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Drying Up: Climate Change & Water Scarcity

Sustainability Industry Report

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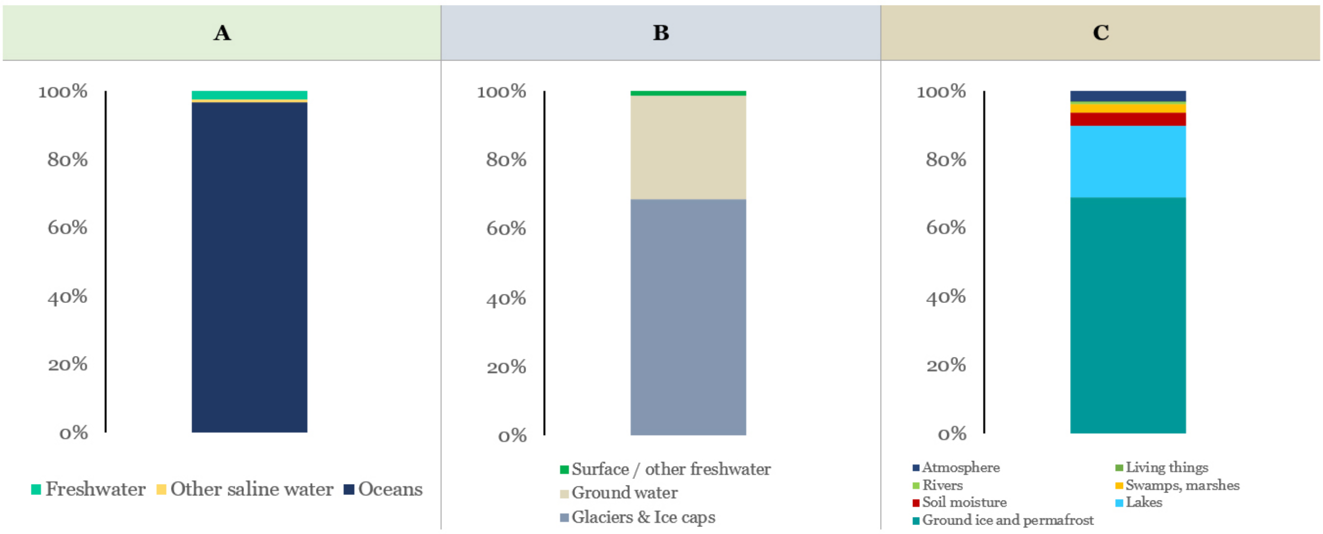
Climate change will alter patterns of precipitation, river flow and evaporation. At the same time, water use is increasing in many countries. This brings increasing challenges of providing sufficient, affordable, high-quality water for agriculture, human needs, and industry, while not depriving ecosystems. How will water scarcity manifest itself? Which regions and areas of human activity are most threatened? How can the challenges be addressed?

SUSTAINABILITY REPORT

This research paper is part of a 12-month series published by the Al-Attiyah Foundation every year. Each in-depth research paper focuses on a current sustainability topic that is of interest to the Foundation's members and partners. The 12 technical papers are distributed to members, partners, and universities, as well as made available on the Foundation's website.

Freshwater	Water extracted from non-saline lakes, rivers, the ground, and artificial reservoirs – i.e., not the sea, with a salinity less than 1000 ppm (seawater is 35 000 ppm). Freshwater is utilised for all human activities and consumption (very little currently is from desalinated water), and makes up only 2.5% of the earth's total water resources. The amount of available freshwater today is ~4,000 km3 per year.
Groundwater	Groundwater is the water present beneath Earth's surface in rock and soil pore spaces and in the fractures of rock formations. 30% of all readily available freshwater in the world is groundwater. Glaciers and icecaps make up 68.9% of freshwater and other surface and freshwater sources make up the remainder.
Surface Water	Surface water is any body of water above ground, including streams, rivers, lakes, wetlands, reservoirs, and creeks. It is water located on top of the Earth's surface, and may also be referred to as blue water. The ocean, despite being saltwater, is also considered surface water, although it is not freshwater surface water.
Blue Water	Fresh surface and ground water
Green Water	The precipitation on land that does not run off or recharge the groundwater but is stored in the soil or temporarily stays on top of the soil or in vegetation, and available only to plants.
Renewable Water Resources	Renewable fresh water. The sources of renewable water are precipitation from the atmosphere in the form of mist, rain and snow. Underground water that is not being fully recharged by precipitation is not renewable and is being diminished steadily.

Figure 1 A: Total global water resources; B: Breakdown of freshwater resources; C: Breakdown of Surface water and other freshwater resources[i]



- Water is essential for sustainable development, and is critical for food security and healthy ecosystems. It is vital for reducing the global burden of disease and improving the health, welfare and productivity of populations.
- Changes in the global water cycle have increased the occurrence and impacts of events, such as major natural disasters, ecological changes, temperature rises, food insecurity, socio-political tensions, and energy vulnerability. In turn these events damage the ability to manage the water sector effectively, and further encourage unsustainable practices.
- The impacts of climate change on water availability underscores the challenge of meeting its demand for energy, agriculture, industry, transport, and human consumption in a judicious and sustainable manner, particularly in areas of the world already facing water stress.
- Water use has increased by a factor of six over the last century, and continues to grow steadily at a rate of ~1% annually, about the same as population growth. Projections for future water demand suggest industrial and domestic demand will grow faster than agricultural demand, but overall demand for agriculture will remain the largest.
- As water supply itself depends on energy, and energy supply on water, they are both part of the same nexus that will ensure a low-carbon, sustainable future.
- Mitigating the worst impacts of climate change-induced water variability cannot be achieved through unilateral, isolated approaches that are limited in their ability to address the inherent complexities involved in water challenges and the actions required to address them.
- Overcoming and reducing such challenges requires a concerted, collective effort and wide alliances, between the public sector, the private sector, and civil society.

> "Water is the most critical resource issue of our lifetime and our children's lifetime. The health of our waters is the principal measure of how we live on the land."
>
> ***Luna Leopold, US Hydrologist (1915-2006)***

Water is a human right[ii]. It is essential for sustainable development, and is critical for food security and healthy ecosystems. It is vital for reducing the global burden of disease and improving the health, welfare and productivity of populations. In so doing, it promotes sound socioeconomic development.

Climate change and water are indisputably correlated. The climate change crisis has increased variability in global water cycles, reducing the predictability of water availability and demand, affecting water quality, exacerbating water scarcity, and threatening sustainable development[iii].

Figure 2 Factors contributing to water cycle variability and its consequences [iv]

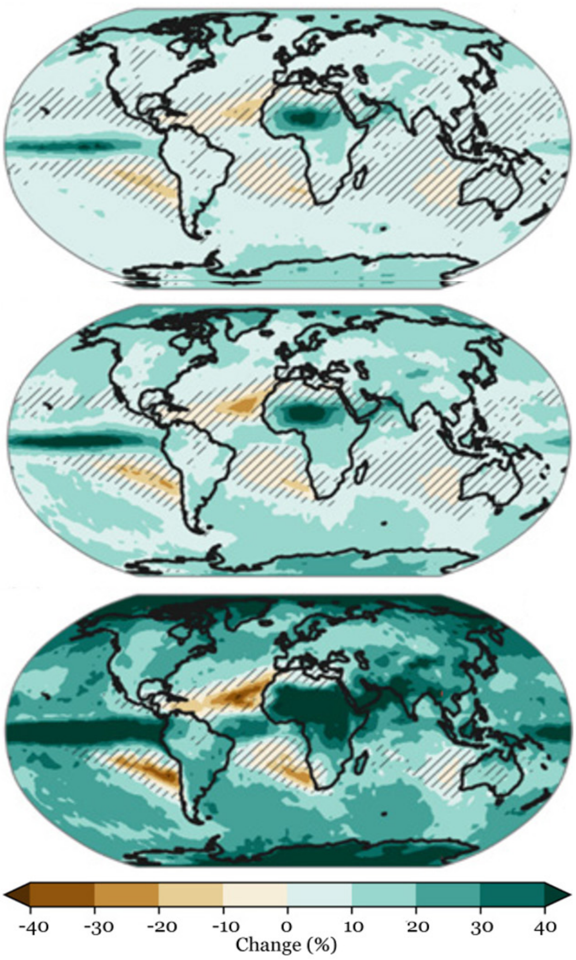
In turn, water crises the world over have increased the occurrence and impacts of climate change, such as major natural disasters, ecological changes, changes in precipitation and snowfall patterns, temperature rises, food insecurity, socio-political tensions, and energy vulnerability.

