	1	2	10	150
Slow rate, ridge + furrow (facultative lagoon)	1	1	0.1	3	181
Overland flow (facultative lagoon)	5	5	5	3	226
Facultative lagoon + intermittent sand filter	15	15	-	10	241
Facultative lagoon + microscreens	30	30	-	15	281
Aerated lagoon + intermittent sand filter	15	15	-	20	506
Extended aeration + sludge drying	20	20	-	-	683
Extended aeration + intermittent sand filter	15	15	-	-	708
Trickling filter + anaerobic digestion	30	30	-	-	783
Rotating biological contactors + anaerobic digestion	30	30	-	-	794
Trickling filter + gravity filtration	20	10	-	-	805
Trickling filter + N removal + filter	20	10	-	5	838
Activated sludge + anaerobic digestion	20	20	-	-	889
Activated sludge + anaerobic digestion + filter	15	10	-	-	911
Activated sludge + nitrification + filter	15	10	-	-	1051
Activated sludge + sludge incineration	20	20	-	-	1440
Activated sludge + advanced wastewater treatment	<10	5	<1	<1	3809
Physical chemical advanced secondary	30	10	1	-	4464

Source: Created based on data from Crites et al., 2014.

As part of the technological options mentioned in table 20, AD biogas is mentioned multiple times. Anaerobic digestion, though a very old process,[96] has become more popular in the recent past because it tends to be less energy intensive than aerobic treatment and because it generates biogas as a by-product.[97] The methane thus generated is often used as source of energy for the treatment plant itself. Therefore, the plant has lower energy costs and a lower carbon footprint, issues which have currently become very important for WWTPs. Nevertheless, compared to aerobic digestion, anaerobic digestion does have some disadvantages: It can only treat a smaller range of water[98] and is usually followed by aerobic treatment as part of post-treatment.[99] At the same time, the disadvantage of anaerobic digestion of requiring greater heat input than aerobic digestion is actually not really a disadvantage in the ESCWA region where ambient temperatures tend to be relatively high, thus providing a favourable environment for the anaerobic digestion process. As of 2009,there were an estimated

Table 19. Summary of potential savings through use of best practices in wastewater treatment plants

Energy conservation measure	Treatment stage	Energy savings range (%)
Wastewater pumping optimization	Throughout system	<0.7%
Aeration system optimization	Secondary treatment	~15 to 38%
Addition of pre-anoxic zone for BNR	Secondary treatment	~4 to 15%
Flexible sequencing of aeration basins	Secondary treatment	~8 t0 22%
High-efficiency UV	Disinfection	~4%
Lighting system improvements	Support facilities (buildings)	~2 to 6%

Source: Created based on data from Deines, 2013.

Table 20. Summary of energy recovery potential using established technologies

		Net energy: "Gap" reduction possible (percentage)
Biosolids technology	AD biogas with boilers	13-57
	AD biogas with cogeneration engines	11-61
	AD biogas with microturbines	5-38
	AD biogas with turbines	7-46
	AD biogas with fuel cell	6-42
	AD biogas after WAS pretreatment	~2-60
	AD biogas with co-digestion	2-128
	Incineration	2-69
	Gasification	~9-82
Other technology	Enhanced solids removal	10-71
	Anaerobic primary treatment	25-139
	Heat recovery	13-49
	Hydraulic	0
	Ammonia as fuel	~6-12
	Heat from centrate	13-49
	Microbial fuel cells	8-110
	Biofuel from algae	~39-208
	Enhanced solids removal	10-71

Note: AD: Anaerobic digester; WAS: Waste-activated sludge.
Source: Deines, 2013.

64 anaerobic installations in the Middle East and Africa.[100] The As-Samra Wastewater Treatment Plant, the largest wastewater treatment plant in Jordan, has four anaerobic sludge digesters, and 80 per cent of its electricity needs are fulfilled internally through the biogas the plant generates.[101] Along the same lines, Gabal El Asfar, one of the largest wastewater treatment facilities in Egypt, fulfils up to 65 per cent of its power needs internally.[102] More such facilities are being built in the MENA region. For instance, a municipal wastewater treatment plant is being expanded in Al Kharj in Saudi Arabia to include anaerobic sludge treatment, thereby allowing the expanded plant to cover 50 per cent of its power needs autonomously through the conversion of biogas to electricity upon completion in 2017.[103]

Demand response (DR)

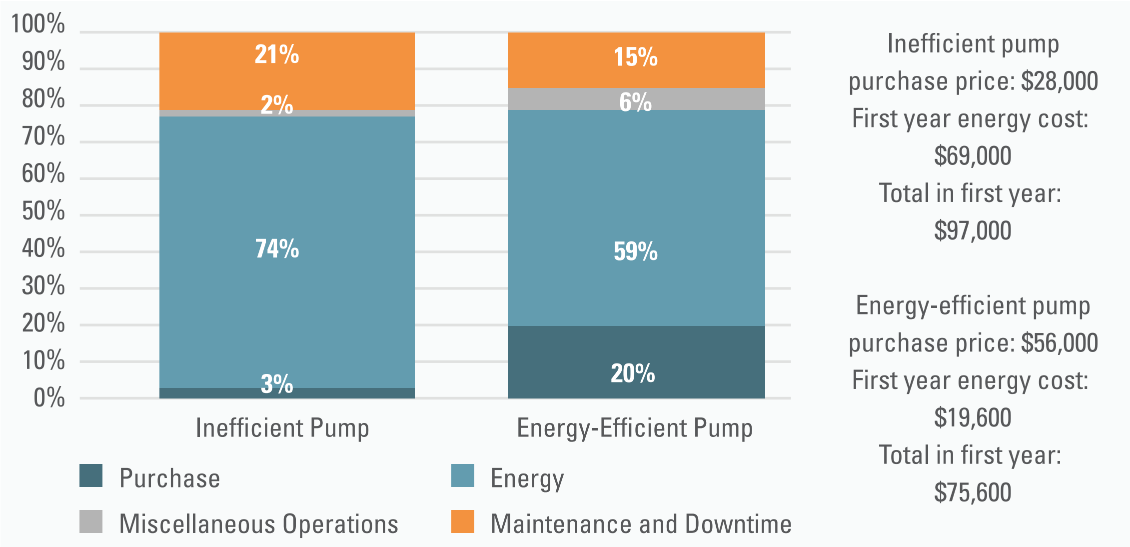
As demonstrated thus far, water and wastewater treatment plants include several processes, which can be energy intensive. In addition, they rely on water storage facilities to respond to water flow variations, which allows them a certain level of flexibility insofar as the operation of certain equipment (such as centrifuges and pumps) is concerned. These characteristics of water and wastewater treatment plants make them good candidates for the use of DR strategies. As such, they can coordinate with electric utilities to manage their electrical load through DR programmes. There are four general ways in which a plant can reduce the amount of electricity it consumes from the grid during peak periods, namely: (i) load shedding/load curtailment (achieved by dimming or turning off lights, turning off non-critical equipment, among others); (ii) load shifting (shifting equipment use to off-peak from on-peak time periods); (iii) switching to onsite generation; and (iv) a combination of the previous three strategies. By implementing DR strategies, the plants are able to reduce their utility costs. As an example, a wastewater treatment plant in Southern California was able to reduce its electricity demand by 30 per cent of its total plant load on a particular day.[104] In order for the above to be possible, local utilities and electric power providers must provide such DR programmes.

Energy efficiency in water distribution systems

Water supply systems consume significant amounts of energy during the various processes along the water supply chain. These processes include pumping and distributing the water along the network. Energy efficiency can be improved by, for example, upgrading the design of pump stations, increasing tank capacity and installing variable speed drives (VSDs) for the pumps. VSDs provide flexibility and improve operational efficiency by enabling a certain pressure value to be maintained in response to varying flow conditions and vice versa. This helps decrease the number of times the pumps stop and start, facilitating more energy-efficient operations. Water loss can also be reduced (and therefore energy efficiency increased) in distribution systems by installing pressure-reducing valves along the pipes network. Such valves reduce the pressure in the pipes when water flow is low during off-peak periods, preventing leakages.[105,106]

In the specific case of irrigation, energy efficiency can be improved by choosing the most appropriate irrigation method. For example, surface irrigation requires the least amount of energy as water flow is caused by gravity along the field but such a system may lead to greater water losses. Microirrigation systems, which apply water near the

Figure 17. Life cycle costs of inefficient vs. efficient pump systems (percentage)



Source: Reekie, 2013.

bases of each plant, could also be a suitable option. They are more water efficient (since evaporation and seepage losses are reduced) and energy efficient (as low pumping power is required). If a sprinkler system is to be used, one which uses less energy should be preferred.[107]

Pumping accounts for a large portion of the energy consumption of water distribution systems. As a result, when designing such systems, much care should be taken to ensure that all components are appropriately sized to reflect expected conditions. This is especially true for pumps which have a capital cost that is usually less than 10 per cent of their whole-life costs and energy costs that are often greater than 80 per cent of their whole-life costs (see figure 17).[108]

Energy efficiency in desalination

Desalination is a crucial process for the countries of the ESCWA region, which have very limited access to freshwater resources. In fact, almost 50 per cent of the global desalination capacity is located in the MENA region.[109] Indeed, five of the top ten seawater desalination countries by online capacity are in the ESCWA region, and the top two countries are Saudi Arabia and the United Arab Emirates.[110] Furthermore, it is forecasted that, by 2050, Saudi Arabia and other countries in the MENA region will consume most of the oil they produce for desalination and other domestic purposes.[111]

Amongst the drawbacks of desalination are that it is costly, energy intensive, and detrimental to the environment. It is, therefore, of utmost importance to increase energy efficiency in desalination technology. Table 21 provides information about the different desalination technologies, elucidating their advantages and disadvantages, which vary greatly from one technology to the other. Organizations may accordingly decide which desalination type is most suitable for their particular situation.

Table 21. Comparison between various desalination technologies

Treatment Method	Features	Strength(s)	Weakness(es)
RO	• Pressure-driven membrane process • Pre-treatment required to prevent membrane fouling • Seawater recovery 30-60 per cent • Brackish water recovery 50-80 per cent	• Dominant technology • Effectively removes salts • Viable for large-scale (>25 million gallons per day) operations • Works with seawater • Less investment cost	• Energy intensive • Relatively low recovery creates large brine volumes • Does not remove all contaminants (e.g., boron) • Cost-prohibitive for high TDS waters • Current membranes prevent higher-pressure operation
Nanofiltration	• Pressure-driven membrane process • Lower pressures than RO • Performs well for lower-salinity water • Different pollutants can be removed in the same filtration step	• Can selectively retain healthy trace minerals in drinking water • Removes many potential RO/FO membrane foulants • Proven technology	• Inadequate contact time can limit contaminant removal • Primarily viable as a pre-treatment step
FO	• Osmotic pressure-gradient-driven membrane process • Pre-treatment required to prevent fouling • Seawater recovery >60 per cent demonstrated • Brackish water recovery >90 per cent demonstrated (in conjunction with RO) • Pressure-assisted FO also an option	• Effectively removes salts and other contaminants, including boron and arsenic • Substantial reduction in energy requirements compared to RO • First commercial-scale deployments in operation in Middle East in Oman (Thompson and Nicoll, 2011)	• Generation of sufficient osmotic pressure still challenging for high-TDS feed waters • Improved membranes needed to maximize performance
Membrane Distillation	• Lower-temperature alternative to traditional thermal techniques • Relies on evaporation rather than boiling • Membranes select for water vapour versus liquid water	• Water quality competitive with traditional thermal techniques • Can effectively use waste heat • Relatively small footprint, low capital costs • Relatively insensitive to feed TDS levels	• Not fully proven for large-scale applications • Volatile contaminants may require pre-treatment • Membrane degradation issues not fully understood

Treatment Method	Features	Strength(s)	Weakness(es)
Dewvaporation	• Novel use of heat transfer and energy recovery in a humidification/ dehumidification process • First two commercial plants operational in 2012, treating produced waters from Marcellus shale play in Pennsylvania, United States • Operates at atmospheric pressures • Recovery rates >90 per cent • Removes heavy metals, organics, and radionuclides	• Water quality competitive with traditional thermal techniques • Efficient use of low-grade heat • Relatively insensitive to feed TDS levels • Absence of membranes reduces fouling potential • Lower capital and operating costs • Smaller footprint	• Requires large heat transfer areas • May be sensitive to ambient temperature and humidity conditions • Needs relatively low-temperature sink • More energy intensive if waste heat is not available
Capacitive deionization	• Ion removal via electric charge • Adsorption/desorption cycle	• Energy reductions versus RO possible for brackish water • Relatively low capital costs • Possibility for energy recovery	• Currently limited to waters <5,000 mg/L TDS • At lab/bench scale of development
Hybrid systems	• All of the above systems can be combined in hybrid treatment trains • Possibilities for enhanced recovery, system energy usage	• Strengths of single technologies can be synergistic in sequence • Opportunities for beneficial use of brines	• Additional complexity compared to single-technology systems • Additional design and testing required for commercialization
Nanoenhanced membranes	• Enabling technologies for a variety of treatment strategies • Nanoporous materials offer possibilities for improved selectivity and permeance • Embedded nanoparticles allow highly tailored membrane designs • Nanostructured materials may support higher-pressure operation	• Improved fouling resistance • Customized membranes for specific contaminants • Reductions in capacitive polarization • Multilayered engineering could increase strength and performance • Enhanced flux over time	• Potential for undesirable release of nanoparticles • Consequences of nanoparticle release to the environment poorly characterized • Early stage of technological development

Note: FO: Forward osmosis; RO: Reverse osmosis; TDS: Total dissolved solids.
Source: Created based on data from Bauer et al., 2014.

