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A local water-energy equation

Introduction to the Water and Energy Challenge

A.T. Kearney Energy Transition Institute
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Compiled by the A.T. Kearney Energy Transition Institute

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About the “ Energy Transition Series”

This is a ” is a series of publicly available studies on low-carbon energy technologies conducted by the A.T. Kearney Energy Transition Institute that aim to provide a comprehensive overview of their development status through a technological and scientific prism.

About the FactBook - Introduction to the water and energy challenge

This FactBook seeks to provide a global picture of the main water resources, the many dimensions of freshwater inequality challenges, and current uses of freshwater. It then presents an overview of the current and forecast mismatch between supply and demand, the reasons for the mismatch and its likely consequences if left unaddressed. The FactBook then summarizes the water risks facing our society and their multi-dimensional nature. It also describes the water industry’s principal value chains, market trends, and promising solutions. Finally, it compares water consumption for different energy-production pathways and illustrates the impact water constraints have already had, and continue to have, on the development of conventional and unconventional resources.

About the A.T. Kearney Energy Transition Institute

The A.T. Kearney Energy Transition Institute is a nonprofit organization. It provides leading insights on global trends in energy transition, technologies, and strategic implications for private sector businesses and public sector institutions. The Institute is dedicated to combining objective technological insights with economical perspectives to define the consequences and opportunities for decision makers in a rapidly changing energy landscape. The independence of the Institute fosters unbiased primary insights and the ability to co-create new ideas with interested sponsors and relevant stakeholders.

Accessible, reliable, sustainable and usable freshwater amounts to just ~0.0003% of total water reserves and is unevenly distributed

The total volume of freshwater is finite (~35 M km3: 2.5% of the 1.4 Bn km3 of global water resources), remains globally constant in various forms in the water cycle, and exists largely in the form of unusable glaciers and groundwater. Only ~200,000 km3 (~0.6% of total natural freshwater resources) are usable by humans and ecosystems, according to one frequently quoted figure. However, only about 2% of this potential resource is actually accessible, reliable and sustainable (~0.01 of global freshwater resources and ~0.0003% of global water resources).

Water resource inequality is a local challenge that is not simply a function of physical availability. It is more complex and should be examined in its many dimensions:

Freshwater availability is the physical quantity of freshwater available in each region/country and is sometimes measured on a per capita basis. At the country level, freshwater reserves are unevenly spread geographically, with the top-10 water-rich countries cumulating ~62% of freshwater supply. Per capita imbalances are further exacerbated by extremely low natural supplies of renewable water and/or a mismatch between the size of the population and its water supply.

Freshwater stress can be measured as an absolute water quantity or as a relative ratio of water withdrawal to available resources. Both indicators reveal that ~64% of the population is vulnerable to water stress and that, globally, the proportion of the population (and the share of GDP) under high water-stress are forecast to increase significantly.

Access to freshwater/improved drinking-water sources (protected from outside contamination) can be limited locally even in countries with sufficient supply.

Water footprint is an indicator of both direct and indirect freshwater use embedded in goods and services, quantifying the water intensity of different products, and the types of water used to produce them.

Virtual water measures the freshwater used in the production and trade of a commodity/product & is used to quantify indirect trade in water associated with the movements of goods around the world.

Source: A.T. Kearney

Agriculture currently withdraws ~70% of freshwater globally. Population growth is expected to create a gap between supply and demand by 2030. This is forecast to average ~40% globally but will be subject to significant regional variations

At the sector level, agriculture withdraws ~70% of global freshwater withdrawal, but industrial withdrawal dominates in Europe and North America. On a per capita basis, stark water-usage differences exist between developed and developing countries, highlighting disparities in industrialization and domestic water use levels.

Freshwater withdrawal (i.e. demand) is forecast to surpass reliable accessible supply by ~40% globally by 2030 both as a result of falling supply and rising demand. The threat of such a large deficit must be urgently addressed. Supply is falling largely because of excessive use and pollution. This is expected to remain the case, exacerbated by rising temperatures and atmospheric concentrations of CO2, both of which will affect the quantity and quality of water available. Rising water demand is the result of population and economic growths, urbanization, and increases in the production of food (plus changing diets), animal feed, fiber and biofuels.

For the last 100 years, water demand has risen at twice the rate of population growth; ~90% of the 2.59 Bn population growth forecast by 2050 will occur in Africa and Asia, which are already facing severe water challenges. Furthermore, since 1997, the domestic sector’s freshwater withdrawal has risen twice as fast as industrial and agricultural demand, with each sector exhibiting significant regional variations.

By 2030, about 60% of the mismatch may remain unaddressed, leading to depletion of fossil (non-renewable) reserves, drainage of water vital for the environment, or unmet demand. In several Middle East and North Africa (MENA) countries, a large fraction of demand (70-90%) is already unmet and the average figure for this unmet demand across the MENA region could increase from 16% (2000-09) to ~50% by 2040-50.