In general, areas that are already wet have become much wetter, and already arid areas have become prone to greater drought. Heavier extreme precipitation events in the high latitudes and tropics, such as flooding and heavy storms, have resulted in soil erosion and land destruction. Higher temperatures continue reducing surface water in arid and semi-arid areas, drying out soils and vegetation, and subsequently making periods with low precipitation drier than they would be in cooler conditions[v].

These impacts are further compounded by a variety of contributing factors, including population increase, unmanaged migration, land-use change, increased industrial activity and transportation, accelerated groundwater and surface water extraction, desalination, and widespread ecological degradation and biodiversity loss for recreational purposes like landscaping, or mining and quarrying for energy uses.

The impacts of climate change-induced variability in the world's water cycle are highly variable and uneven. Countries typically adapted to life with floods, such as the Netherlands, are facing a recent advent of drought, highlighting this unevenness and often the unforeseen nature of water cycle changes.

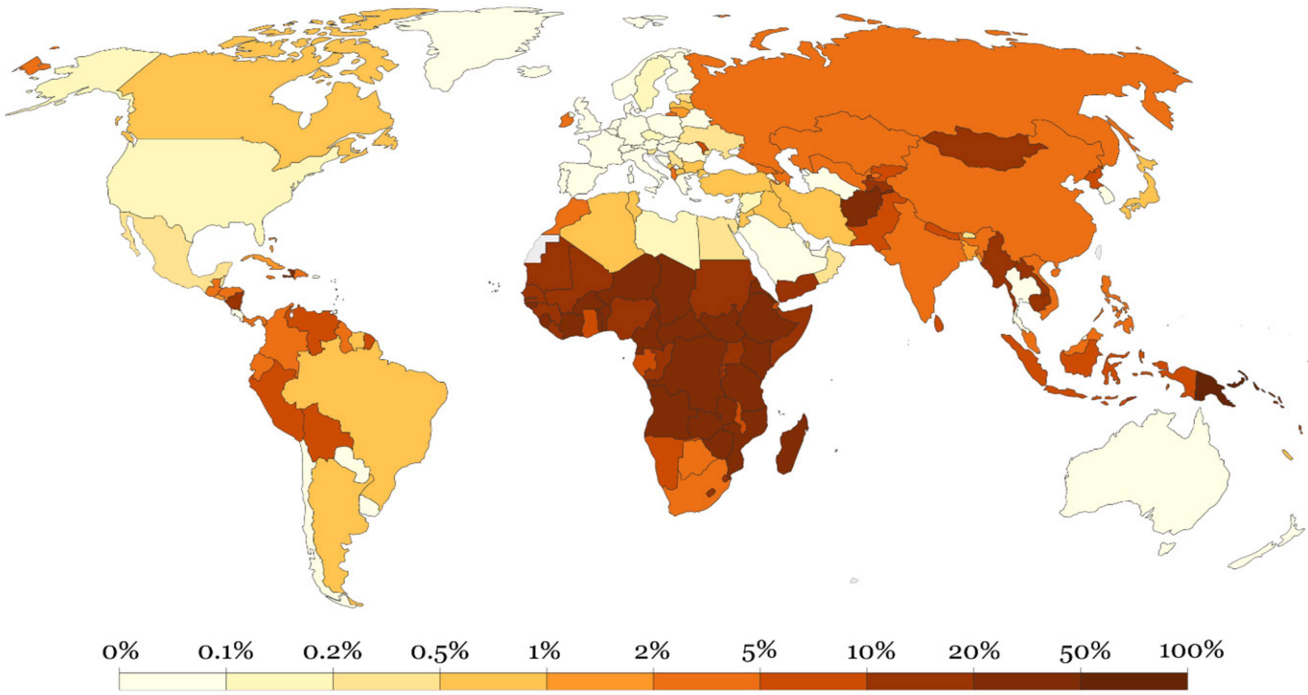
Figure 3 Projected changes in annual maximum daily precipitation at 1.5°C (top), 2°C (middle) and 4°C (bottom) of global warming compared to the 1851-1900 baseline. Brown shading indicates decreases, while green indicates increases. Hatching shows parts of the world with limited agreement across climate models[vi]



Drought-prone regions on the other hand are now susceptible to prolonged, extraordinary periods of drought, or multi-year droughts (such as in the western USA and the eastern Mediterranean). Both meteorological droughts (less rainfall) and agricultural droughts (less soil moisture) have increased the frequency of sudden "flash" hydrological droughts, resulting in less surface water and groundwater.

Rain-prone areas are experiencing increasingly severe precipitation. Although wetter countries typically have higher groundwater and surface water resources, many of the poorer ones are unable to provide safe water for drinking and sanitation to their populations, due to contamination (as a result of flooding, increases in sediment, pollutant loadings due to acid rain, reduced dilution of pollutants due to disruption of treatment facilities), lack of investment in infrastructure needed to deliver reliable supply, and lack of political will to advance technologies that capture, store, treat and pipe rainwater effectively.

Figure 4 Share of global population without access to an improved water source that can deliver safe water, 2020 [ix]



Countries like Papua New Guinea, Sierra Leone, Liberia, Myanmar, and Madagascar, which are high on the list of the world's wettest countries, struggle to deliver reliable supply[vii], with 30-65% of their populations lacking access[viii] (Figure 2).

Some regions may face both sets of extremes, or "double-whammy weather", such as in mid-latitude areas, including Asia, Southern Africa, and Oceania. According to the American Geophysical Union, 11% of global droughts in the past seven decades have been followed by at least one heavy rain event in the following three months in a concentrated area or region. For example, the Democratic Republic of Congo, Kenya, Brazil, Botswana, Iran, China, and Myanmar had an average seesaw occurrence of >25% during this period[x].

Others may experience slower-onset impacts, derived from accelerated sea-level rise, such as coastal areas and smaller low-lying island nations. For example, a tiny Japanese island, Esanbe Hanakita Kojima, off the northeast coast of the mainland, disappeared into the Pacific Ocean in 2018 due to rising sea levels[xi], becoming the ninth such low-lying Pacific Ocean island in recent years to have gone under.

Low-lying islands and coastal regions also face increased exposure to the risks associated with saltwater intrusion into their freshwater systems as a result of sea rise.