Desalination processes are broadly classified as either thermal or membrane-based technologies depending on the separation process used. In the Gulf region, thermal desalination has historically been the dominant desalination technology used but membrane-based technologies have been developing rapidly for the past five decades and currently are the technology of choice for new plants. For some Arab countries outside the Gulf region, such as Algeria and Libya, rapid increases in installed desalination capacity have taken place in the recent past (from 2000 onwards) and the technologies of choice have been membrane desalination processes.[112] Another important example is Egypt, which still depends primarily on the Nile River for its water resources[113] but is currently actively developing its membrane desalination capacity[114] since the gap between its water supply and demand is increasing.

Membrane-based technologies are increasingly being favoured since they have substantially lower energy consumption rates (2-6 kWh/m^3) than thermal desalination technologies (7-14 kWh/m^3).[115] RO, a membrane-based technology, is the dominant technology, which accounts for more than half of global desalination capacity.[116] However, it is quite energy intensive and its energy consumption accounts for a substantial portion of operating costs due to the high pressure pumps required by the process.[117] This once again proves how much room there is for improvement. Various strategies may be implemented to make RO operations more efficient.

Improving the RO system, considering the configuration of membrane units in particular, can increase the energy efficiency of the system considerably[118] and can help optimize the processes involved. Control schemes can also be used to improve energy efficiency. For instance, a closed loop control system using sensor data received in real-time in coordination with permeate flow requirements as defined by the user/client can be used to calculate the optimum set points from the perspective of energy efficiency and operation of the system close to theoretically predicted ideal values.[119] Tests of a similar system demonstrated the achievement of "energy-optimal operation", meaning operation that achieved energy consumption values very similar to those predicted theoretically.[120] In multi-pass RO systems, overall energy requirements may be reduced by having a portion of the first-pass permeate pumped to the second-pass and by using membranes with the highest salt rejection in the first-pass. Yet another design modification, which can be used to reduce the energy consumption of an RO system treating high salinity water is the use of a two-stage hybrid system with concentrate staging or a two-pass nanofiltration (NF) membrane system.[121] Additionally, locating membrane desalination plants adjacent to power plants at the coast can help reduce energy consumption (as the source water is of a higher temperature), which also directly reduces the environmental impact of operations. Similarly, in the ESCWA region, RO and thermal desalination technologies have been used together in a hybrid design, which helps provide capital savings and increases in water production.[122] In addition, as pumping consumes substantial amounts of energy during the desalination process, implementing the strategies mentioned in section 3.2 can increase energy efficiency. High-efficiency pumping, using premium efficiency motors, among others, can be beneficial. Furthermore, energy consumption for RO desalination processes can be reduced by the use of energy recovery devices (ERD) that can assist in the recovery of most of the energy content of the high-pressure RO concentrate. As a result of passing through an ERD, pressure from the concentrate stream is recovered before the latter is discarded.[123] Table 22 shows strategies, which can be used to improve the energy efficiency of membrane-based desalination. Though these strategies have the primary objective of decreasing expenses, they inevitably lead to decreases in energy consumption as well.

Table 22. Strategies for energy savings through capital (CAPEX) and operational expenditure (OPEX) reduction with higher productivity membranes

Option	Design strategy	Resulting impact	Practical implications
Option 1 (OPEX reduction): Reduce feed pressure	Compared to design with lower productivity membrane elements, use the same number of pressure vessels and membrane elements, produce same flow rate at same recovery (constant permeate flow).	Lower feed pressure results in a lower energy consumption of the feed pressure pump. Hence, savings in energy cost can be captured.	• Possible with positive displacement pump and centrifugal pump (CP) with variable speed drive (VSD). For CP without VSD, impellers have to be trimmed or impeller sections of multi-stage pumps removed; • Operating higher productivity elements at lower pressure to match the design flow of lower productivity elements may result in an increase in permeate salt concentration; this should be checked.
Option 2 (OPEX and CAPEX reduction): Increase plant output and recovery	Compared to a design with lower productivity elements, use the same feed pressure and the same number of pressure vessels and elements.	Increase water production and recovery. Higher water production means capital savings in pressure vessels and elements, higher recovery means less capital cost in pre-treatment and less operation cost for pumping and pre-treatment.	• It should be verified that the brine control valves, product and brine tubing, storage and post-treatment can accommodate modified flow rates; • Increasing average flux and recovery may result in minor permeate quality changes; • The impact of higher recovery on scaling in the brine should be checked and necessary precautions taken; • The higher expected brine concentration also should be compared to the discharge concentration limits and other environmental regulations; • Higher permeate flow on the lead elements, higher average permeate flux and/or lower brine flow might result in a modified fouling behaviour. The possible impact should be assessed.

Option	Design strategy	Resulting impact	Practical implications
Option 3 (CAPEX reduction): Higher flux operation at same recovery	Compared to a design with lower productivity membrane elements, use the same feed pressure and the same recovery but increase average permeate flux.	**Option 3a: At same plant output, fewer pressure vessels and dements, savings in capital cost;**	• Increasing average flux at the same recovery leads to a reduction of salt passage because salt flux remains constant. Therefore, this is an option to improve permeate quality; • It should be verified that capacity of pre-treatment and feed pump can accommodate the higher feed flow required in this option.
		Option 3b: At same number of pressure vessels and elements, capacity increase.	• It should be verified that the brine control valves, product and brine tubing, storage, and post-treatment can accommodate modified flow rates; • Higher permeate flow on the lead elements, higher average permeate flux and/or lower brine flow might result in a modified fouling behaviour. The possible impact should be assessed; • Increasing average flux at the same recovery leads to a reduction of salt passage because salt flux remains constant. Therefore, this is an option to improve permeate quality; • It should be verified that capacity of pre-treatment and feed pump can accommodate the higher feed flow required in this option.

Source: Created based on data from Busch and Mickols, 2004.

It should also be mentioned that, in the case of RO, if the total energy required per volume of permeate is plotted as a function of the RO system recovery, initially, as recovery increases, the total energy required decreases. However, after a threshold value of 50-55 per cent, the energy requirement begins to increase with increasing recovery.[124] Therefore, aiming for recovery greater than the threshold value reduces energy efficiency even though the product of the process has increased. As a result, there is a trade-off between these two parameters, which provided the motivation for research and development of more efficient desalination technologies.

Efficiency dependence on energy source

Technological solutions can only improve the energy efficiency of desalination processes to a certain extent. In addition, in the countries of the ESCWA region, resource access is becoming more challenging due to limited supplies, particularly where freshwater is concerned. As a result, desalination will continue to be an important process in the region and, in light of decreasing fossil reserves and increasing greenhouse gas (GHG) emissions, powering desalination with renewable energy will be unavoidable. Such options are already the best alternative for stand-alone power-generating systems in remote regions. Solar, wind and geothermal energy have the potential to power desalination processes. The energy efficiency of a certain type of desalination does not greatly vary depending on whether a renewable or conventional source of energy is used to power it.[125] One of the greatest drawbacks associated with renewable energy is its intermittence. Desalinated water is constantly required in the ESCWA region, which makes matching this demand with the renewable energy supply a challenge. Various options such as demand-side management and energy storage can be used to address this challenge. What is more, the capital costs associated with renewable energy options tend to be prohibitive. These costs along with factors, such as planned plant size and renewable energy potential in the area, are of relevance when determining the energy source(s) of a desalination plant.[126]

Key performance indicators for the water-energy nexus

One of the objectives of this toolkit is to facilitate the strengthening of energy and water resource capabilities for the countries of the ESCWA region. To measure improvement in these areas, indicators need to be established, which are described in this section. The Food and Agriculture Organization of the United Nations (FAO), for instance, established integrated water, energy, and food security indicators related to the water and energy nexus, which deal with issues of sustainable water, sustainable energy, and food security. Sustainable water indicators cover access to water resources, for different uses, sustainable use and management of water resources and resilience of societies and ecosystems to water-related disasters. Sustainable energy indicators cover access to modern energy services, efficiency of energy use, and levels of purity and renewability of the energy produced and consumed.[127]

Indicators for water use for water and energy-related services

When discussing indicators related to water use, SDG 6 is of relevance. This goal aims to "ensure availability and sustainable management of water and sanitation for all".[128] The portion of this goal on sustainable water management addresses water and energy-related services and consequently water efficiency. Table 23 shows some of the targets identified under SDG 6 and the different indicators, which are associated with each of these targets.

The sustainable utilization of water resources cannot be achieved without intensified coordination between the entities, which develop, manage, and consume water resources. Consequently, the targets and indicators under Goal 6 aim to help relevant stakeholders evaluate and utilize water resources using a more holistic perspective. This is a result of the adoption of a more integrated approach, which facilitates greater collaboration between different entities and sectors.[129] These indicators, initially introduced as part of the *World Water Development Report 2014* of the United Nations, are a first attempt to cluster indicators related to the energy-water nexus. Though these indicators may be considered relatively complete, they do not facilitate much the identification of energy-water hot spots.[130]

Similarly, the World Bank has specified indicators relevant to water use for water and energy related services. These indicators tend to be broad in nature and then can be applied to specific sectors/industries. For instance, the general indicator of annual freshwater withdrawals (as a percentage of internal resources) can be measured for, and applied to, the power sector.[131]

"Reliable and comprehensive data on the energy-water nexus are scarce, inhibiting informed decisions on operations and investments and on monitoring them over the long term."[132] This is especially true for data on water availability and consumption since the distribution of water tends to vary with space and time, water resources are divided into surface water and groundwater, and these resources are accounted for differently from one country to another. In fact, presently, most global estimates for the water requirements of the energy sector have been derived from assumptions.[133] Thus, reliable indicators related to water efficiency in the energy sector in particular and, consequently, effective water management policies for the energy sector are challenging to devise and implement. Therefore, it is important for governments to ask energy production facilities to report data on their water use so that the relevant indicators may be implemented more easily and consequently used in policymaking.

Indicators on water use for the energy sector should also consider environmental aspects; indicators focusing only on water use values may inadvertently promote unsustainable practices. Furthermore, indicators can be region-specific, addressing challenges related to water use in different regions. In general, indicators must provide data that can be effectively

Glass light bulb with water and cityscape inside © Sergey Nivens - shutterstock_328601216.

Table 23. Targets and indicators related to SDG 6 and water efficiency

Target	Target area	Target number	Global indicator	Global indicator number
"By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally"	Water quality and wastewater	6.3	Proportion of wastewater safely treated	6.3.1
			Proportion of bodies of water with good ambient water quality	6.3.2
"By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity"	Water use and scarcity	6.4	Change in water use efficiency over time	6.4.1
			Level of water stress: freshwater withdrawal as a proportion of available freshwater resources	6.4.2
"By 2030, implement integrated water resources management at all levels, including through transboundary cooperation as appropriate"	Water resources management	6.5	Degree of integrated water resources management implementation (0-100)	6.5.1
			Proportion of transboundary basin area with an operational arrangement for water cooperation	6.5.2
"By 2030, expand international cooperation and capacity-building support to developing countries in water- and sanitation-related activities and programmes, including water harvesting, desalination, water efficiency, wastewater treatment, recycling and reuse technologies"	International cooperation and capacity-building	6.a	Amount of water- and sanitation-related official development assistance that is part of a government coordinated spending plan	6.a.1

Source: Created based on data from UN-Water, work in progress.

and sensibly compared; for instance, if values that deal with different water sources (surface water and groundwater) are compared, the resulting analysis would not be sound.[134]

Indicators for energy use for water related services

Sustainable Energy for All (SE4All) is a global initiative that was launched in 2011 by the United Nations Secretary-General Ban Ki-moon. It involves all sectors of society and aims to achieve three objectives by 2030, namely providing universal access to modern energy services; doubling the global rate of improvement in energy efficiency; and doubling the share of renewable energy in the global energy mix.[135] This doubling of energy efficiency can only be measured using energy indicators. Energy indicators for sustainable development, in general, help to clarify statistical information, monitor the progress of policies related to energy, and provide a way to assess energy policy proposals.[136] These activities are facilitated through energy system modelling. Energy indicators for sustainable development look into the social, economic, and environmental aspects of energy. Examples of such indicators are share of household income spent on fuel and electricity, energy use per unit of GDP, and air pollutant emissions from energy systems.[137]

Energy efficiency can only be measured precisely when considering individual processes and technologies and not many countries have the data for such measurements; and even if they do, such data leads to too many indicators, which makes it a challenge to evaluate the situation in a holistic manner. As a result, the indicator used by the SE4All initiative in order to measure energy efficiency, as described in the Global Tracking Framework (GTF) reports which measure progress towards the attainment of the SE4All objectives, is energy intensity (usually measured as compound annual growth rate (CAGR) of primary energy intensity as a percentage of GDP in purchasing power parity (PPP) terms).[138] This variable tends to be used as a proxy for energy efficiency for the purpose of global comparison since data to determine energy intensity seems to be more readily available. Energy intensity is an approximation since its value is affected by more than just variations in the energy efficiencies of the underlying processes. It is also susceptible to factors, such as weather variability and changes in the mix of primary energy sources. To partially make up for this, statistical decomposition methods can be used, which allow the removal of compound effects.[139]

Energy intensity may be expressed from national and sectoral perspectives to provide a more complete representation of energy efficiency. Energy consumption can be measured in terms of primary or final energy. Primary energy is more relevant when considering highly aggregated energy intensity measures while final energy is more relevant when considering energy intensity from the sectoral or subsectoral perspective.[140] Since fluctuations in energy intensity values are possible, it is useful to consider the CAGR in calculations. The GTF report for 2015 mentions that, due to the continual improvements in energy intensity, energy consumption in 2012 was reduced by 25 per cent, compared to the level of consumption that would have been achieved if energy intensity had not changed since 2000. Energy intensity improved by the average annual value of 1.7 per cent during 2010-2012; this was greater than corresponding energy intensity improvement values during 1990-2010 but not as high as required by the relevant SE4All objective (namely, 2.6 per cent annual improvement between 2010 and 2030).[141] As a result, more action needs to be taken to reach this particular SE4All goal.