Finally, water challenges are local. Competition for water resources among economic sectors, domestic/international geographies, and between rural and urban environments will intensify. There is no single freshwater crisis, as different regions/countries face very different water constraints (and will continue to do so). There are local in nature and should be treated as such. Generalizations should thus be treated with caution.

Source: A.T. Kearney

Water risks constitute environmental, social, and economic constraints that will require global and local compromises

Water risks are often considered purely in terms of water quantity or quality. However they exist in numerous others dimensions, such as geographical location, changing availability over time, reliability and the water price. Societal, cultural, regulatory and reputational dimensions must also be considered in order to build a complete picture of the magnitude of water risks and their potential consequences. This FactBook considers only a few of the multiplicity of water risks.

Water pollution causes are numerous and can result in water being not only unfit for human consumption, but also for industrial and agricultural uses.

Floods, storms, and droughts have severe security, health, environmental, and economic consequences.

Human health is both directly and indirectly affected by poor water quality, which is the cause and/or the vector of diseases responsible for millions of fatalities. Increased access to sanitation and improved water sources (protected from outside contamination) are vital for reducing the impact of water-related diseases. For instance, unsafe water supply and sanitation resulted in 1.8 million premature child fatalities in 2012, especially in low-income countries, where diarrhea’s impact on children under 15 is greater than HIV AIDS, malaria, and tuberculosis combined.

Social impacts associated with the availability of freshwater are well-documented and date back to conflicts that are thousands of years old. Freshwater has been at the root of numerous conflicts, either as the source (limited supply or limited access to water has caused many disputes, motivated by economic and social development); the target (of military actions by nations or violence/coercion by non-state groups); and/or as a military or political tool, and even for the purposes of terrorism (water resources or systems can be used as a weapon or a political tool by state or non-state actors).

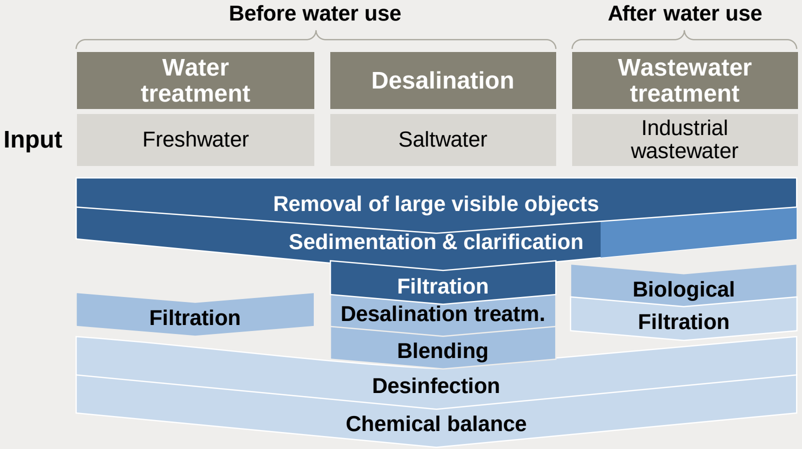
Energy development in the Middle East and China is considered at risk because of the lack of water.

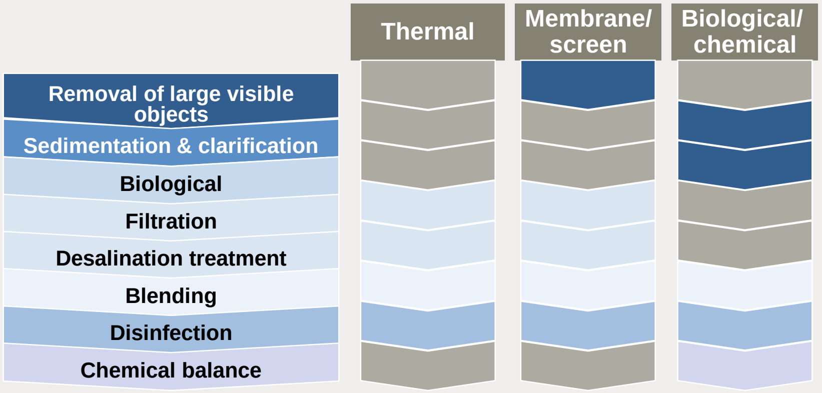
Water and energy are highly interconnected and their relationship is, and will remain, under stress. The close links between water, energy and land resources means strong demand for one can limit demand for the others. Challenging compromises will need to be made globally and locally. For instance, increased water scarcity by 2030 could cause annual losses in global grain production of ~30% at a time when food production will need to increase by 70-100% . In addition, the fastest-growing economies will see a sharp rise in energy/industrial demand, which is problematic because they are currently allocating, on average, 60-90% of their water to agriculture.