Figure 5 Global average sea level rise (relative to the 1993-2008 average) [xxii]

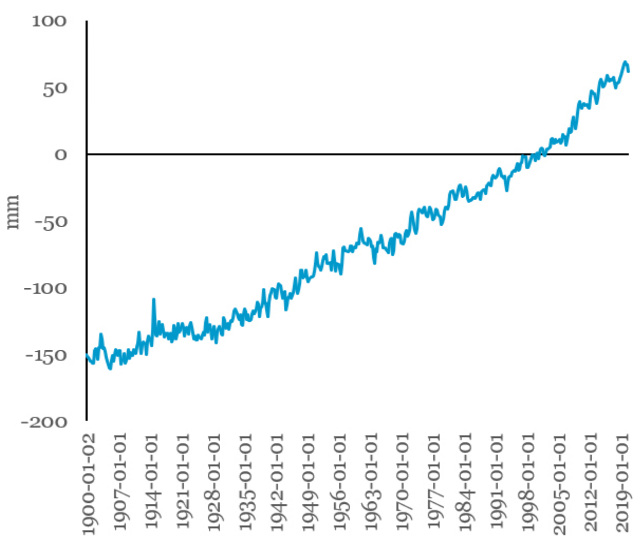
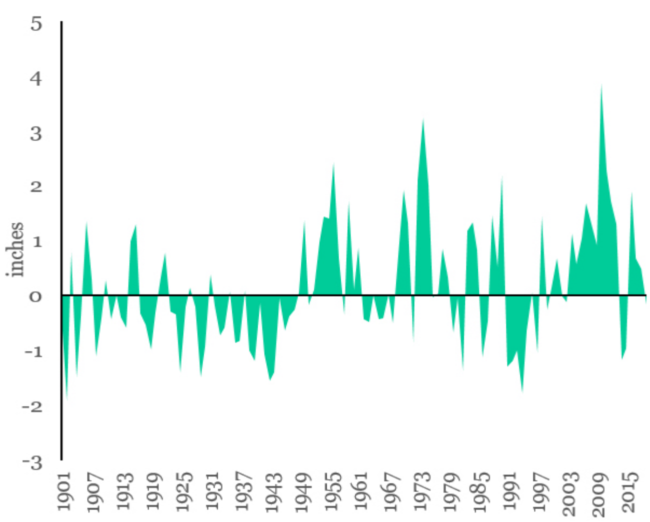


Figure 6 Global precipitation anomaly, 1901-2019 [xv]



Dramatically depleting glaciers and ice sheets are the primary contributor to rising sea levels. Over the past 100 years, mountain glaciers, Arctic glaciers, and Greenland's ice sheets have decreased significantly in size. This means less ice trapped on land, and more melted ice in the ocean, resulting in higher sea levels.

Climate change-induced variability also increases sea levels by expanding the ocean as it warms. Since 1955, >90% of the excess heat held in the atmosphere by heat-trapping greenhouse gases (GHGs) has made its way into the ocean[xiii].

In almost all regions with snowfall, climate change will continue to alter streamflow seasonality. With the exception of very cold regions, warming has reduced the spring maximum snow depth and brought forward the spring snowmelt, leaving less snow in storage for dry summer months [xiv]. Smaller snowmelt floods, increased winter flows, and reduced summer flows have all been observed in the Scandinavian countries and Arctic region.

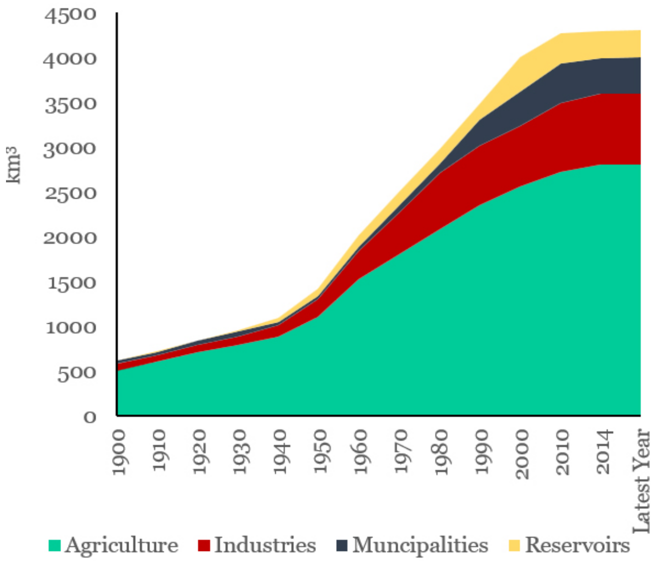
The impacts of climate change on water availability underscores the challenge of meeting its demand for energy, agriculture, industry, transport, and human consumption in a judicious and sustainable manner, particularly in areas of the world already facing water stress. For these reasons, it is often said that climate change is felt most directly through water.

"Water is the primary medium through which we will feel the effects of climate change... It [water] will play a pivotal role in how the world mitigates and adapts to the effects of climate change. An integrated view on water, the biosphere and environmental flows is required to devise sustainable agricultural and economic systems that will decelerate climate change, protect us from extremes and to adapt to the unavoidable at the same time."

United Nations Water (unwater.org)

Water is almost entirely used for human purposes. Freshwater withdrawals for irrigation are nearly 70% of the total withdrawn for human uses, or about 2,800 of 3,997 km3[xvi]. Withdrawals for industry are about 20%, and for municipal use about 10%[xvii].

Figure 7 Freshwater use by sector, where water use refers to withdrawals for agricultural, industrial and domestic uses [xviii]



Water withdrawal differs from water consumption in that a portion of withdrawn water may be returned to its source and become available to be used again. Consumed water is water removed for use and not returned to its source. About 55%[xix] of all water withdrawn is consumed. Around 5-7%[xx] of withdrawn water is in the form of evaporation from water reservoirs (artificial lakes).

Water use has increased by a factor of six over the last century, and continues to grow steadily at a rate of ~1% annually, about equal to population growth[xxii]. Projections for future water demand suggest industrial and domestic demand will grow faster than agricultural demand, but overall demand for agriculture will remain the largest[xxiii].

Demand is expected to reach 5,500-6,000 km3 per year by 2050[xxiv], as the global population swells to 10.2 billion people, an increment of ~31% from current population levels (7.8 billion). Most of this population growth will occur in Africa (+1.3 billion) and Asia (+0.75 billion), with the middle class growing the fastest, resulting in a significant increase in freshwater consumption.

The simplest means of forecasting future water demand is to estimate current per capita consumption multiplied by the expected future population, although this approach fails to take into account water-efficient and nature-based solutions that could significantly alter demand requirements.

Figure 8 Freshwater use by region, where water use refers to withdrawals for agricultural, industrial and domestic uses [xxi]

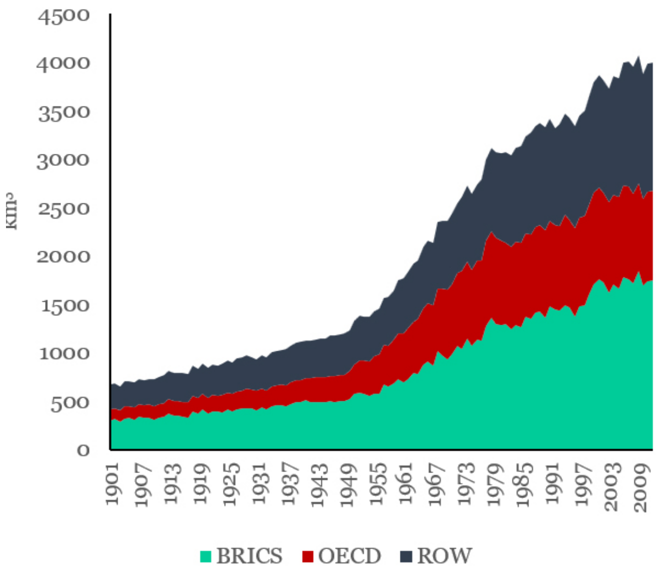


Figure 9 Projected future global water use and supply[xxv]