Compared to other sectors, industry consumes the most energy worldwide,[142] and energy efficiency issues must be addressed as has been done by this toolkit. Addressing industry is easier since it is the sector where most information is available at the aggregate level.[143] By using indicators, which describe energy consumption in industry, policies can be devised, which would have a greater impact on reducing energy consumption rates.

Some energy efficiency indicators for various sectors are listed in table 24. It includes the residential sector since it is responsible for higher energy consumption, namely 41 per cent, than the industrial sector, namely 26 per cent (2011 values) in the Arab countries.[144] It is important to remember that, if two countries have the same value for a certain indicator, this does not necessarily entail similar performance; factors to be considered are the state of development of each country and the availability of indigenous energy resources in the country. Progress for each country can only be truly assessed by analysing the changes in the values of the indicator over certain periods of time.[145]

The indicators mentioned in table 24 have been taken from a publication, which covers the following Arab countries: Algeria, Egypt, Jordan, Lebanon, Libya, Morocco, Palestine, Syrian Arab Republic, Tunisia, and Yemen. The energy transformation sector for these countries primarily consists of crude oil refineries and power generation facilities. The approximate average values of some of the indicators for these countries are as follows:

- Primary energy intensity: 0.459 ton of oil equivalent (toe)/1000 $\$_{2000}$ in 2009 (corresponding OECD average value: 0.174 toe/1000 $\$_{2000}$);
- Final energy intensity: 0.268 toe/1000 $\$_{2000}$ in 2009 (corresponding OECD average value: 0.108 toe/1000 $\$_{2000}$);
- Electricity intensity: 642 kWh/1000 $\$_{2000}$ in 2009 (corresponding OECD average value: 324 kWh/1000 $\$_{2000}$);
- Specific consumption of power generation (SCPG): 220 toe/gWh in 2009 (corresponding 2003 value 224 toe/gWh);
- Final energy intensity of industry sector: 0.24 toe/1000 $\$_{2000}$ in 2009 (corresponding 2003 value 0.30 toe/1000 $\$_{2000}$);
- Unit consumption of energy per dwelling: 616 kilogram of oil equivalent (kgoe) in 2009 (corresponding 2003 value 545 kgoe).[146]

These values show the potential improvement for these countries relative to the countries of the Organisation for Economic Co-operation and Development (OECD) (when considering indicators like primary energy intensity, final energy intensity, and electricity intensity) and in general (when considering the unit consumption of energy per dwelling indicator). Though the final energy intensity of the industry sector and specific consumption of power generation have improved from 2003 to 2009, it must be remembered that these values can be very different for energy importing and energy exporting countries. The Arab countries considered here import energy to a greater extent than exporting it, and so if these average values covered the whole ESCWA region, including Gulf countries, which are primarily energy exporting countries, the values of the indicators obtained could be significantly different. There are also transition countries, such as Egypt, which is moving from being net exporter of energy to being an importer.[147] Since this toolkit is giving significant attention to electricity generation, it should be mentioned here that the SCPG indicator (see table 24), which measures the efficiency of installed power generation capacity, depends on parameters, such as electricity generation technology, energy mix, obsolescence of plants, renewable energy share, diversified energy resources for electricity generation, efficiency of plant operation and maintenance, and shape of the load demand curve.[148]

Table 24. Energy efficiency indicators

Abbreviation	Indicators	Unit	Definition
		Macro-level indicators	
EDR	Energy dependence ratio	%	1- (energy production/gross inland energy consumption)
IPE	Intensity of primary energy	toe/1000 LC	Ratio between primary energy consumption and GDP
IFE	Intensity of final energy	toe/1000 LC	Ratio between final energy consumption and GDP
RFEPE	Ratio of final energy consumption to primary energy	%	Ratio between final energy consumption and primary energy consumption
REB	Ratio of national energy bill to GDP	%	Ratio between national energy bill and GDP
RPSE	Ratio of public subsidies for energy to GDP	%	Ratio between national public subsidies and GDP
AEF	Average emission factor	tCO_2e /toe	Ratio between the total GHG emission of the energy sector and the gross inland consumption
ICO2	Intensity of CO2	tCO_2e / 1000 LC	Ratio between the total GHG emission of the energy sector and the GDP at constant price
AECH	Average primary energy consumption per inhabitant	ktoe/1000 inhab	Ratio between primary energy consumption and population
AELCH	Average electricity consumption per inhabitant	MWh/inhab	Ratio between total electricity consumption and population
		Transformation Sector Indicators	
SREC	Share of installed RE electricity capacity	%	Ratio between installed RE electricity capacity (excluding hydro) and total installed plants capacity
URIC	Usage rate of the installed power plants capacity	%	Ratio between total produced electricity (all sources included) and total installed plants capacity
AETS	Apparent efficiency of energy transformation sector	%	Ratio between total energy output of the overall transformation sector (before distribution losses) and the total energy input to the energy transformation sector

Abbreviation	Indicators	Unit	Definition
PGEFF	Power generation efficiency of thermal plants	%	Ration between total generated electricity by thermal plants and fossil fuel input of thermal plants
SCFFP	Specific consumption of thermal power plants	toe/GWh	Ratio between total energy input of all thermal power plants in the country and total electricity produced by those power plants
PGF	Power generation efficiency	%	Ratio between total generated electricity plants and fossil fuel input of thermal plants
SCPG	Specific consumption of power generation	toe/GWh	Ratio between total energy input of all power plants in the country and total electricity produced by those power plants
TDEE	Transmission and distribution electricity system efficiency	%	Ratio between total electricity output of the transmission and distribution system and total electricity input of the transmission and distribution system
PGEF	Power generation emission factor	tCO_2e/GWh	Ratio between the total GHG emission due to national power generation system and total produced electricity, all technologies and all resources included
ESEF	Electricity sector emission factor	tCO_22e/GWh	Ratio between the total GHG emission due to national power generation system and total electricity output of the transmission and distribution system
		Industry Sector Indicators	
FEIIS	Final energy intensity of industry sector	toe/1000 LC	Ratio between the final energy consumption for the industrial sector and value added of industry sector at constant prices
IEBR	Ratio of industry sector energy bill to value added	%	Ratio between the energy bill for the industrial sector and value added of industry sector
IESR	Ratio of public subsidies to value added	%	Ratio between the public subsidies for the industrial sector and value added of industry sector
IESRGB	Ratio of public subsidies for energy to government budget	%	Ratio between the public subsidies for the energy sector and government budget
IELSR	Ratio of public subsidies for electricity to value added	%	Ratio between the public subsidies for electricity sector and value added of industry sector

Abbreviation	Indicators	Unit	Definition
IICO2	CO_2 intensity of industry sector	tCO_2e/1000 LC	Ratio between the total GHG emission of the energy sector and value added of industry sector at constant prices
FEIIS	Final energy intensity of industry sector	toe/1000 LC	Ratio between the final energy consumption for the industrial sector and value added of industry sector at constant prices
	Residential Sector Indicators		
UCED	Unit energy consumption per dwelling	kgoe/dw	Ratio between total final energy consumption for households sector and total number of dwellings
SCEM²	Specific energy consumption per area unit	kgoe/m²	Ratio between total final energy consumption for households sector and total area of households
UEICD	Unit electricity consumption per dwelling	kWh/dw	Ratio between the total yearly electricity consumption for households sector and total number of dwellings
SCEIM²	Specific electricity consumption per m²	kWh/m²	Ratio between the total yearly electricity consumption for households sector and total area of households
RIPE	Intensity of residential sector	toe/ 1000 LC	Ratio between the final energy consumption for the residential sector and the private consumption of households at constant prices
RELSR	Ratio of public subsidies for energy to private consumption	%	Ratio between the public subsidies for the residential sector and private consumption at constant price
RESRGB	Ratio of public subsidies for energy to government budget	%	Ratio between the public subsidies for the residential sector and government budget
RAEF	Average emission factor	tCO_2/toe	Ratio between the total GHG emission of the residential sector and final energy consumption of the residential sector
$RICO_2$	CO_2 intensity of residential sector	tCO_2/ 1000 LC	Ratio between the total GHG emission of the residential sector and value added of residential sector at constant prices
RDRSHR	Diffusion rate of solar water heaters in residential sector	m²/1000 inhab	Ratio between total solar water heater area in residential sector and population

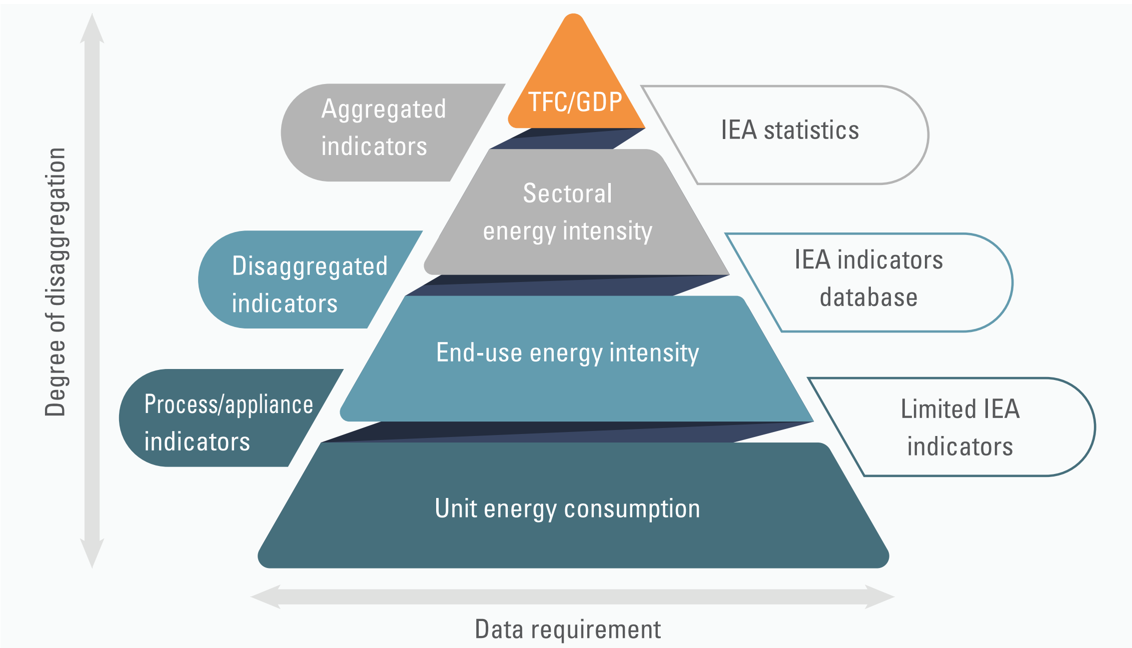
Note: dw: dwelling; GDP: gross domestic product; GHG: greenhouse gas; inhab: inhabitant; kgoe: kilogram of oil equivalent; ktoe: kiloton of oil equivalent; toe: ton of oil equivalent; LC: local currency; mWh: megawatt-hour; RE: renewable energy; tCO_2e: ton of CO_2 equivalent.
Source: Created based on data from Missaoui, Ben Hassine and Mourtada, 2012.

The discussion hitherto has been primarily concerning the perspective of the United Nations regarding energy efficiency indicators. In contrast thereto, the approach of the International Energy Agency (IEA) is based on the indicators pyramid shown in figure 18. This structure portrays a hierarchy of energy indicators with decreasing levels of detail the further you go up the pyramid. In other words, the lower levels of the period entail greater amounts of data and more complex analysis than higher levels. The top row of the pyramid is the ratio of energy consumption to a macro-economic variable, such as GDP or population. This makes it possible to evaluate energy consumption in light of the drivers of this consumption. The second row of the pyramid is for indicators, which detail the energy intensity (energy consumption per unit of activity) of major sectors.

Relevant indicators for this toolkit could be the energy consumption of the water and wastewater treatment sector, for example. The lower rows of the pyramid would represent energy consumption for subsectors or specific applications/end uses. Indicators with higher and lower degrees of aggregation must be used in order to effectively analyse energy use for water-related services and accordingly formulate a sound policy. The hierarchy shown in figure 18 is useful as it shows how changes at the lowest levels due to such factors as technological progress, policy changes, behavioural change, and structural reform may lead to changes in energy consumption at a more general scale.[149] The specific issues on which future policies should focus can thus be identified.