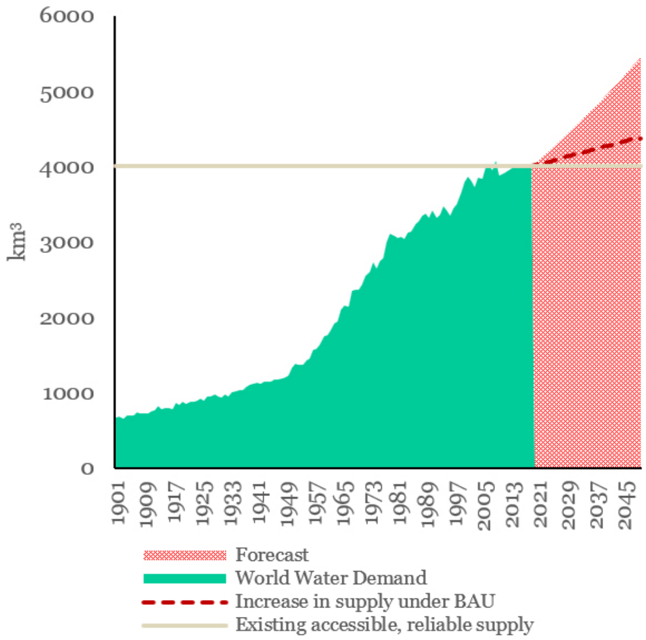


Figure 9 shows future demand and supply. Existing accessible, reliable supply is ~4,000 km3, which could increase to 4,375 km3 by 2050 under business-as-usual infrastructure buildout to improve capture of raw water (and excluding unsustainable extraction). Regardless this results in a demand-supply gap of 24%, which will increase further without productivity and demand improvements[xxvi].

Available surface water resources should remain about constant at continental level, but their quality will deteriorate, changing spatial and temporal distribution. Aquifers will likely shrink, and salt intrusion in coastal areas will be very dramatic[xxvii], necessitating energy-intensive filtration processes to supply safe water.

According to the MIT's Integrated Global System Model Water Resource System (IGSM-WRS), >50% of the world's population in 2050 will be living in water-stressed regions. Population and economic growth will be the socioeconomic factors most responsible for increased water stress, resulting in an additional 1.8 billion people living in increasingly water-stressed areas. 80% of these will live in developing countries[xxviii].

Water is imperative to food and rural development, making the agricultural sector its largest user. Irrigation raises agricultural productivity, particularly in regions where evaporation and transpiration (water loss from crop plants) exceeds precipitation or rainfall[xxix]. This is most prominent in Asia, which contains about 70% of the world's irrigated area[xxx]. The Middle East, South and East Asia, Pakistan, Bangladesh and South Korea irrigate more than half their agricultural area. India irrigates 35% of its agricultural area[xxxi] .

Depending on the technology, consumption can range from 30-40% for flood irrigation to 90% for drip irrigation[xxxii]. The rest recharges groundwater, or contributes to drainage or return flows. This water is often reused, but it has higher salt concentrations and is contaminated with sediments and chemical particles from pesticides and herbicides which can damage the ecosystem.

Self-managed groundwater irrigation has become an engine of agricultural growth in the Asia subcontinent countries, substantially increasing food production by providing farmers with a dependable source of water. However, lack of regulation of this common resource, combined with subsidised fuel or electricity for irrigation pumps, has increased wastefulness.

This creates significant economic impacts on the sector, as well as hindering efforts to tackle issues of agriculture-caused water pollution, fertiliser run-off, and livestock effluents.

Water for the industrial sector covers a large base of related sub-sectors, including industry (construction, manufacturing (steel, cement, glass, DRI, aluminium), mining and petroleum extraction, refining, petrochemicals, medicine, pharmaceuticals, etc.), power generation, and leisure or recreation, and other urban development, such as landscaping.

A large share of the water withdrawn by these uses is returned as wastewater, but often in a highly degraded state necessitating major clean-ups before it can be reused.

Table 1 summarises estimated water consumption and wastewater characteristics for some of the major industrial sub-sectors and the power sector.

"Energy needs water, water needs energy; and these linkages have enormous significance for economic growth, life and well-being."

IEA, World Energy Outlook 2016

Table 1 Water consumption and wastewater characteristics of the power and industry sectors

Sector	Sub-sector		Water Consumed	Uses Embedded Water	Amount of wastewater	Quality of wastewater
Industry	Building Construction		350 L/m^2 of wall construction[xxxiv]	Yes	High	Extremely poor [SSC[1] 100-40,000 mg/L, pH 13][xxxv]
	Manufacturing	Steel	Up to 75,000 gal/tonne[xxxvi]	Yes	High	Very poor [SSC 1000-5000 mg/L][xxxvii]
		Cement	147-350 L/tonne[xxxviii]	Yes	Moderate	Poor [SSC 20-1,590 mg/L, pH 9-10][xxxix]
		Concrete	100-240 L/m^3[xl]	Yes	Moderate	Poor [SSC in the range of cement, pH 11-12[xli]]
		Glass	1 t water per tonne glass	Yes	Very low	Extremely poor [SSC up to 15,000 mg/L[xlii], pH 8.07[xliii]]
		Aluminium	0.28-1.1 gal/lb; for reduction works 1.24-36.33 gal/lb	Yes	Very high	Very poor [due to mixing with red mud, 2 t per tonne of aluminium]
	Gold mining		60,000-100,000 m^3/d for large-scale surface gold mines[xliv]	~	Very high	Poor [SSC 167-700 mg/L, pH 6-8[xlv]],
	Oil & Gas production		3-5 bbl of water per bbl of oil; 30-40 m^3 per m^3 of unconventional gas[xlvi]	~	Very high	Poor [SSC 1100 mg/L[xlvii], pH 3.5-7]
	Refining		1-2.5 gal to refine 1 gallon of gasoline	~	High	Poor [SSC 214.2-1080 mg/L[xlviii], pH 7.3]

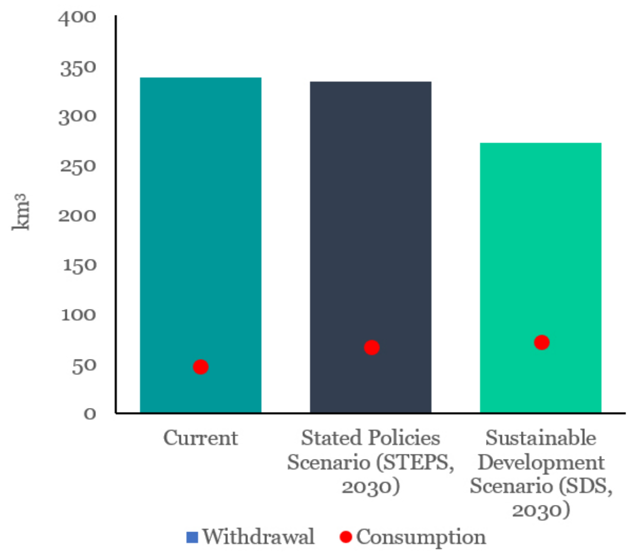
Power	Combined Cycle Gas Turbine	780 L/MWh (with recirculating system)[xlix]	Yes	Moderate	Poor
	Nuclear Power Plant	2,500 L/MWh[l]	Yes	Very high	Very poor, can have a monoethanolamine concentration of up to 7465 mg/L
	Utility-Scale Solar Power Plant	20 gal/MWh (for cleaning solar collection and reflection surfaces)[li]	Yes	Very low	~

The energy sector can be considered part of industry, with many overlapping applications in both industrial and power sector processes. As water supply itself depends on energy, and energy supply on water, they are both part of the same nexus that will ensure a low-carbon, sustainable future.

There is no formal definition for the water-energy nexus, but the concept refers to the relationship between the water used for energy processes (i.e., water intensity), including both electricity and sources of fuel including biofuels, and the energy consumed to extract, purify, desalinate, deliver, heat/cool, treat and dispose of water and wastewater (sometimes referred to as energy intensity). The relationship between water and energy is not always a closed loop, as the water used for energy production may not be the same water that is processed using that energy. However, since all forms of energy production require some input of water, it makes the relationship between the two inextricable.

The energy sector utilises a lot of water for power generation (which varies from source to source), district cooling systems, refining, upstream, midstream, and downstream operations, exploration activities, petrochemicals, biofuels, and petroleum products activities, which amounts to ~9.8% of global water withdrawals (~392 km3). Withdrawals are slated to increase by some 2% by 2040 to reach 400 km3 of water withdrawn, but the amount of water consumed will increase nearly 60% to over 75 km3.

Figure 10 Global water use by the energy sector by scenario[lii]

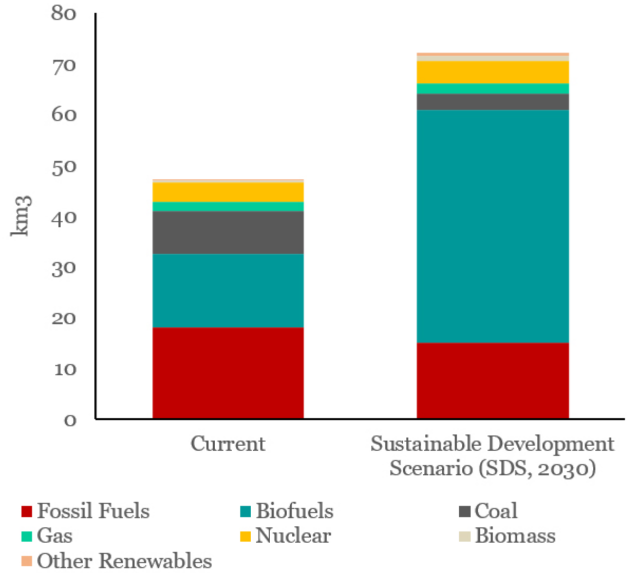


The major contributor to increased consumption will be the power sector, where a switch to advanced cooling technologies that withdraw less water will counterintuitively consume more. Other low-carbon technologies, such as wind and solar PV, require very little water, but others, such as biofuels, solar CSP, engineered geothermal, carbon capture, utilisation and storage (CCUS), and nuclear power are all water-intensive. Nascent technologies like green hydrogen, which is being touted as one of the major solutions to electrify and decarbonise all sectors of the economy, could also become a significant water user.

Water scarcity is already having an impact on energy production and reliability. For example, hydropower output in Africa is being curtailed by increased incidence of droughts due to changes in the water cycle as a result of climate change. Water stress in China, meanwhile, is exerting a material impact on cooling technologies required for thermal, particularly coal-fired power plants. Nuclear plants in France have been forced to shut down during heat-waves because of low river levels and/or limits on the acceptable temperature of cooling water. Low water levels along the Rhine also hinder the delivery of coal and petroleum products by barge. Diminished freshwater resources have increased the reliance of Middle Eastern countries on energy-intensive sources of water supply like desalination, which has significant costs.

Decarbonisation pathways that rely on a major role for biofuels and CCUS could, if not properly managed, exacerbate this water stress in regions that are already lacking in freshwater resources. Biofuels rely on agricultural feedstock for production, which will often require increased irrigation, while CCUS equipment, which carries high expectations as a way to extend the acceptable use of fossil-fuel based power plants and industry, can almost double a plant's water withdrawals and consumption, depending on the cooling technology used.

Figure 11 Global water consumption in the energy sector by fuel type[lviii]



In countries where nuclear energy is a major source of power, both water withdrawals and consumption will remain high because these plants have large cooling needs and cannot always dismiss heat directly into the atmosphere. Nuclear plants typically use water for cooling to convey heat from the reactor core to steam turbines, and to remove and dump surplus heat from the steam circuit. A large difference between the temperature of the internal heat source and the external environment where surplus heat is dumped is conducive to a more efficient process in achieving mechanical work. This is why it is often desirable to place nuclear power plants alongside very cold water, and why they have higher net output in winter than in summer. Siting them in countries with hotter temperatures, therefore, could decrease their efficiencies considerably.

Municipal and domestic uses (personal use) are relatively small compared to the agriculture and industrial (including energy) sectors. Bathroom usage typically makes the bulk of residential use, followed by laundry processes.

In North America, an average family of 4 members can use more than 1,000 litres of water per day at home, with 70% of this amount used indoors. Outdoor water use varies from region to region, depending on a host of factors, such as topography and climate, but on average accounts for 30% of household use (gardens, swimming pools, recreations). In drier regions or places with water-intensive landscapes, this could be much higher.

Per capita residential use in Europe is much lower on the other hand, at about 140-200 litres a person, in response to higher prices, environmental awareness, and smaller gardens and/or little landscaping around their homes.

The GCC countries in the Middle East have some of the highest per capita water consumption rates, at an average of 560 litres per capita per day, compared to a world average of 180 litres per capita per day. This is despite the development of effective water-saving fittings installed in new homes and water tariff revisions. This partly reflects the widespread use of garden irrigation and swimming pools.

But in the surrounding region, the average per capita use rates are undesirably low. For example, the average per capita water use rate in Sub-Saharan African countries is 10-20 litres per person a day, which needs to increase.

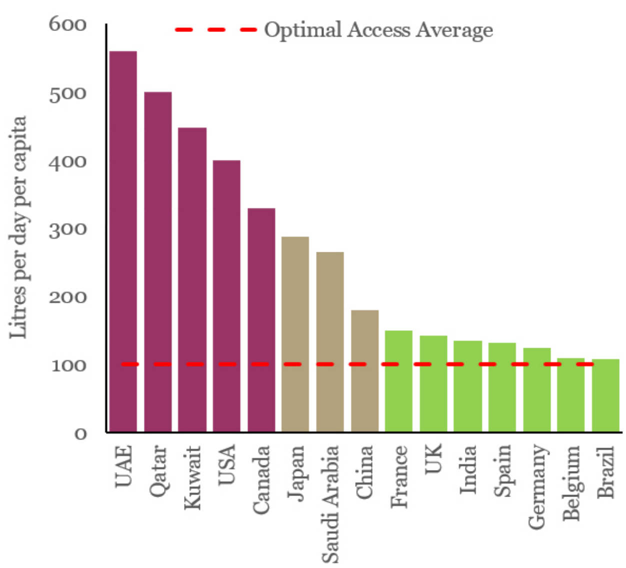
In many larger cities in Asia and Latin America, the total water produced by utilities is very high, from 200-600 litres per person per day, but nearly 70% is lost due to leaks and dilapidated infrastructure.

Another water use, that is not directly linked to human use, is allocations for the environment (ecosystems). Data on the amount of water utilised for ecological restoration is limited, patchy, and mostly related to rivers and water courses of a few large developed and developing markets with higher freshwater resources. Some major ecosystems, typically riverine, have suffered badly from excessive water withdrawals upstream, such as the Colorado River in the USA, the Tigris-Euphrates in Iraq, and the Murray-Darling in Australia.

Nevertheless it shows that when implemented correctly, treated wastewater can be returned to rivers, coastal areas, and small water courses to support restoration, and consequently improve flood control, reduce drainage of wetlands and canalisation of rivers, reduce habitat and biodiversity loss, and return the recreational value of such water bodies.