In terms of the water supply system in particular, a relevant energy indicator that has been proposed is the structure indicator, which takes into consideration how energy consumption is influenced by the spatial distribution of users and water sources.[150] As a result, minimal energy is defined as the energy required to lift a cubic meter of water to users and to give it a pressure of 6 bar (typical water pressure at the tap). Yet, as per another indicator, minimal energy is the difference between the potential energy of the water delivered (over unit time)

Figure 18. The IEA energy indicators pyramid



Note: GDP: gross domestic product; IEA: International Energy Agency; TFC: total final consumption.
Source: IEA, n.d.© OECD/IEA 2014 Energy Efficiency Indicators: Essentials for Policy Making, IEA Publishing. Licence: www.iea.org/t&c.

and the potential energy of the same quantity of water at the source. The quality indicator is the ratio of the effective energy (the energy actually used) to the minimal energy; it is used to assess the overall water supply system efficiency.[151] Other relevant indicators of the International Water Association include:

- Average pumping energy consumption in the system per 1 m^3 at 100m of head;
- Percentage of the total energy consumption for pumping that corresponds to reactive energy consumption;
- Percentage of the total energy consumption for pumping that is recovered by the use of turbine reverse pumps;
- Energy resource efficiency use (kWh/m^3) for wastewater services;
- Standardized energy consumption (kWh/m^3/100m) for water supply services.[152]

Table 25. Possible indicators for tracking the energy-water nexus at country levels worldwide

Component	Indicator	Data availability	Current or potential source
Impacts of energy on water access	Water (m3) pumped/treated/distributed/desalinated by energy source/technology (if off grid)	Limited data at utility level	
	Shutdown time (hours) and operational losses ($) due to energy-related issues (at the water utility level)	No public data	
Energy requirements of the water sector	Energy intensity (GJ/m3) and unit cost ($/m3) by energy source/technology (if off grid) of drinkable water/treated wastewater/desalinated water	Limited data at utility level	*World Water Development Report 2014*
	Energy intensity (GJ/m3) and unit cost ($/m3) of water heating by energy source/technology (if off grid)	No data	
Water requirements of the energy sector	Water (m3) withdrawn/consumed/discharged by energy source (and cooling technology) at the energy production facility level	Limited data	IEA 2012/ Carbon Disclosure Program (CDP)
	Number of operating power plants by energy source and cooling technology	Limited data	IEA 2012/CDP
	Intensity of water withdrawn/consumed/discharged (gallons/mWh) by energy source at the energy production facility level, disclosing type of cooling system (for thermal power plants), type of water used (freshwater, saline, wastewater, other) and regional climate	Limited or no public data	CDP/Water for Energy Framework (W4EF)
	Yields (kilograms or hectares) and water requirements (m3) for major biofuel crops (at the country level)	Limited data	FAO
	Cost of water withdrawn ($/litre) for the energy sector (by energy facility)	Limited or no public data	
	Number of energy companies disclosing their water use (withdrawal, consumption, discharge) and water risks	Limited data	CDP

Table 25 summarizes this section of the toolkit by listing indicators for both water use related to energy services and energy use related to water services. It is an initial attempt by the GTF to collate potential indicators for monitoring the energy-water nexus across countries. The GTF acknowledges that these indicators are not finalized; they are instead "intended to stimulate discussions on a future nexus-tracking framework".[153] Indeed, the SE4All initiative also aims to catalyse this "data revolution for the energy sector".[154] This revolution is much needed; even a cursory glance at the data availability column of table 25 shows the lack of data available for the different indicators. The Arab countries are certainly no exception when it comes to this poor data availability; still, they must put much effort towards accurately measuring relevant parameters, which would assist in better accounting for their attainment of the SE4All objectives.

Component	Indicator	Data availability	Current or potential source
Impacts of the energy sector on water resources	Percentage of water treated prior to discharge at the energy production facility level	Limited data	CDP
	Number of aquifers contaminated during drilling related to energy extraction	Limited data	
	Number of energy extraction facilities that recycle water	Limited data	
	Percentage of available water (in the water body) used by energy activities	Limited data	W4EF
	Water stress levels prior and after the establishment of energy activities	Limited data	W4EF
Water risks for energy companies	Percentage of energy companies considering water-related issues as a major risk to business operations	Limited data	CDP
	Percentage of energy companies that have water risk assessment	Limited data	CDP
Integrated policy and planning	Perceived change over the past 20 years in the importance of water for energy by country governments (percentage scale, from significant decrease to significant increase)	Limited data	UNEP 2012
	National energy policy/strategy/plan with water resources management component (percentage scale, water resources management ranked from not relevant to fully implemented)	Limited data	UNEP 2012
	Water requirements and water sustainability considered at planning stage or during project development (yes/no)	No data	
	Percentage of energy companies with water integrated into their business strategy	Limited data	CDP

Notes: CDP: Carbon Disclosure Programmeject; FAO: Food and Agriculture Organization of the United Nations; GJ: gigajoule; mWh: megawatt-hour; UNEP: United Nations Environment Programme; W4EF: Water for Energy Framework.
Source: Created based on data from World Bank, 2015.

The Global Water Carbon Disclosure Project(CDP) Report provides investors with information on how companies identify, manage, and mitigate risks and opportunities related to water. The Water for Energy Framework (W4EF) is helping energy actors assess and report on the relations between energy production activities and the local water environment by developing a common terminology and methodology. It is an official action group of the European Innovation Partnership on Water (EIP Water).

Efficiency-improving technologies: Financial perspective

Thus far, this report has not focused primarily on the financial implications of the water and energy efficiency strategies recommended. Nonetheless, there are financial costs and/or benefits associated with such strategies. Table 26 helps understand the financial perspective of some energy efficiency-increasing practices by mentioning the payback period for each of these practices. As can be seen from the table, there is much variation with regards to the payback of many of these strategies since the effectiveness of these practices depends substantially on such factors as the location of the plant, specific types of operations, which take place in coordination with these practices, energy/water pricing schemes, and more. Therefore, before implementing any strategy, a thorough analysis is required on a case-by-case basis.

Table 27 provides information about the investment and water costs for different desalination technologies. It is clear that, as the energy required by the processes increases, the water cost, which they entail also increases. Investments costs also seem to be increasing in parallel. Since investment costs vary over such a wide range, though, it is difficult to make any such conclusions. The cost of desalination with different technologies is site-specific. More clarity about the total water cost, for example, could be provided with knowledge of the type of fuel being used to power the desalination plant. However, in general, thermal-based desalination processes use more expensive materials and equipment, consume higher amounts of specific energy, and require more chemicals than membrane-based desalination processes.[155] These are important reasons behind the current prevalence of membrane-based desalination technologies.

Table 26. Typical energy savings and payback periods for best practices in the water and wastewater industry

Best Practices	Typical energy savings of unit of process (percentage)	Typical payback years
General		
Real-time energy monitoring	5 - 20	Variable
Electric peak reduction	Variable	< 1
Electric motors: install high efficiency motors	5 - 10	< 2
Electric motors: variable frequency drive applications	10 - 40	0.5 – 5
Electric motors: automate to monitor and control	Variable	Variable
Electric motors: improve power factor	Variable	Variable
Pumps: optimize pump system efficiency	15 - 30	0.25 – 3

Best Practices	Typical energy savings of unit of process (percentage)	Typical payback years
Water Treatment		
Integrate system demand and power demand in system demand	Variable	Variable
Computer-assisted design and operation	Variable	Variable
Manage well production and drawdown	Variable	Variable
Sequence well operation	Variable	Variable
System leak detection and repair	Variable	Variable
Optimize storage capacity	Variable	Variable
Wastewater		
Staging of treatment capacity	10 - 30	<2
Optimize aeration system	30 – 70	3 - 7
Fine-bubble aeration	20 - 75	1 - 5
Variable blower air flow rate	15 - 50	< 3
Dissolved oxygen control	20 - 50	2 - 3
Post-aeration: cascade aeration	Variable	Variable
Aerobic digestion options	20 - 50	Variable
Blower technology options	10 - 25	1 - 7
Assess aeration system configuration	Variable	Variable
Sludge: improve solids capture in dissolved air flotation (DAF)	Variable	Variable
Sludge: evaluate replacing centrifuge with screw press	Variable	Variable
Sludge: replace centrifuge with gravity belt thickener	Variable	Variable
Biosolids digestion options	Variable	Variable
Biosolids mixing options in aerobic digesters	10 - 50	1 - 3
Biosolids mixing options in anaerobic digesters	Variable	Variable
Wastewater heat recovery	Variable	Variable
Anoxic zone mixing options	25 - 50	3 - 5
Sidestream deammonification	Variable	Variable
Biotower energy efficiency	15 – 30	Variable
Optimize anaerobic digester performance	Variable	Variable
Use biogas to produce combined heat and/or power (CHP)	Variable	Variable
Biogas assessment of beneficial utilization	Variable	Variable

Source: Created based on data from Public Service Commission of Wisconsin, 2016.

Table 27. Energy consumption and water costs (average values) of large-scale commercial desalination processes

Process	Thermal energy kWh/m³	Electrical energy kWh/m³	Total energy kWh/m³	Investment cost $/m³/d	Total water cost US$/m³
MSF	7.5–12	2.5–4	10–16	1200–2500	(0.8–1.5)*
MED	4–7	1.5–2 5.	5–9	900–2000	0.7–1.2
SWRO	-	(3–4)**	3–4	900–2500	0.5–1.2
BWRO	-	0.5–2.5	0.5–2.5	300–1200	0.2–0.4

Notes: BWRO: brackish water reverse osmosis; MED: multiple-effect distillation; MSF: multi-stage flash distillation; SWRO: seawater reverse osmosis.
*** Including subsidies (price of fuel).**
**** Including energy recovery system.**
Source: Created based on data from Ghaffour, Missimer and Amy, 2013.

Recycling water has been mentioned in this report as a way to increase efficiency. In terms of cost, one of the greatest economic impacts of recycling water is the result of the installation of a piping system to distribute the recycled water (the so-called purple pipe). Using a separate system of pipes for the recycled water helps to keep it separated from potable water. Depending on the characteristics of a particular project (project location and pipe material, for instance), installing a new set of pipes can be "prohibitively expensive", however.[156] The cost of installing a purple pipe varies depending on such factors as pipe diameter, type of pipe used, and where it is installed. For instance, installing the pipes in low density brownfield (previously developed land no longer in use) areas is much more costly than installing such pipes in areas with high density developments or greenfield areas (undeveloped land).[157] Reticulation is the term used to describe the street level infrastructure, which is needed to transport recycled water to the commercial and residential establishments where it would be used, in other words, the purple pipes. An Australian report estimates these costs to be 1.30-1.90 Australian dollars (AUD) per kiloliter of water.[158] The same report estimates that direct costs associated with a new recycling water scheme (accounting for all capital and operational expenses except for reticulation costs) can be around AUD2 per kiloliter of water.[159] This gives an idea of how significant purple pipe construction costs can be.

Economic incentives for more efficient consumer use

Many residents of the ESCWA region have been used to paying minimal tariffs for water and energy due to subsidies provided by their governments. This has led to high rates of consumption, particularly in GCC countries. For example, Saudi Arabia is the world's third-largest water consumer,[160] a position it shared with the United Arab Emirates.[161] However, the situation is changing slowly. The United Arab Emirates has recently legislated increases in water and electricity tariffs and Saudi Arabia has legislated increases in the electricity tariff.[162] This is true for ESCWA countries outside the GCC region as well: Egypt and Jordan have been reducing subsidies leading to increases in utility tariffs[163,164] and Lebanon is contemplating such changes as well.[165] It is too early to discuss the results of these policy changes but there is no doubt that they were much required. In general, the production costs of these utilities are greater than the amount charged through tariffs. Therefore, only by regulating tariffs more effectively will the investment required for the adoption of more energy- and water-efficient technologies be facilitated.

In the United Arab Emirates, the Emirates Wildlife Society together with the World Wildlife Fund (EWS-WWF) carried out a statistically representative survey in 2015, which aimed to comment on the barriers and solutions to implementing energy- and water-efficiency measures in the country's private sector. According to the results, the utility bill was not a significant cost for 24 per cent of the respondents while 53 per cent found it significant. Furthermore, the top reasons for organizations not implementing efficiency measures include the lack of consideration of these measures (41 per cent), lack of funding (31 per cent), lack of expertise to implement them (28 per cent), and low priority for efficiency (27 per cent).[166] This indicates the potential for improvement in the implementation of efficiency measures in the ESCWA region.

Conclusion and recommendations

The implementation of water- and energy-efficiency measures is a subject, which needs to be given more attention around the world. The adoption of such measures has not developed as quickly as desirable for a number of reasons, including financial challenges, limited access to relevant data, and lack of awareness. It is through this toolkit that some of these barriers will hopefully be addressed.

Based on the data presented in this document, it can be concluded that there is no ideal efficiency solution for all ESCWA member countries. Strategies must be assessed with reference to the respective situation. This report has given particular attention to the oil and gas industry as this sector is of high importance for the ESCWA region and has discussed efficiency measures for more oil and gas resources.