In desert ecosystems, ecological restoration may look much different, initially requiring supplemental watering for plants to achieve a survival of >50% and re-establish return of animal species. Manipulating soil properties by mixing water with certain forms of fungi can also help form relationships with plant roots that can assist the plant's uptake of water and nutrients.

Figure 12 Daily per capita domestic / residential water use[liv]

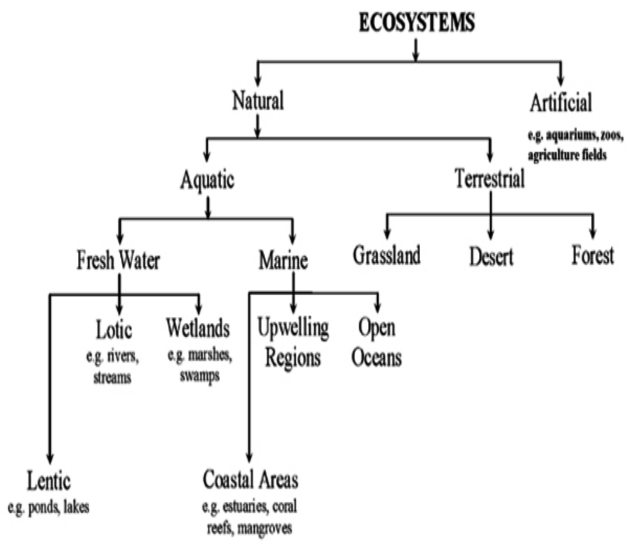


Managing water through irrigation and other methods such as contouring land to create water catchments can also improve ecological restoration. The utility of water management techniques, such as for increasing plant survival, can be assessed in the context of costs versus benefits. For example, if irrigation increases plant survival by only 10%, it might be more economical to simply plant 10% more plants and not irrigate[lv].

Ecological water requirements (EWRs) are therefore a key component of environmental water planning, and depend on understanding the requirements of species at the ecological site. In its simplest form this means protecting the habitat by ensuring the habitat is restored to sufficient quality, and that species have access to it at the right time.

Accurately assessing the risk of water applications to ecological sites is therefore imperative to understand how they will affect ecological end-points. This is a complex process as it needs to consider differences between and within systems, for example, other changes that may be occurring in a catchment due to land uses or climate.

Figure 13 The main types of ecosystems in our biosphere



19 WHAT ARE THE MAJOR WATER CHALLENGES FACED BY DIFFERENT CLIMATE REGIONS?

Table 2 highlights the major water challenges faced by the four major climate regions – polar, continental/mild, arid/dry, and tropical.

Table 2 Major water challenges faced by the world's different climate regions[lvi]

Climate change-related water challenges are not the only challenges some of these regions face. "Hydropolitics" can challenge the availability of and access to water from shared water bodies, such as rivers, tributaries, or seas between countries.

Region	Sub-region	Characteristics	Main water-stressed or water-challenged countries	Examples of water challenges
Polar	Subarctic	• Brief, cool summers; bitterly cold winters • Extreme temperatures (<-30°C in winter to 30°C in summer)	Norway, Sweden	• Drought in Norway due to little rain, snowmelt, and unmodified consumption of water from freshwater sources • Drought in Sweden and constrained water availability (low groundwater levels)
	Tundra	• Subfreezing mean annual temperatures (<0°C for 6-10 months)) • Moderately low precipitation; characterised by permafrost	Above Arctic Circle: Canada, Russia	• Degraded quality of drinking water in Canada partly due to more frequent and extreme damage from floods, droughts, wildfires • West Russia particularly vulnerable to water stress, low agricultural yield due to high levels of contamination from Soviet-era dumping (including radioactive wastewater)
	Polar ice cap	• Extremely cold temperatures throughout the year (average -17°C) • Long polar nights • "Polar desert"	Arctic, Antarctica	• Melting glaciers, decreasing seasonal rates of precipitation, increasing evapotranspiration, and drying lakes and rivers existing in permafrost grounds • Lowland areas flooded with salty ocean water during storms • High turbidity from permafrost-driven thaw
Continental	Mediterranean	• Mild wet winters • Warm to hot, dry summers • Occur on the west side of continents between 30°-40° latitude	Mediterranean Basin, California, Central Chile, Western and South Australia	• Prolonged and intense droughts in Spain; many drylands – 74% of territory at risk of desertification • Extreme droughts in California due to rising temperatures, groundwater depletion, shrinking Colorado river, low precipitation • Declining and more variable inflows into dams and reservoirs in Western Australia
	Temperate	• Moderate rainfall and sporadic drought • Mild to warm summers • Cool to cold winters	Southeast Argentina, Uruguay, southeast portions of East Asia, some regions in USA	• Argentina experienced one of the worst hydrological droughts in 2017-2018 due to constrained freshwater sources • Rapid increase in heavy rain and torrential rain events in southern and central Korean peninsula due to climate change

Arid	Hot desert	• Very high temperatures in summer • Greater evaporation than precipitation • Low humidity	Arabian Peninsula, large parts of Iraq and Iran, northwest India, South Africa, Australia	[illegible] renewable water sources in Saudi Arabia; shallow groundwater near major cities is polluted because of industrial effluent discharge, use of fertilisers in agriculture, and domestic sewerage • Severely contaminated water, water-borne diseases in India and Iraq; exhaustion of groundwater resources in major cities; polluted groundwater; droughts due to low precipitation • Global highest variability in climate and streamflow in Australia
	Cold desert	• Short, moist, and moderately warm summers (21°-26°C) • Fairly long, cold winters (-2°-4°C)	Iran, Turkmenistan, Northern and Western China	• Declining precipitation in Iran, resulting in low agricultural yields and drought; vanishing lakes and pollution • Extreme water stress in Turkmenistan – regarded as 9th most water insecure country in the world • China forced to divert water from comparatively wet regions to drought-plagued north and west; unsustainable agriculture is causing desertification
Tropical	Tropical wet	• Warm temperatures and regular rainfall (>59 inches annually) • Temperature varies more in a day than over a year	Large areas found in Brazil, DRC, Indonesia, Philippines	• 1.2 million people in Brazil lack access to safe water and 20 million are without access to improved sanitation; increasing severity of droughts and 15% reduction in surface water in last 3 decades • DRC has >50% of Africa's water reserves but collapse of infrastructure and pollution has left 33 million people without access to safe water • 18 million Indonesians lack safe water due to pollution of surface and groundwater from heavy rains and flooding; industrial activity
	Tropical monsoon	• Monthly mean temperatures above 18°C in every month of the year and a dry season	Southern and South-Eastern Asia	• Depletion and degradation of water resources due to heavy pollution with domestic sewage and industrial effluents, and in rural areas with agricultural runoff in Pakistan, India, Sri Lanka, and Bangladesh; also Laos and Cambodia • Increased incidence of flash floods and torrential rains, followed by periods of drought in India, Pakistan, Bangladesh
	Tropical wet and dry	• Occurs between 5°-20° latitude • Receives low rainfall	Central Africa countries, Brazil, Central and East India	• Limited access to clean water in CAR due to limited infrastructure and political instability • Severe floods in West and Central Africa due to torrential rains • Extreme rainfall has turned heavier due to extreme weather events

For example, the Nile River basin is shared between Egypt, Sudan, South Sudan, Eritrea, Ethiopia, Kenya, the Democratic Republic of Congo, Burundi, Rwanda, Uganda, and Tanzania, but this has exposed it to a number of regional water use conflicts. There is a long-running dispute between Egypt, Sudan and Ethiopia over a massive hydroelectric dam that is being built on the river, which Egypt views as an existential threat to its water share from the Nile. Ethiopia regards the dam as the only way to bring electricity to millions of its citizens and has for a second year begun to fill up the reservoir behind the dam, threatening to once again disrupt water supply to Egypt and to Sudan, which already has one of the world's lowest per capita per day water usage.