With regard to water efficiency, the recycling of wastewater was a strategy that was repeadly addressed across sectors. Water from sinks in offices and houses can be recycled and reused to flush toilets and produced water can be treated in order to be used in cooling towers in the oil and gas industry, among others. As environmental standards for discharged waters become more stringent, recycling such water becomes more feasible and is advisable from the perspective of water security as well.

Desalination has been a further point of discussion in this report since it is the primary technology used to obtain potable water in the region. More energy-efficient desalination technologies can play a pivotal role in improving the overall energy consumption of the region. Once again, there are various pros and cons for each desalination technology. RO is currently the technology of choice but there is still room for improvement; and the use of renewable energy to power desalination is rapidly being adopted in the region as pilot projects, such as the Masdar's Renewable Energy Desalination Programme in the United Arab Emirates or projects under construction, such as the solar desalination plant in Al Khafji in Saudi Arabia.

Intelligent systems, which on a relative scale do not entail substantial capital costs also have the potential to increase efficiencies. Such technologies help match supply and demand and decrease demand by the client. Since water resources in the ESCWA region are limited, water security may be considered a more pressing issue than energy security. However, due to the water-energy nexus, focus on improving energy efficiency will positively affect the region's water security.

Table A1. Advantages, disadvantages and applicability of different water treatment technologies for the oil and gas industry

Treatment	Description	Advantages	Disadvantages	Waste Stream	Oil and Gas Produced Water Applications
			De-oiling		
Corrugated plate separator	Separation of free oil from water under gravity effects enhanced by flocculation on the surface of corrugated plates	No energy required, cheaper, effective for bulk oil removal and suspended solid removal, no moving parts, technology robust and resistant to breakdowns in the field	Inefficient for fine oil particles, requires high retention time, high maintenance	Suspended particles slurry at the bottom of the separator	Oil recovery from emulsions or water with high oil content prior to discharge, produced water from water-drive reservoirs and water flood production are most likely feed-stocks, water may contain oil and grease in excess of 1000 mg/L.
Centrifuge	Separation of free oil from water under centrifugal force generated by spinning the centrifuge cylinder	Efficient removal of smaller oil particles and suspended solids, less retention time, high throughput	Energy requirement for spinning, high maintenance cost	Suspended particles slurry as pre-treatment waste	
Hydroclone	Free oil separation under centrifugal force generated by pressurized tangential input of influent stream	Compact modules, higher efficiency and throughput for smaller oil particles	Energy requirement to pressurize inlet, no solid separation, fouling, higher maintenance cost		
Gas floatation	Oil particles attach to induced gas bubbles and float to the surface	No moving parts, higher efficiency due to coalescence, easy operation, robust and durable	Generation of large amount of air, retention time for separation, skim volume	Skim off volume, lumps of oil	

Extraction	Removal of free or dissolved oil soluble in lighter hydrocarbon solvent	No energy required, easy operation, removes dissolved oil	Use of solvent, extract handling, regeneration of solvent	Solvent regeneration waste	Oil removal from water with low oil and grease content (< 1000 mg/L) or removal of trace quantities of oil and grease prior to membrane processing. Oil reservoirs and hermogenic natural gas reservoirs usually contain trace amounts of liquid hydrocarbons. Biogenic natural gas such as coalbed natural gas (CBNG) may contain no liquids in the reservoir but when pumped to the surface, the water takes up lubricating fluids from the pumps.
Ozone/ hydrogen peroxide/ oxygen	Strong oxidizers oxidize soluble contaminant and remove them as precipitate	Easy operation, efficient for primary treatment of soluble constituents	On-site supply of oxidizer, separation of precipitate, byproduct CO2, etc.	Solids precipitated in slurry form	
Adsorption	Porous media adsorbs contaminants from the influent stream	Compact packed bed modules, cheaper, efficient	High retention time, less efficient at higher feed concentration	Used adsorbent media, regeneration waste	
			Disinfection		
UV light/ozone	Passing UV light or ozone produce hydroxyl ions that kill microbial	Simple and clean operation, highly efficient	On-site supply of ozone, other contaminants reduce efficiency	Small volumes of suspended particles at the end of the treatment	Microbes may exist in the subsurface reservoir or can be introduced during production or water treatments. Disinfection may be needed to protect potability or to prevent fouling of the reservoir, tubulars and surface equipment.
Chlorination	Chlorine reacts with water to produce hypochlorous acid which kills microbial	Cheaper, simplest method	Does not remove all types of microbial		

Treatment	Description	Advantages	Disadvantages	Waste Stream	Oil and Gas Produced Water Applications
			Desalinization		
Lime softening	Addition of lime to remove carbonate, bicarbonate, etc., hardness	Cheaper, accessible, can be modified	Chemical addition, Post-treatment necessary	Used chemical and precipitated waste	These technologies typically require less power and less pre-treatment than membrane technologies. Suitable produced waters will have total dissolved solids (TDS) values between 10,000 and 1,000 mg/L. Some of the treatments remove oil and grease contaminants, while others require that the oil and grease contaminants be treated before these operations.
Ion exchange	Dissolved salts and minerals are ionized and removed by exchanging ions with ion exchangers	Low energy required, possible continuous regeneration of resin, efficient, mobile treatment possible	Pre- and post-treatment require high efficiency, produce effluent concentrate	Regeneration chemicals	
Electrodialysis	Ionized salts attract and approach to oppositely charged electrodes passing through ion exchange membranes	Clean technology, no chemical addition, mobile treatment possible, less pre-treatment	Less efficient with high concentration influent, require membrane regeneration	Regeneration waste	
Electro-deionization	Enhanced electrodialysis due to presence of ion exchange resins between ion exchange membranes	Removes weakly ionized species, high removal rate, mobile treatment possible	Regeneration of ion exchange resins, pre-/post-treatment necessary	Regeneration waste, filtrate waste from post-treatment stage	
Capacitive deionization	Ionized salts are adsorbed by the oppositely charged electrodes	Low energy required, higher throughput	Expensive electrodes, fouling	Regeneration waste	
Electrochemical activation	Ionized water reacts with ionized chloride ion to produce chlorite that kills microbial	Simultaneous salt and microbial removal, reduced fouling	Expensive electrodes	Regeneration waste	

Rapid spray evaporation	Injecting water at high velocity in heated air evaporates the water which can be condensed to obtained treated water	High quality treated water, higher conversion efficiency	High energy required for heating air, required handling of solids	Waste in sludge form at the end of evaporation	
Freeze thaw evaporation	Utilize natural temperature cycles to freeze water into crystals from contaminated water and thaw crystals to produce pure water	No energy required, natural process, cheaper	Lower conversion efficiency, long operation cycle		
			Miscellaneous Treatment		
Trickling Filter	Develops film of microbial on the surface of packed material to degrade contaminants within water	Cheaper, simple and clean technology	Oxygen requirement, large dimensions of the filter	Sludge waste at the end of the treatment	Removal of suspended and trace solids, ammonia, boron, metals, etc. Post-treatment is normally required to separate biomass, precipitated solids, dissolved gases, etc.
Constructed wetland treatment	Natural oxidation and decomposition of contaminants by flora and fauna	Cheaper, efficient removal of dissolved and suspended contaminants	Retention time requirement, maintenance, temperature and pH effects		
Sodium adsorption ration (SAR) adjustment	Addition of Ca or Mg ions	Cheaper option	Chemical addition		Balance high SAR and very low TDS (higher percentage of sodium salts) after membrane processes.

Treatment	Description	Advantages	Disadvantages	Waste Stream	Oil and Gas Produced Water Applications
Naturally occurring radioactive materials (NORM) treatment					
NORM treatment	Extraction of radioactive material with aqueous solution	Efficient for reducing radioactive waste volume	Extracted radioactive materials need further treatment or disposal		Produced waters containing high levels of uranium or thorium. Unless treated, radioactive scale can form in surface equipment extensive remediation.
Natural gas recovery					
Air stripping	Stripping of dissolved gas from water	Concurrent or countercurrent operations, cheaper	Post-treatment, lower efficiency		

Source: Created based on data from Arthur, Langhus and Patel, 2005.

Table A2. General energy management best practice description: Electric motors – Variable frequency drives applications

Best practice	Variable frequency drives (VFDs) match motor output speeds to the load requirement and avoid running at constant rated power, thereby saving energy. Equipment must be designed to operate at peak flows. These designs often are not energy efficient at average existing flow conditions. Assess variations in facility flows and apply VFDs, particularly where peak demand is significantly higher than the average demand and where the motor can run at partial loads to save energy.
Primary area/process	VFDs apply to most processes in water and wastewater systems. They can replace throttling valves on discharge piping, control the pumping rate of a process pump, control conveyance pressure in force mains, control air flow rates from blowers, and control the speed of oxidation ditch drives.
Productivity impact	Impact should only be short term with interruption of service during installation, startup and fine-tuning.
Economic benefit	Now more available and affordable, paybacks for VFDs range from six months to five years. The payback period will vary with application depending on the drive size, hours of operation and variation in load. Large drives, long hours and high load variability yield the highest savings.
Energy savings	Savings vary with application and technology. Many VFD retrofits have saved 15-35 per cent. In some installations, particularly where throttling is used to control flow, savings of 10-40 per cent are possible. Applied to a wastewater secondary treatment process, a VFD can save more than 50 per cent of that process's energy use.
Applications and limitations	Applications for VFDs include controlling pressure, daily demand in gallons per minute (gpm), fire flow and well recovery and replenishment. Other applications include controlling aeration blowers, the pumping rate of raw sewage and sludge processing.
Practical notes	Calculations that account for load variation can help justify the cost. The system must be reviewed by an expert before selecting and installing the VFD to ensure system compatibility and cost-effectiveness. VFDs allow operators to fine-tune their collection, conveyance and treatment processes. Matching drives to loads also puts less stress on equipment and reduces maintenance.
Other benefits	Associated benefits include better control of system flowrate and pressure, more consistent supply and increased flexibility to meet demand requirements with minimum energy use. Better control of process flows can lead to reduced chemical usage. Reduced emissions from the power source directly related to the reduced consumption of electrical power are additional benefits.
Stage of acceptance	Widely accepted and proven in the water and wastewater sectors. New and upgraded wastewater systems are commonly equipped with VFDs for most treatment applications.

Source: Created based on data from Malcolm Pirnie, Inc., 2010.

Table A3. Description of wastewater energy management best practices

Best practice	Fine bubble aeration	Variable blower air flow rate	Dissolved oxygen control	Post-aeration: cascade aeration	Sludge: replace centrifuge with screw press	Sludge: replace centrifuge with gravity belt thickener	Reduce fresh water consumption/ final effluent recycling	Use biogas to produce combined heat and/or power (CHP)
Description	Assess the feasibility of implementing fine bubble aera-tion at activated sludge treatment facilities. This practice provides energy-efficient treatment of wastewater. It can be installed in new or existing systems. The technology usually improves operations and increases the organic treatment capability of a wastewater treatment facility. For optimum performance, combine this practice with dissolved oxygen	Require that aeration system and aerobic digester blowers have variable air supply rate capability, such as single stage centrifugal blowers with variable frequency drives (VFD), positive displacement blowers with VFD, and inlet guide-controlled multistage centrifugal blowers. The range of variability should respond to the specific requirements	Consider DO monitoring and control technology that will maintain the DO level of the aeration tank(s) at a preset control point by varying the air flow rate to the aeration system.	Consider the installation of a cascade aeration system for post-aeration applications. If the topography is favourable, this technology provides re-aeration of the effluent by increasing the water turbulence over the steps, with no need for electricity.	Replace the sludge dewatering centrifuge with a screw press for energy savings.	Replace centrifuge with gravity belt thickener for improved sludge thickening.	Reduce the consumption of potable water through the use of final effluent (FE) in process applications or washing down of tanks may save energy by limiting the volume of water treated and/or pumped. The FE system should include a pressure tank and pump control system, where appropriate, and direct pumping where consistently high pressure is required (belt press).	Biogas produced by an anaerobic digester can drive reciprocating engines which can be directly connected to a pump, blower or electric generator, or can fuel micro-turbines, turbines or fuel cells to generate electricity. In addition, the thermal energy generated by these systems can often be captured and utilized to meet digester heat loads and, where applicable, to build heating. Alternatively, the biogas can be used directly as

	(DO) monitoring and control, and a variable capacity blower. Plan for periodic diffuser cleaning (in-place gas cleaning system or scheduled drain and manual cleaning), as diffuser fouling influences system pressure and oxygen transfer efficiency.	of a site to precisely match system demands. The blower system should be able to supply the minimum air flow required to meet existing small load conditions or mixing, and to meet the big loads of design conditions. Avoid air flow discharge throttling.					Additional applications are possible with an inline filter prior to each application.	boiler fuel for the production of heat. In some limited applications, biogas is even being utilized as vehicle fuel.
Primary area/ process	Primary application for this practice will be on aeration tanks and aerobic digesters.	This practice applies to all aeration systems, including activated sludge aeration tanks and aerobic digestion systems.	The primary applications are aeration tanks at activated sludge facilities and aerobic digestion and post-aeration systems.	Post-aeration of wastewater treatment plants effluent.	Sludge dewatering and thickening.	Sludge dewatering and thickening.	Typical applications are in the recycle system for tank wash-down, gravity belt thickener, belt wash water, belt press, belt wash water, cooling water for a compressor, etc.	This practice applies to anaerobic sludge digestion.

Best practice	Fine bubble aeration	Variable blower air flow rate	Dissolved oxygen control	Post-aeration: cascade aeration	Sludge: replace centrifuge with screw press	Sludge: replace centrifuge with gravity belt thickener	Reduce fresh water consumption/ final effluent recycling	Use biogas to produce combined heat and/or power (CHP)
Productivity impact	A minor impact on production during installation.	Interruption in production should occur only during installation.	Installation of most systems can be accomplished without interfering with normal operation.	Installation can be accomplished without interfering with normal operation.	Minimal impact during installation and replacement of equipment.	Minimal impact during installation and replacement of equipment.	No impacts are expected, other than minor interruptions during the installation of any required equipment.	This practice has minimal impact during the installation of a CHP system.
Economic Benefit	Economic benefits vary from new facilities to retrofit applications. A new system may pay back in as little as one year. Payback on a retrofit will vary depending on the inefficiency of the existing system and the amount of new equipment required.	Payback is usually under three years.	Payback from improved monitoring and control using DO control is two to three years.	Payback varies depending on the existing post aeration system used.	Payback will depend on the size of the application.	Payback will depend on the size of the application.	Payback periods for this best practice are typically two to three years and will vary with the volume of potable water currently used.	If sufficient biogas is available to fuel a CHP process that can generate electricity to operate the facility and capture heat to offset process needs, the facility may attain energy neutrality. Whether the system generates electricity or heat, or both, the internal use of the energy will offset energy utility bills.

Energy savings	Energy savings range from 20-75 per cent of the aeration or aerobic digestion unit's energy consumption.	Energy savings depend on site conditions and which parameter, mixing or organic loading, dictates the lesser amount of air flow. Savings will range from 15-50 per cent of the energy consumed by this process.	Savings vary depending on the efficiency of the present system. Generally, energy savings for the aeration system are in the 20-50 per cent range.	If cascade aeration is used to replace an existing post-aeration system with a subsurface diffuser system and blowers, 100 per cent of the electricity used will be saved.	Potentially high energy savings can be obtained by this best practice.	Potentially high energy savings can be obtained by this best practice.	Savings may reach 50 per cent of the total system energy if the existing system does not use a pressure tank system to regulate supply.	Utilities should assess biogas-to-electricity generating systems for treatment facilities that have existing anaerobic digesters or are planning to install new ones. Each system needs to be individually assessed for feasibility.
Applications and limitations	This practice applies to all aeration systems. A limit exists for aerobic digestion: If the system operates at a solids concentration of 2.5 per cent or greater, further review must be done.	This practice can be applied wherever blowers are installed.	Limitations will vary with characteristics of the waste being treated. If the waste has characteristics that would easily foul the DO probe, then the system will not be readily applicable.	The application is site specific. At least 10 to 15 feet of head are needed between the plant effluent point and the final discharge, due to the low oxygen transfer rate and the temperature dependency of oxygen transfer.	A centrifuge is a relatively large energy consumer. Replacing a centrifuge with a screw press saves energy, due to the simple, slow-moving mechanical dewatering equipment that continuously dewaters the sludge	A gravity belt thickener consists of a gravity belt driven by a motor. As the sludge makes its way down the horizontally moving belt, water drains through the porous belt. The solids are constantly turned to improve the	Application is limited by the quality of effluent available for recycling.	The characteristics and quality of the biogas to be utilized must be assessed on a facility-by-facility basis to determine what level of biogas conditioning (clean up) is required for the beneficial, reliable and non-harmful utilization in an

Best practice	Fine bubble aeration	Variable blower air flow rate	Dissolved oxygen control	Post-aeration: cascade aeration	Sludge: replace centrifuge with screw press	Sludge: replace centrifuge with gravity belt thickener	Reduce fresh water consumption/ final effluent recycling	Use biogas to produce combined heat and/or power (CHP)
				The application is site specific. At least 10 to 15 feet of head are needed between the plant effluent point and the final discharge, due to the low oxygen transfer rate and the temperature dependency of oxygen transfer.	by gravity drainage. The primary disadvantages with a screw press include potential for odor problems and larger space requirements. Solids thickening impacts energy use in sludge digestion, dewatering, and disposal. The screw press produces sludge with a lower solids concentration than a centrifuge, therefore the full life cycle of solids operation must be considered for cost effective operation.	drainage process. Solids thickening impacts energy use in sludge digestion, dewatering, and disposal. The gravity belt thickener produces sludge with a lower solids concentration than a centrifuge, therefore the full life cycle of solids operation must be considered for cost effective operation.		engine, boiler or process to be fuelled. The utility should also determine the volume of biogas generated to assess the need for incorporating auxiliary feed stock for the digester to make biogas production viable.

Practical notes	Fine bubble technologies have applications for all sizes of wastewater treatment facilities. The percentage range of energy savings will be similar regardless of facility size.	Variable air flow rate blowers should be integrated with Fine bubble aeration and DO monitoring and control for optimum energy efficiency. Also consider the potential advantages of replacing two blowers and staging loadings with three, four or five smaller units that can meet current and future demands.	This control should be employed at post-aeration systems and wherever activated sludge is used as the secondary treatment process. Variable flow may be established with VFDs.	None.	When designing sludge dewatering equipment, it is more efficient to fit the minimum size equipment for the dewatering requirements and have the plant running continuously than to install oversized equipment that runs for just a few hours per day. This can save energy in two ways. First, any sludge that is held in liquid form before dewatering will need to be agitated or aerated, both of which require unnecessary power. Second, smaller dewatering equipment	None.	This best practice is usually implemented when the final effluent quality is sufficiently high so that its use will not hamper the function of pumps, hoses and nozzles used in its distribution. The practice is also cost-effective when large volumes of wash water are required, such as for biosolids processing or facility wash-down.	Reciprocating engines can be used in a majority of facility sizes. Microturbines and fuel cells are available in smaller capacity sizes for small facilities, where emissions are a concern. Combustion turbines can be used for facilities with generating capacities shown to be greater than 1 megawatt (MW). The utility should assess the potential to directly operate pumps or blowers using biogas to identify the most beneficial utilization option for the site.

Best practice	Fine bubble aeration	Variable blower air flow rate	Dissolved oxygen control	Post-aeration: cascade aeration	Sludge: replace centrifuge with screw press	Sludge: replace centrifuge with gravity belt thickener	Reduce fresh water consumption/ final effluent recycling	Use biogas to produce combined heat and/or power (CHP)
					will require smaller motors. Sludge-cake storage and transportation requirements must be considered prior to commencing 24-hour sludge dewatering operations.			
Other benefits	Most sites that have implemented this practice report improved biosolids management, reduced polymer use, better clarification and better overall effluent.	When teamed with fine bubble diffusers and DO control technologies, effluent quality and biosolids processing are usually improved.	Waste biosolids from a DO-controlled system have reportedly better dewatering characteristics. Also, a DO-controlled system usually has fewer problems treating a fluctuating influent load.	Not applicable.	In addition to lower energy consumption, the screw press also has lower operation and maintenance costs than the centrifuge. Furthermore, the screw press can produce class A biosolids if modified (by adding heat).	Other advantages associated with gravity belt thickeners include small-space requirements and ease of automation and control.	Other potential benefits associated with this measure include reducing well water consumption, reducing operation of booster pumps, where applicable, and possibly eliminating the need for two water distribution systems throughout the facility.	Collecting and using biogas avoids venting and flaring, which release greenhouse gases. Beneficial utilization of biogas can also help a facility become self-sustaining.

Stage of acceptance	This technology has gained a high level of acceptance within the industry.	Technologies for varying air flow rates are well received. Variable speed positive displacement blower arrangements and variable capacity centrifugal blowers are becoming more available and well known.	DO control is a well-accepted control methodology. The primary factor affecting acceptance is the reliability and associated maintenance related to DO probes.	Cascade aeration for effluent re-aeration is a well-accepted method.	Screw presses are widely accepted for sludge dewatering.	Gravity belt thickeners are widely accepted for sludge thickening.	Reducing the volume of potable water used in the wastewater treatment process is widely accepted throughout the industry.	Combined heat and power systems are gaining acceptance and being increasingly implemented in the wastewater industry.

Sources: Created based on data from Malcolm Pirnie, Inc., 2010; and Public Service Commission of Wisconsin, 2016.

Endnotes

1. Economic and Social Commission for Western Asia (ESCWA), 2012.
2. ESCWA, 2016.
3. UN-Water, 2014.
4. Ibid.
5. Weinberg, 2015.
6. The Nexus Network, 2016.
7. World Economic Forum, 2015.
8. Pew Research Center, 2014.
9. Institut National d'Etudes Démographiques (INED), 2016.
10. Roudi-Fahimi and Kent, 2007.
11. Droogers et al. 2012.
12. Reig, Maddocks and Gassert, 2013.
13. Immerzeel et al., 2011.
14. Droogers et al., 2012.
15. Kinninmont, 2010.
16. United States Energy Information Administration (EIA), 2016.
17. Maddocks, Young and Reig, 2015.
18. Weinberg, 2015.
19. Ibid.
20. Leigh, 2016.
21. McIntyre, 2014.
22. Xylem, 2014.
23. Gustard et al., 1997
24. United States Department of Energy, 2010.
25. Rutkowski, 2007.
26. Martín, 2012.
27. Martín, 2012.
28. Ibid.
29. Rodriguez et al., 2013.
30. Pechtl et al., 2003.
31. Saif, Mezher and Arafat, 2014.
32. Rodriguez et al, 2013.
33. Saudi Aramco, 2016.
34. Asaba, 2016.
35. Martín, 2012.
36. Rodriguez et al., 2013.
37. Shell Global, 2016.
38. Fantini, 2016.
39. Organization of Arab Petroleum Exporting Countries (OAPEC), 2015.
40. Organization of the Petroleum Exporting Countries (OPEC), 2015.
41. Gulf Petrochemicals and Chemicals Association (GPCA), 2012.
42. Carson, 2016.
43. Diala-McBride, 2016.
44. Ibid.
45. Carson, 2016.
46. SUEZ, 2014.
47. Canadian Society for Unconventional Resources (CSUR), 2013.
48. SUEZ, 2014.
49. Goodwin et al., 2012.
50. Frankel, 2007.
51. Rodriguez, 2015.
52. Meldrum et al., 2013.
53. Frankel, 2007.
54. Global CCS Institute, 2013.
55. Goldenberg, 2014.
56. Xylem, 2014.
57. Boersma, Vandendriessche and Leber, 2015.
58. Moore, 2014.
59. Osama, 2015.
60. Xylem, 2014.
61. Ibid.
62. Al-Mjeni et al., 2010.
63. Al-Mjeni et al., 2010.
64. Intermountain Oil and Gas BMP Project, n.d.
65. Getches-Wilkinson Center for Natural Resources, Energy, and the Environment, n.d.
66. Cohen, Ortez and Pinkstaff, 2009.
67. Cohen, Ortez and Pinkstaff, 2009.
68. Arab Forum for Environment and Development (AFED), 2011.
69. European Commission, 2016.
70. Arab Forum for Environment and Development (AFED), 2011.
71. Lepisto, 2006.
72. Kulkarni, 2011.
73. Ibid.
74. AFED, 2011.
75. United States Environment Protection Agency (EPA), 2016.
76. Kulkarni, 2011.
77. World Bank, 2002.
78. Intelligent Energy Europe, 2007.
79. Intelligent Energy Europe, 2014.
80. Utilities ME Staff, 2013.
81. Dubai Electricity and Water Authority (DEWA), 2015.
82. Utilities ME Staff, 2013.
83. Boyle et al., 2013.
84. Pataki, 2003.
85. EPRI, 2007.
86. Boyle et al., 2013.
87. Boyle et al., 2013.
88. Ibid.
89. Cutler, 2011.
90. Rahman, 2013.
91. Darwish et al., 2016.
92. Bodík and Kubaska, 2013.
93. Daw et al., 2012.
94. WERF2012.
95. WERF, 2012.
96. Mittal, 2011.
97. Seaman Corporation, 2011.
98. Marchaim, 1992.
99. Mittal, 2011.
100. Seaman Corporation, 2011.
101. Water-technology.net, 2016.
102. Chatila, 2015a.
103. Chatila, 2015b.
104. Reekie, 2013.
105. Feldman, 2009.
106. Lincus Energy, 2011.
107. Gellings, 2009.
108. Brandt, Middleton and Wang, 2010.
109. Clean Energy Business Council, 2014.
110. International Desalination Association (IDA), 2013.
111. Negewo, 2012.
112. Negewo, 2012.
113. Ministry of Water Resources and Irrigation, 2014.
114. Shakweer and Yousef, 2011.
115. Subramani et al., 2011.
116. Clean Energy Business Council, 2014.
117. Subramani et al., 2011.
118. Ibid.
119. Ibid.
120. Bartman et al., 2010.
121. Subramani et al., 2011.
122. Ibid.
123. Ibid.
124. Ray and Jain, 2011.
125. Al-Karaghouli and Kazmerski, 2013.
126. Subramani et al., 2011.
127. Huppé, 2015.
128. United Nations Department of Economic and Social Affairs (UNDESA), 2016.
129. UN-Water, work in progress.
130. World Bank, 2015.
131. World Bank, 2016.
132. World Bank, 2015.
133. World Bank, 2015.
134. Ibid.
135. United Nations and World Bank, 2016.
136. International Atomic Energy Agency (IAEA) and UNDESA, 2007.
137. Ibid.
138. World Bank, 2015.
139. Ibid.
140. Ibid.
141. Ibid.
142. Ibid.
143. Ibid.
144. AbdelGelil, 2015.
145. International Atomic Energy Agency, 2005.
146. Missaoui, Ben Hassine and Mourtada, 2012.
147. Ibid.
148. Ibid.
149. Trudeau and Dennehy, 2014.
150. Pelli and Hitz, 2000.
151. Ibid.
152. Alegre et al., 2007.
153. World Bank, 2015.
154. Ibid.
155. Ghaffour, Missimer and Amy, 2013.
156. Cohen, Ortez and Pinkstaff, 2009.
157. Marsden Jacob Associates, 2013.
158. Ibid.
159. Ibid.
160. Abboud, 2010.
161. Chaudhury, 2004.
162. Staff Report, 2016.
163. Al-Daameh, 2014.
164. International Institute for Sustainable Development (IISD), 2014.
165. 165 The Business Year, 2015.
166. 166 Rouchdy and Alam, 2015.