Fact Table 1 What are the main water international organisations and what do they do?

Organisation / Body	Affiliated with / Linked to	Description	Main activities
UN-Water	SDG 6, Paris Agreement	UN interagency mechanism	Coordinates the UN international observances on freshwater and sanitation by informing policies, monitoring and reporting and inspiring action to speed up progress on water issues
World Water Council	SDG 6, High Level Political Forum (HLPF) reviews of SDG 6	International think tank	Promotes awareness, builds political commitment to trigger action on critical water issues at all levels, including the highest decision-making level, to facilitate the efficient conservation, protection, development, planning, management and use of water
Global Water Partnership	SDG 6, specifically indicator SDG 6.5.1 (implementation of Integrated Water Resources Management)	International network for practical advice	Assists governments in designing and implementing country-led responses to SDG 6.5.1 as an entry point to accelerate progress towards the achievement of water-related SDGs
Food and Agriculture Organisation	SDG 6, Paris Agreement	UN specialised agency on food security	Works in tandem with UN-Water to track progress towards SDG 6 targets; works with countries to ensure water use is made more efficient, productive and environmentally friendly; also provides the AQUASTAT database
International Water Association	SDG 6	Professional association (Non-profit organisation and knowledge hub)	Connects interdisciplinary network of water professionals and partners to find solutions to the world's water challenges; subsidiary is IWA Publishing that publishes leading water, wastewater and environmental publications
IEA	SDG 6, Paris Agreement	Autonomous intergovernmental organisation	Provides policy recommendations, analysis and data on the entire global energy sector, including on the water-energy nexus, with a strong focus on sustainability and the Paris Agreement, and on curbing carbon emissions. The IEA published the Water-Energy Nexus report as part of its World Energy Outlook 2016

Another riparian conflict is over the Euphrates-Tigris Basin shared between Turkey, Syria, Iraq, and Iran. Turkey's South-eastern Anatolia Project (GAP), which consists of 22 dams and 19 hydroelectric power plants in the basin is of particular concern to Syria and Iraq, who will likely receive the polluted downstream flow, consequently polluting their own waters. This is particularly troubling for Iraq, who runs into water shortages each year, impacting its power generating operations due to lack of cooling water and its own depleted groundwater and freshwater resources (Shatt Al-Arab river, formed by the confluence of the Tigris and Euphrates rivers).

Other examples are the Colorado River dispute. The river, which traverses seven US states before reaching Mexico is dammed at the border, leaving Mexicans with a dry delta (even though it supplies two Mexican states), which has led to a "megadrought" and crisis in the Rio Grande Valley, threatening displacement of local villagers.

The Indus River basin conflict between India and Pakistan and the Mekong River conflict between China and countries of the Lower Mekong are other major riparian conflicts. Cambodia is one of the most affected by China's activities on the Upper Mekong, which has made the Tonle Sap river in Cambodia flow backward for weeks recently, rather than months, leaving the lake's water warm, shallow, and oxygen-starved.

SOLUTIONS AND POLICIES TO MITIGATE AND REDUCE WATER CHALLENGES

Mitigating the worst impacts of climate change-induced water variability and limiting the incidence of acute, extreme water events like severe precipitation, flooding, or droughts cannot be achieved through unilateral, isolated approaches. Such approaches are limited in their ability to address the inherent complexities involved in water challenges and the actions required to address them.

Instead, overcoming and reducing such challenges requires a concerted, collective effort and wide alliances, between the public sector, the private sector, and civil society. Partnerships are the cornerstone of every effort and endeavour to solve the world's water crisis. In their various forms, they can offer innovative, inclusive, and flexible approaches. They are versatile and adaptable to regional and local contexts, and can tap into a wide range of benefits from considering diverse perspectives, experiences, and knowledge.

Solutions like better climate modelling and forecasting (to track changes in the water cycle and accurately predict adverse weather events or events of extreme water variability); advances on water use efficiency and conservation, reuse, and recycling; technologies to encourage agricultural adaptation (shifting cultivation, growing different crops, or altering irrigation practices) to lessen the sector's use; flood control and wastewater management exercises, storage, and dams; cloud-seeding for exceptionally arid regions; and finding ways to reduce costs and environmental impacts for energy-intensive solutions to water scarcity, like desalination, can all benefit from partnership-based approaches.

Figure 14 An optimal "body of knowledge" around water can result in novel solutions and policies to meet the water challenge

Table 3 Novel solutions and ideas to meet the water challenge

Strategy	Description	Applications / Benefits
Digitalisation for better water management	• Governments and policymakers can collaborate with big data-analytics, real-time and near-real-time monitoring, IoT and ICT developers to establish the relevant legislative framework for their implementation into better water management • Developing a combined "system standard" can enable smart water solutions in line with SDG 6 • Collaborative efforts can be supported through grants and funding to expand their reach through open models/data	• Digitalisation has applicability across all water use sectors • Water quality and quantity monitoring for secure water resources • Safe and resilient water supply across all sectors • Advanced water treatment and automation • Pressure control and leakage detection • Accurate weather real-time and near-real-time monitoring
Governance for sustainable water scarcity measures	• Integrated policies can coordinate sector-specific public actions with R&D and technological strides to validate equilibrium between the economy, the environment, and water supply • Decentralised governance can result in the improvement of water pricing approaches, through new financial and procedural incentives to accurately reflect water demand vs available supply and scarcity	• Decentralised governance measures can match the cross-cutting nature of water across all sectors, helping analyse water scarcity issues through the lens of climate change • Can help foster equitable access and improve risk management arising from climate and weather emergencies
Production and consumption control to allow legal enforcement; Optimising to match water supply and demand	• "Greening" water laws can improve the management and allocation of freshwater resources, thereby helping in realising the objectives of multilateral environmental agreements • Legal enforcement to control over consumption can encourage dispute prevention and possible resolution for riparian conflicts by optimising water demand to availability	• Water use permits and licences • Pollution prevention and abatement standards • Environmental impact assessments • Prioritisation of water allocations for all water consuming sectors • Groundwater exploitation controls for ensuring the viability of dependant ecosystems
Awareness regarding local risks and measures	• Governmental institutions with a specific water mandate should engage in national multistakeholder platforms to foster awareness regarding unique local risks to water security and supply • Sharing specific knowledge about ideas, innovations and solutions can help design ways that mitigate water challenges • Institutions should collaborate with decision-makers, SMEs, industry, graduates, farmers, NGOs, and the general public	• Valuable capacity building on water challenges management • Innovation ecosystems • Strengthen connections to enhance international cooperative networks
Fostering climate change readiness from the perspective of water	• Conventional climate change mitigation strategies focus more on reducing GHG and CO_2 emissions from all sectors, limiting potential of mitigation through water-based strategies • The above strategies can yield tremendous benefits for the environment when applied to water consumption and supply patterns, ecological restorations, and monitoring of water events	• Acting on sustainable water resource management strategies can propel countries and voluntary actors in meeting their climate goals faster than they would by relying solely on decarbonisation and emission mitigation strategies

Water pricing, which is an important metric for exercising public policy, can also benefit from partnerships on proper water management, which itself tends to be highly scale-dependent. Tailored approaches developed jointly between the public sector and civil society for macro-scale usage, such as raw water abstraction, and for micro-scale usage, such as municipal water supply, need to be negotiated at their corresponding demand levels, and within a country, a range of prices, in combination with other instruments. To contribute to sustainable water management, the right water price will need to reflect not only the costs of supply (i.e. service delivery), but also costs related to scarcity (e.g. externalities and opportunity costs).