Bibliography

Abboud, N. (2010). Middle East Gears Up for Water Reuse Technologies. Available from http://www.waterworld.com/articles/wwi/print/volume-25/issue-1/regional-spotlight/middle-east-africa/middle-east-gears-up-for-water-reuse-technologies.html. Accessed 16 September 2016.

AbdelGelil, I. (2015). Energy Demand Profile in Arab Countries. Arab Environment 8: Sustainable Consumption. 2015 Report of the Arab Forum for Environment and Development (AFED).

Al-Daameh, M. (2014). "Jordan's Finance Minister: We will eliminate electricity subsidies by 2017", Asharq Al-Awsat, 14 May. Available from http://english.aawsat.com/2014/05/article55332275/jordans-finance-minister-we-will-eliminate-electricity-subsidies-by-2017. Accessed 10 October 2016.

Alegre, H., and others (2007). Performance Indicators for Water Supply Services – Second edition. Manual of Best Practice. London: International Water Association.

Al-Karaghouli, A., and L.L. Kazmerski (2013). Energy Consumption and Water Production Cost of Conventional and Renewable-energy-powered Desalination Processes. Renewable and Sustainable Energy Reviews, No. 24, pp. 343-356; doi:10.1016/j.rser.2012.12.064.

Al-Mjeni, R., and others (2010). Has the Time Come for EOR? Oilfield Review, vol. 22, No. 4 (Winter 2010/2011).

Arab Forum for Environment and Development (AFED) (2011). Water use efficiency in buildings. Available from http://www.afedonline.org/water%20efficiency%20manual/PDF/5Chapter%204_Buildings.pdf.

Arthur, J.D., Langhus, B.G., and C. Patel (2005). Technical Summary of Oil and Gas Produced Water Treatment Technologies. Available from http://www.all-llc.com/publicdownloads/ALLConsulting-WaterTreatmentOptionsReport.pdf.

Asaba, B. (2016). Saudi Aramco's electricity capacity to exceed 12GW. Utilities-Me.com, 14 January. Available from http://www.utilities-me.com/article-4025-saudi-aramcos-electricity-capacity-to-exceed-12gw/. Accessed 8 October 2016.

Bartman, A.R., and others (2010). Minimizing energy consumption in reverse osmosis membrane desalination using optimization-based control. Journal of Process Control, vol. 20, No. 10, pp.1261-1269; doi:10.1016/j.jprocont.2010.09.004. Available from https://www.researchgate.net/publication/229316944_Minimizing_energy_consumption_in_reverse_osmosis_membrane_desalination_using_optimization-based_control.

Bauer, D., and others (2014). The Water-Energy Nexus: Challenges and Opportunities. United States of America Department of Energy.

Bodík, I., and M. Kubaska (2013). Energy and sustainability of operation of a wastewater treatment plant. Environment Protection Engineering, vol. 39, No. 2, pp. 15-24; doi:10.5277/EPE130202.

Boersma, T., Vandendriessche, M., and A. Leber (2015). Shale gas in Algeria: No quick fix. Policy Brief, No. 15-01. Washington, D.C.: Brookings.

Boyle, T., and others (2013). Intelligent metering for urban water: A review. Water, vol. 5, Issue 3, pp. 1052-1081; doi:10.3390/w5031052.

Brandt, M.J., Middleton, R.A., and S. Wang (2010). Energy Efficiency in the Water Industry: A Compendium of Best Practices and Case Studies : Global Report. London: UK Water Industry Research.

Busch, M., and W.E. Mickols (2004). Reducing energy consumption in seawater desalination. Desalination, vol. 165, pp. 299–312; doi:10.1016/j.desal.2004.06.035.

Canadian Society for Unconventional Resources (CSUR), 2013. Water Consumption. Available from http://www.csur.com/sites/default/files/Water_Consumption_v3_wBleed.pdf.

Carson, R. (2016). Saudi Aramco CEO calls on upstream industry to transform business model to remain at forefront of global energy scene. Zawya, 27 September. Available from http://www.zawya.com/mena/en/story/Saudi_Aramco_CEO_calls_for_transformation_of_oil_and_gas_industry-ZAWYA20160927030832/. Accessed 8 October 2016.

Chatila, F., 2015a. Gabal El Asfar Plant Worth USD95.8 Million. Arab Water World, vol. 38, Issue 3. Available from http://www.awwmag.com/PDFFiles/AWW-March-2015.pdf.

Chatila, F., 2015b. WABAG to Supply 200,000 m3/d Municipal WWTP. Arab Water World, vol. 38, Issue 3. Available from http://www.awwmag.com/PDFFiles/AWW-March-2015.pdf

Chaudhury, M.D. (2004). UAE is world's third largest water consumer after U.S. Khaleej Times, 25 December. Available from http://www.khaleejtimes.com/business/uae-is-world-s-third-largest-water-consumer-after-u.s. Accessed 16 September 2016.

Clean Energy Business Council (2014). Water and Energy in MENA: Challenges, Opportunities, and Potential.

Cohen, R., Ortez, K., and C. Pinkstaff (2009). Increasing water efficiency in California's commercial, industrial, and institutional (CII) sector, pp. 1-40.

Crites, R.W., and others (2014). Natural wastewater treatment systems, Second edition. ed. IWA Publishing : CRC Press, Taylor & Francis Group, Boca Raton. Available from http://www.crcnetbase.com/isbn/978-1-4665-8326-9.

Cutler, S. (2011). Smart Water Metering Networks An Intelligent Investment? WaterWorld, vol. 26, Issue 5. Available from http://www.waterworld.com/articles/wwi/print/volume-26/issue-5.html.

Darwish, M.A., and others (2016). The role of energy to solve water scarcity in Qatar. Desalination and Water Treatment, vol. 57, pp. 18639-18667; doi:10.1080/19443994.2015.1103666.

Daw, J., and others (2012). Energy Efficiency Strategies for Municipal Wastewater Treatment Facilities. Golden, Colorado: National Renewable Energy Laboratory (NREL).

Deines, A. (2013). Energy Production and Efficiency at Wastewater Treatment Plants. Water Environment Research Foundation.

Diala-McBride, C. (2016). Middle East Salves Global Slowdown Wounds. Breakbulk. Events Media. Available from http://www.breakbulk.com/middle-east-salves-global-slowdown-wounds/. Accessed on 8 October 2016.

Droogers, P., and others (2012). Water resources trends in Middle East and North Africa towards 2050. Hydrolology and Earth System Sciences, vol. 16, pp. 3101-3114; doi:10.5194/hess-16-3101-2012.

Dubai Electricity and Water Authority (DEWA) (2015). HE Saeed Mohammed Al Tayer Inaugurates 5th Smart Grids and Smart Meters Summit. Available from https://www.dewa.gov.ae/en/about-dewa/news-and-media/press-and-news/latest-news/2015/10/he-saeed-mohammed-al-tayer-inaugurates-5th-smart-grids-and-smart-meters-summit. Accessed 9 October 2016.

Economic and Social Commission for Western Asia (ESCWA) (2012). Report on Intergovernmental Consultative Meeting on the Water and Energy Nexus in the ESCWA Region (E/ESCWA/SDPD/2012/IC.1/2/Report), Beirut, 27-28 June 2012. Available from https://www.unescwa.org/sites/www.unescwa.org/files/events/files/water_and_energy_nexus_in_escwa_region_report_e.pdf.

Economic and Social Commission for Western Asia (ESCWA) (2016). *Developing the Capacity of ESCWA Member Countries to Address the Water and Energy Nexus for Achieving Sustainable Development Goals: Regional Policy Toolkit (E/ESCWA/SDPD/2016/Manual)*. Beirut: United Nations. Available from https://www.unescwa.org/sites/www.unescwa.org/files/events/files/nexus_training_module.pdf.

Electric Power Research Institute (EPRI) (2002). Comparison of Alternate Cooling Technologies for California Power Plants: Economic, Environmental and Other Tradeoffs. Sacramento, CA: California Energy Commission.

Electric Power Research Institute (EPRI) (2007). Advanced Metering Infrastructure (AMI). Available from https://www.ferc.gov/CalendarFiles/20070423091846-EPRI%20-%20Advanced%20Metering.pdf.

EPA WaterSense (2016). Commercial Water Use and Conservation – Facility Types. U.S. Environmental Protection Agency. Available from https://www3.epa.gov/watersense/commercial/types.html#tabs-office. Accessed on 2 September 2016.

European Commission, 2016. Best Available Techniques (BAT) Reference Document for Common Waste Water and Waste Gas Treatment/Management Systems in the Chemical Sector. Available from http://eippcb.jrc.ec.europa.eu/reference/BREF/CWW_Bref_07_2016.pdf.

Fantini, A.-M. (2016). OPEC Annual Statistical Bulletin 2016. Vienna: Organization of the Petroleum Exporting Countries (OPEC).

Feldman, M. (ed.), 2009. Aspects of energy efficiency in water supply systems. Presented at the 5th IWA Water Loss Reduction Specialist Conference, 26-30 April 2009, Cape Town, South Africa.

Frankel, C., 2007. Environmental, Health, and Safety Guidelines for Liquefied Natural Gas (LNG) Facilities. Available from http://www.ifc.org/wps/wcm/connect/87e7a48048855295ac04fe6a6515bb18/Final+-+LNG.pdf?MOD=AJPERES. [TPU: Fix left alignment pls]

Gellings, C.W. (2009). Energy Efficiency in Pumping and Irrigation Systems. In Efficient Use and Conservation of Energy, Vol. II, Encyclopedia of Life Support Systems. Available from http://www.eolss.net/sample-chapters/c08/e3-18-04-01.pdf.

Getches-Wilkinson Center for Natural Resources, Energy, and the Environment (n.d.). Anadarko's Completion Transport System – ACTS. Available from http://www.oilandgasbmps.org/resources/casestudies/anadarko-acts.php. Accessed on 28 August 2016.

Ghaffour, N., Missimer, T.M., and G.L. Amy (2013). Technical review and evaluation of the economics of water desalination: Current and future challenges for better water supply sustainability. Desalination, No. 309, pp. 197–207; doi:10.1016/j.desal.2012.10.015.

Global CCS Institute, 2013. CCS Learning from the LNG Sector: A Report for the Global CCS Institute (No. 401010–1060–0-NaN-NaN-1). Melbourne: WorleyParsons. Available from http://hub.globalccsinstitute.com/sites/default/files/publications/120081/ccs-learnings-lng-sector-gccsi.pdf. [TPU: Pls adjust left alignment] [Division: Please make sure that reference is correct. Could not be accessed online.]

Goldenberg, S. (2014). Fracking is depleting water supplies in America's driest areas, report shows. The Guardian, 5 February.

Goodwin, S., and others (2012). Life cycle analysis of water use and intensity of oil and gas recovery in Wattenberg field, Colo. Oil & Gas Journal, 7 May.

Gulf Petrochemicals and Chemicals Association (GPCA) (2012). GCC Petrochemicals and Chemicals Industry: Facts and Figures.

Gustard, A., and others (eds.) (1997). FRIEND'97: Regional Hydrology: Concepts and Models for Sustainable Water Resource Management. IAHS Publication, No. 246. Wallingford, UK: IAHS Press.

Huppé, G.A. (2015). Indicators for Water, Energy and Food (WEF) Security.

Immerzeel, W., and others (2011). Middle-East and Northern Africa Water Outlook. FutureWater Report, No. 98. World Bank.

Institut National d'Etudes Démographiques (INED) (2016). Mid-year Population. Available from https://www.ined.fr/en/glossary/mid-year-population/. Accessed on20 September 2016.

Intelligent Energy Europe, 2007. Energy Savings from Intelligent Metering and Behavioural Change (No. EIE/04/107/SO7.38635). European Commission.

Intelligent Energy Europe (2014). Energy Savings from Intelligent Metering and Behavioural Change. European Commission. Available from https://ec.europa.eu/energy/intelligent/projects/en/projects/intelligent-metering. Accessed 9 October 2016.

Intermountain Oil and Gas BMP Project (n.d.). Development Process for Oil and Gas Production. Available from http://www.oilandgasbmps.org/resources/

development.php. Accessed 28 August 2016.