These solutions and policies can be grouped under a wider "body of knowledge" that is developed through collective public and private sector, and civil society alliances. An optimal "body of knowledge" to drive targeted solutions and policies can include some novel ideas highlighted in Figure 15.

Oil and gas producers have a unique opportunity to cement the water-energy nexus as a pillar of global decarbonisation efforts. Exploration and production companies typically face two obstacles: obtaining water needed for drilling wells and other operations and finding a place to put the wastewater that comes up from the well after oil and gas is extracted. Oilfield water is usually highly saline (more than seawater), and may contain heavy metals, traces of oil and sometimes naturally occurring radioactive materials (NORM).

Oilfield use of water is not much compared to other water use sectors like power generation and agriculture, but still yields significant volumes of wastewater. Oil and gas extraction, along with other mining, makes up ~2% of total water use[lvii]. Oil production in the US yields about 20-30 billion barrels per year[lviii], while worldwide volumes were estimated at 202 billion barrels in 2014 and projected to increase to 340 billion barrels in 2020[lix] . Volumes of produced water are increasing as fields mature. For comparison, US oil-field produced water is equivalent to about 1% of all freshwater and saline water withdrawals in the country[lx].

Reinjection of large volumes of wastewater has been a trigger for major swarms of small and moderate earthquakes, particularly in parts of the USA. In Iraq, secondary recovery for production increases at oilfields requires maintaining reservoir pressures at levels that ensure optimal recovery, necessitating injection of ~1.3-1.5 barrels of water for every barrel of oil extracted , in a country that is already water-stressed.

By implementing cost-effective water management strategies, oil and gas producers can optimise their supply chain operations. They can also utilise effective and efficient water management practices as part of their ESG strategies, especially in countries where they require social licence to operate.

Fracking has increased the overall water use by the oil and gas industry since 2008, which has increased groundwater stress in large shale producing countries like the US, subsequently raising water costs. The average cost of a barrel of water varies by type, but it becomes dramatically cheaper when water is reused. "Produced" water can help save oil and gas companies a significant amount of money, as well as reducing stress on precious groundwater and freshwater resources.

While the move to reuse water is possible today, more technology and investment, and the introduction of regulations is needed for water reuse and recycled water to reach scale. Some of the water solutions that can work for the oil and gas industry include:

1. **Water recycling**
   Treating wastewater to acceptable standards through robust treatment technologies. Oil and gas companies can help alleviate water shortages and create a new resource through recycled water, which could also be used for other industries. Recently, interest has grown in extracting lithium, a crucial material for batteries, from oilfield brines[lxii].

   In arid countries, it can also be utilised to "green the desert". In Oman, research is underway to assess the viability of utilising produced water from southern oilfields for the farming of palm trees and growing algae in large ponds[lviii].

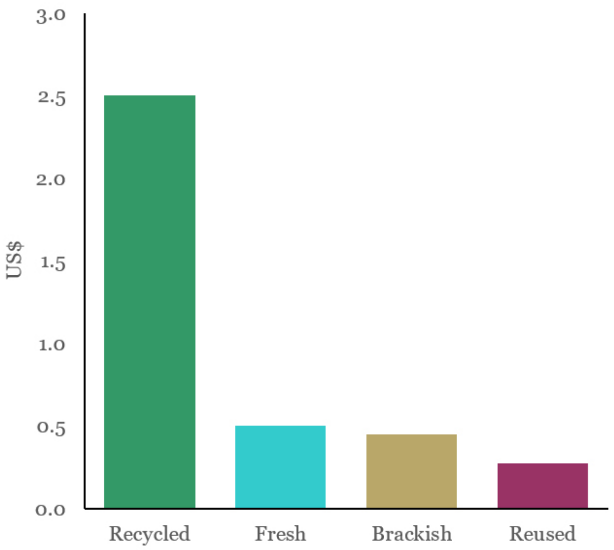
2. **Pipelines versus trucking**
   Reducing transportation costs will inevitably drive investment in pipeline infrastructure for both produced water and freshwater. Although building pipeline infrastructure carries a high upfront capital cost, it reduces operating expenses down the line.

3. **Wastewater reuse**
   Wastewater can be reused easily within a well, which requires very little additional treatment. Reuse alone could lower water-related costs by ~45%, and save 250-500 kbbl of fresh water per well[liv].

4. **Partnerships**
   New opportunities for collaboration will help create sustainable solutions for water management. Farmers can use recycled water from oil and gas producers for irrigation on non-food crops.

5. **Industry guidelines and regulations**
   Clear and standardised regulations on water management and reporting for the oil and gas industry is crucial. Governments should enable shared learning, encourage cross-industry collaboration, and carve funding of new technologies for smaller players.

Figure 15 Average water costs for oil and gas completions in the Permian[lxv]



CONCLUSION

The global climate crisis is not the sole threat to freshwater resources. However, the crisis further exacerbates existing conditions, making the management and projection of future water availability and quality increasingly difficult, and demanding new strategies to ensure security and reliability of supply.

Mitigating the worst impacts of climate change-induced water variability and limiting the incidence of acute, extreme water events like severe precipitation, flooding, or droughts cannot be achieved through unilateral, isolated approaches. Risk and ecosystem-based management approaches developed in collaboration with a wide variety of actors can ensure adoption of "low regret" solutions that can be better adapted over time as underlying conditions change.

Finer scale and more flexible demand management approaches alone might not be sufficient to adequately eliminate the trade-offs made in situations of water scarcity – improving the resilience of our freshwater ecosystems is therefore essential to adaptation. A unique opportunity exists to transform existing governance and management systems, and to increase coherence of global frameworks to bring about a sustainable future. All it requires is conviction, and the joining of hands across all sectors to be realised fully.

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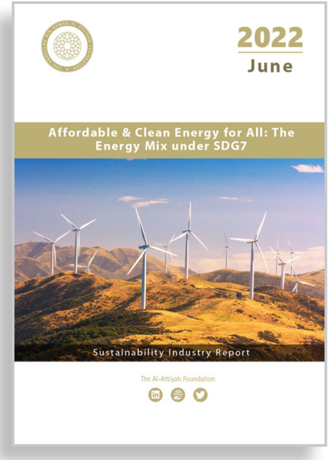

June - 2022

Affordable & Clean Energy for All: The Energy Mix under SDG7

Sustainable Development Goal 7 (SDG7), which is among the 17 UN SDGs established in 2015, aims to "ensure access to affordable, reliable, sustainable and modern energy for all by 2030." Despite reasonable progress between 2015 and 2020, advances seem to have stalled, creating concerns that success by 2030 is out of reach.

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May - 2022

Invisible Menace: What Will it Take to Implement the Global Methane Pledge?

At the 2021 United Nations Climate Change Conference, more commonly referred to as COP26, over 113 countries signed the Global Methane Pledge to reduce their emissions 30% by 2030.

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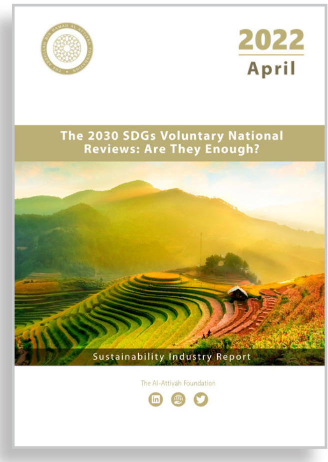

April - 2022

The 2030 SDGs Voluntary National Reviews: Are They Enough?

The 2030 Sustainable Development Goals (SDGs) agenda provides for regular Voluntary National Reviews (VNRs) to assess progress on achieving the SDGs. These have been conducted since 2016, with a growing number of countries participating.

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