International Atomic Energy Agency (IAEA) (2005). Energy Indicators for Sustainable Development: Guidelines and Methodologies. Vienna: International Atomic Energy Agency.

nternational Atomic Energy Agency (IAEA), and United Nations Department of Economic and Social Affairs (UNDESA) (2007). Energy Indicators for Sustainable Development: Country Studies on Brazil, Cuba, Lithuania, Mexico, Russian Federation, Slovakia, and Thailand.

International Desalination Association (IDA) (2013). Global desalination capacity growing substantially, finds study. Available from http://www.waterworld.com/articles/2013/10/global-desalination-capacity-tops-80-million-cubic-meters-per-day.html. Accessed 30 August 2016.

International Energy Agency (IEA) (n.d.). OECD/IEA 2014 Energy Efficiency Indicators: Essentials for Policy Making. Available from https://www.iea.org/publications/freepublications/publication/IEA_EnergyEfficiencyIndicators_EssentialsforPolicyMaking.pdf. [TPU: pls fix left alignment]

International Institute for Sustainable Development (IISD) (2014). Energy Subsidy Country Update: Assessing Egypt's Energy Subsidy Reforms.

Kinninmont, J. (2010). The GCC in 2020: Resources for the future. Economist Intelligence Unit.

Kohli, A., and K. Frenken (2011). Cooling water for energy generation and its impact on national-level water statistics. AQUASTAT Programme of the United Nations Food and Agriculture Organization (FAO).

Kulkarni, S. (2011). Innovative Technologies for Water Saving in Irrigated Agriculture. ResearchGate, No. 1, pp. 226-231.

Kumana & Associates (2011). Pinch analysis for optimizing process water management.

Leigh, J. (2016). Water Tight 2.0: The top trends in the global water sector. Deloitte Touche Tohmatsu Ltd.

Lepisto, C. (2006). WaterSaver Technologies Aqus Uses Sink Greywater for Toilet. TreeHugger. Available from http://www.treehugger.com/bathroom-design/watersaver-technologies-aqus-uses-sink-greywater-for-toilet.html. Accessed 29 August 2016.

Lincus Energy (2011). Energy Savings in Water Distribution Systems. Energy Connection, No. 2, pp. 1-8.

Macknick, J., and others (2012). Operational water consumption and withdrawal factors for electricity generating technologies: a review of existing literature. Environmental Research Letters, Vol. 7, No. 4, 45802; doi:10.1088/1748-9326/7/4/045802.

Maddocks, A., Young, R.S., and P. Reig (2015). Ranking the World's Most Water-Stressed Countries in 2040. World Resources Institute. Available from http://www.wri.org/blog/2015/08/ranking-world%E2%80%99s-most-water-stressed-countries-2040. Accessed 2 September 2016.

Malcolm Pirnie, Inc. (2010). Water and Wastewater Energy Management: Best Practices Handbook. New York State Energy Research and Development Authority.

Marchaim, U. (1992). Biogas processes for sustainable development. FAO Agricultural Services Bulletin. Rome: FAP.

Marsden Jacob Associates (2013). Project report: Economic viability of recycled water schemes. Brisbane, Australia: Australian Water Recycling Centre of Excellence.

Martín, A.D. (2012). Water footprint of electric power generation: Modeling its use and analyzing options for a water-scarce future. Massachusetts Institute of Technology.

McIntyre, G. (2014). World Water Day: Water and Energy. Available from http://www.ch2mhillblogs.com/water/2014/03/19/world-water-day-water-energy/. Accessed 8 September 2016.

Meldrum, J., and others (2013). Life cycle water use for electricity generation: A review and harmonization of literature estimates. Environmental Research Letters, No. 8; doi:10.1088/1748-9326/8/1/015031.

Ministry of Water Resources and Irrigation (2014). Water Scarcity in Egypt: The Urgent Need for Regional Cooperation among the Nile Basin Countries.

Missaoui, R., Ben Hassine, H., and A. Mourtada (2012). Energy Efficiency Indicators in the Southern and Eastern Mediterranean Countries: Regional Report. Plan Bleu.

Mittal, A. (2011). Biological Wastewater Treatment. Water Today.

Moore, D. (2014). Oman oil and gas minister praises fracking at Downtown conference. Pittsburgh Post-Gazette. Available from http://powersource.post-gazette.com/powersource/features-powersource/2014/10/29/Oman-oil-and-gas-minister-praises-fracking/stories/201410280165. Accessed 11 September 2016.

Muggeridge, A., and others (2013). Recovery rates, enhanced oil recovery and technological limits. Philosophical Transactions, Series A, No. 372/20120320; doi:10.1098/rsta.2012.0320.

Negewo, B.D. (2012). Renewable Energy Desalination: An Emerging Solution to Close MENA's Water Gap. Washington, D.C.: World Bank.

Organization of Arab Petroleum Exporting Countries (OAPEC) (2015). Annual Statistical Report. Kuwait: OAPEC.

Organization of the Petroleum Exporting Countries (OPEC) (2015). Annual Statistical Bulletin. Vienna: OPEC.

Osama, B. (2015). The Middle East should think twice about fracking. SciDev.Net. Available from http://www.scidev.net/index.cfm?originalUrl=global/energy/editorials/middle-east-fracking-shale-gas-extraction.html. Accessed 11 September 2016.

Pataki, G.E., 2003. A Primer on Smart Metering. Available from https://www.smartgrid.gov/files/Primer_on_Smart_Metering_200307.pdf. [TPU: Fix alignment]

Pechtl, P., and others (2003). Integrated Thermal Power and Desalination Plant Optimization. Presented at the PowerGen Middle East, General Electric Energy Services, Optimization Software.

Pelli, T., and H.U. Hitz (2000). Energy indicators and savings in water supply. Journal of the American Water Works Association, vol. 92, No. 6, pp. 55-62.

Pew Research Center (2014). Emerging Nations Embrace Internet, Mobile Technology. Global Attitudes and Trends.

Public Service Commission of Wisconsin (2016). Energy Best Practices Guide: Water and Wastewater Industry.

Rahman, S. (2013). UAE's per capita energy consumption among the highest. GulfNews, 16 April. Available from http://gulfnews.com/business/economy/uae-s-per-capita-energy-consumption-among-the-highest-1.1171313. Accessed 13 September 2016.

Ray, C., and R. Jain (eds.) (2011). Drinking Water Treatment. Dordrecht, Netherlands: Springer.

Reekie, L.J. (2013). Electricity Use and Management in the Municipal Water Supply and Wastewater Industries. Electric Power Research Institute.

Reig, P., Maddocks, A., and F. Gassert (2013). World's 36 Most Water-Stressed Countries. World Resoures Institute. Available from http://www.wri.org/blog/2013/12/world%E2%80%99s-36-most-water-stressed-countries. Accessed 5 September 2015.

Rodriguez, D.J., and others (2013). Water Papers: Thirsty Energy. Washington, D.C.: World Bank.

Rodriguez, E.H. (2015). Planning small-scale LNG? Manage engineering risk to maximize returns.

Rouchdy, N., and T. Alam (2015). What is holding back the private sector? A UAE Investigation into Energy and Water Efficiency Barriers. Abu Dhabi: Emirates Wildlife Society.

Roudi-Fahimi, F., and M.M. Kent (2007). Challenges and Opportunities – The Population of the Middle East and North Africa. Population Bulletin, vol. 62, No. 2. Population Reference Bureau.

Rutkowski, M.D. (2007). Power Plant Water Usage and Loss Study. The United States Department of Energy, National Energy Technology Laboratory.

Saif, O., Mezher, T., and H.A. Arafat (2014). Water security in the GCC countries: Challenges and opportunities. Journal of Environmental Studies and Sciences, No. 4, 329-346; doi:10.1007/s13412-014-0178-8.

Saudi Aramco (2016). The power of cogeneration. Available from http://www.saudiaramco.com/en/home/innovation/stories-of-progress/the-power-of-cogeneration.html. Accessed 8 October 2016.

Seaman Corporation (2011). Anaerobic Digestion: Save Cost and Lower Carbon Footprint.

Shakweer, A.F., and R.M. Yousef (2011). Egypt's Desalination Technology Roadmap 2030. European Foresight Platform (EFP) Brief, No. 253.

Shell Global (2016). Pearl GTL – Overview. Available from http://www.shell.com/about-us/major-projects/pearl-gtl/pearl-gtl-an-overview.html. Accessed 8 October 2016.

Staff Report (2016). Abu Dhabi raises water, electricity tariffs. GulfNews. Available from http://gulfnews.com/business/sectors/energy/abu-dhabi-raises-water-electricity-tariffs-1.1647201. Accessed 16 September 2016.

Stockholm Environment Institute (SEI) (2011). Understanding the Nexus: Background paper for the Bonn2011 Nexus Conference. The Water, Energy and Food Security Nexus.–

Subramani, A., and others (2011). Energy minimization strategies and renewable energy utilization for desalination: A review. Water Resources, No. 45, pp. 1907-1920; doi:10.1016/j.watres.2010.12.032.

SUEZ (2014). Water management in the oil and gas industry. Emag, SUEZ. Available from http://www.emag.suez-environnement.com/en/water-management-oil-gas-industry-12010. Accessed 31 October 2016.

Tajer, S. (2011). Investment in Oil and Gas Industry in the MENA Region. Dubai International Financial Centre.

Tanked Australia (2007). Greywater. Available from http://www.tankedaustralia.com.au/index.php?cpage=greywater. Accessed 2 September 2016.

The Business Year (2015). Powering the People. Available from https://www.thebusinessyear.com/lebanon-2015/powering-the-people/interview. Accessed 10 October 2016.

The Nexus Network (2016). Nexuses of the urban: Interactions between water, energy and food provision for sustainable cities. Available from http://www.thenexusnetwork.org/events/nexuses-of-the-urban-interactions-between-water-energy-and-food-provision-for-sustainable-cities/. Accessed 6 September 2016.

The World Bank, 2002. Middle East and North Africa (MNA) Regional Water Initiative First Regional Consultation on MENA Water Challenges and Preparation for the Third World Water Forum – Summary Report (No. 28308). World Water Council, Spain. The-Crankshaft Publishing (n.d.). Water-using equipment: Domestic (energy engineering). Available from http://what-when-how.com/energy-engineering/water-using-equipment-domestic-energy-engineering/. Accessed 20 September 2016.

Thompson, N.A., and P.G. Nicoll (2011). Forward osmosis desalination: A commercial reality. Presented at the IDA World Congress on Modern Water, Perth, Western Australia, 4-9 September 2011.

and E. ()Paris: Union of Concerned Scientists, n.d. How it works: Water for power plant cooling. Available from http://www.ucsusa.org/clean_energy/our-energy-choices/energy-and-water-use/water-energy-electricity-cooling-power-plant.html. Accessed 27 August 2016.

United Nations Department of Economic and Social Affairs (UNDESA), Sustainable Development Knowledge Platform (2016). Sustainable Development Goal 6: Ensure availability and sustainable management of water and sanitation for all. Available from https://sustainabledevelopment.un.org/sdg6#. Accessed 13 October 2016.

United Nations Department of Economic and Social Affairs (UNDESA), Population Division (2014). World urbanization prospects: The 2014 revision (CD-ROM edition).

United Nations, and World Bank (2016). Sustainable Energy for All (SEforAll): About us. Available from http://www.se4all.org/about-us. Accessed 2 November 2016.

UN-Water (2014). Water and urbanization. Available from http://www.unwater.org/topics/water-and-urbanization/en/. Accessed 6 September 2016.

UN-Water (work in progress). Integrated Monitoring Guide for SDG 6: Targets and global indicators. Available from http://www.unwater.org/fileadmin/user_upload/unwater_new/docs/SDG%206%20targets%20and%20global%20indicators_2016-07-19.pdf.

United States Department of Energy, Office of Fossil Energy (2010). Enhanced oil recovery. Available from http://energy.gov/fe/science-innovation/oil-gas-research/enhanced-oil-recovery. Accessed 8 September 2016.

United States Energy Information Administration (EIA) (2016). International Energy Outlook.

United States Environment Protection Agency (EPA) (2016). Water-saving technologies. Available from https://www3.epa.gov/watersense/outdoor/tech.html. Accessed 9 October 2016.

Utilities ME Staff (2013). Smart metering: Slowly, but surely, July 22. Available from http://www.utilities-me.com/article-2442-smart-metering-slowly-but-surely/. Accessed 9 October 2016.

Water Environment Research Foundation (WERF), 2012. Energy Management: Exploratory Team Report Executive Summary. Water in the West (2013). Water and Energy Nexus: A Literature Review. Stanford.

Water-technology.net (2016). As-Samra Wastewater Treatment Plant (WWTP). Available from http://www.water-technology.net/projects/as-samra-wastewater-treatment-plant-jordan/. Accessed 10 October 2016.

Weinberg, J. (2015). Making water-energy food nexus approaches operational to support sustainable urbanization.

World Bank (2002). First Regional Consultation on MENA Water Challenges and Preparation for the Third World Water Forum, Spain, 10-12 June: Summary Report (No. 28308).

World Bank (2002) (2015). Sustainable Energy for All: Progress Toward Sustainable Energy. Washington, D.C.

World Bank (2002) (2016). Indicators. Available from http://data.worldbank.org/indicator. Accessed 16 September 2016.

World Economic Forum (2015). Global Risks 2015, 10th Edition.

Xylem (2014). Water use in oil and gas – Introduction: Trends in oil and gas production globally.

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