Source: A.T. Kearney

The water value chain is complex & fragmented among various industries but shared technologies exist across the water, wastewater treatment, & desalination sectors

The water value chain spans across various industries and incorporates a myriad of technologies, mostly developed after the 1950s. Water treatment, wastewater treatment and desalination are the most technology-intensive parts of the water sector value chain





The wastewater treatment and desalination value chains consist of the same processes (sedimentation, filtration, disinfection etc..) as water treatment with specific additional processes (respectively, biologically activated sludge treatments, and desalination plus blending)

Most sub-processes in these sectors involve membrane, chemical and/or thermal treatment, depending on the technical characteristics, quality of the input/output, and/or cost

This FactBook provides a brief introductory overview of the main water treatment technologies, but does not cover transportation and storage technologies. Energy is also a key requirement in water systems, mainly for water treatment and pumping. Water (mostly hydropower) is also an important source of electricity and accounted for ~16% of the global generation mix in 2011 (3490TWh)

Source: A.T. Kearney

There are various solutions to water challenges, which come at a range of costs and will be required in varying combinations by different geographical areas

Between 1990 and 2010, the water sector in Europe and North America underwent rapid privatization and there is significant potential for further privatization in Asia and MENA.

For individual consumers, the price of water is highly dependent on the water-distribution channel and the geographical location of the consumption center. Water prices often do not reflect the real cost of producing and supplying water, encouraging wastefulness. Some water-scarce countries charge much less for water (it is free in India, and cheap in China and Mexico) than water-rich ones (the UK, Denmark, France).

Solutions or adaptation strategies will involve decreased demand and/or increased supply.

Reductions in water demand can be achieved in:

Agriculture, as a result of increases in yields (no-till farming, improved drainage, optimized fertilizer use), utilization of best available seed types, crop stress management and advanced irrigation techniques.

Both industry and domestic supply, as a result of efficiency, conservation/re-use/recycling, regulation, substitution (economic activities switch, virtual water import), and/or increases in water prices.

Water supply can be increased by improving existing infrastructure, alternative supply (desalination, wastewater treatment), long-distance transportation, and storage. Water reuse and desalination both have a large potential for growth but, combined, still supply less than 1% of freshwater withdrawal globally. Renewable desalination is promising in MENA. And reuse has advantages over desalination, but should focus on high-value uses (where water is sold to meet industry and/or domestic demand).

Finally, cost estimates for solutions to increase supply and decrease demand vary significantly in the literature. The costs of various solutions will be specific to local settings and the chosen technology. Generally, efficiency measures are cheaper than improvements to traditional water-supply infrastructure, which is itself much cheaper than desalination, even with forecast efficiency improvements. And the mix of solution to fill the 2030 supply-demand gap will vary drastically from one location to another.

Source: A.T. Kearney

The constraints imposed by water supply have already affected the development of conventional and unconventional resources and continue to do so

Water & energy flows are complex & interconnected. In the U.S., thermoelectric cooling withdraws the largest volume of freshwater, 526 mn cubic meters per day (Mm3D) [139 bn gallons per day (BGD)], representing ~43% of total withdrawal. Total U.S. freshwater consumption equals 439 Mm3D [116 BGD], of which 363 Mm3D [96 BGD] (~80%) is consumed by agriculture. The petroleum sector (including hydraulic fracturing), only consumes a small fraction: 4.5 Mm3D [1.2 BGD] (~1%) for water flooding and enhanced oil recovery and 0.8 Mm3D [0.2 BGD] (~0.2%) for hydraulic fracturing in oil and natural gas.

Water is used (withdrawn and/or consumed) at different stages of the oil and gas, nuclear, coal, and concentrating solar power (CSP) energy-production pathways: extraction & production, processing, and thermal electricity generation (mostly cooling). Thermoelectric cooling is by far the largest fraction of total life-cycle water consumption (per unit of energy produced). For the scenarios considered, conventional and unconventional gas have, on average, a smaller ratio of water consumed per unit of energy produced (consumptive life-cycle water intensity or median life-cycle water consumption per unit of energy produced) than CSP, nuclear, and coal. When used for transport and heating, conventional and unconventional oil consume the least water per unit of energy because they do not involve a cooling stage.

Water constraints have already had a critical impact the energy sector globally, and continue to do so. Over past 10 years, numerous events have demonstrated the significant impact water constraints have on energy production: high-temperature freshwater, scarcity of freshwater or excess of it frequently impose constraints on energy production (e.g. reduce/shut-down of thermoelectric production to stay within thermal discharge limits). This affects all energy systems and economic regions. For example:

93% of onshore oil reserves in the Middle East are located in medium-to-extremely-high-risk areas in terms of overall freshwater quantity. Inadequate water infrastructure is already constraining asset develop., causing project delays and giving rise to add. costs.

50% of proposed Chinese coal power-generation capacity will be located in high-to-extremely-high water-stress regions (58% of existing coal mines and coal-fired power plants already are).

U.S. CSP and photovoltaic (PV) development may be constrained by a lack of water, particularly in California and New Mexico.

Shale resources are unevenly distributed around the globe

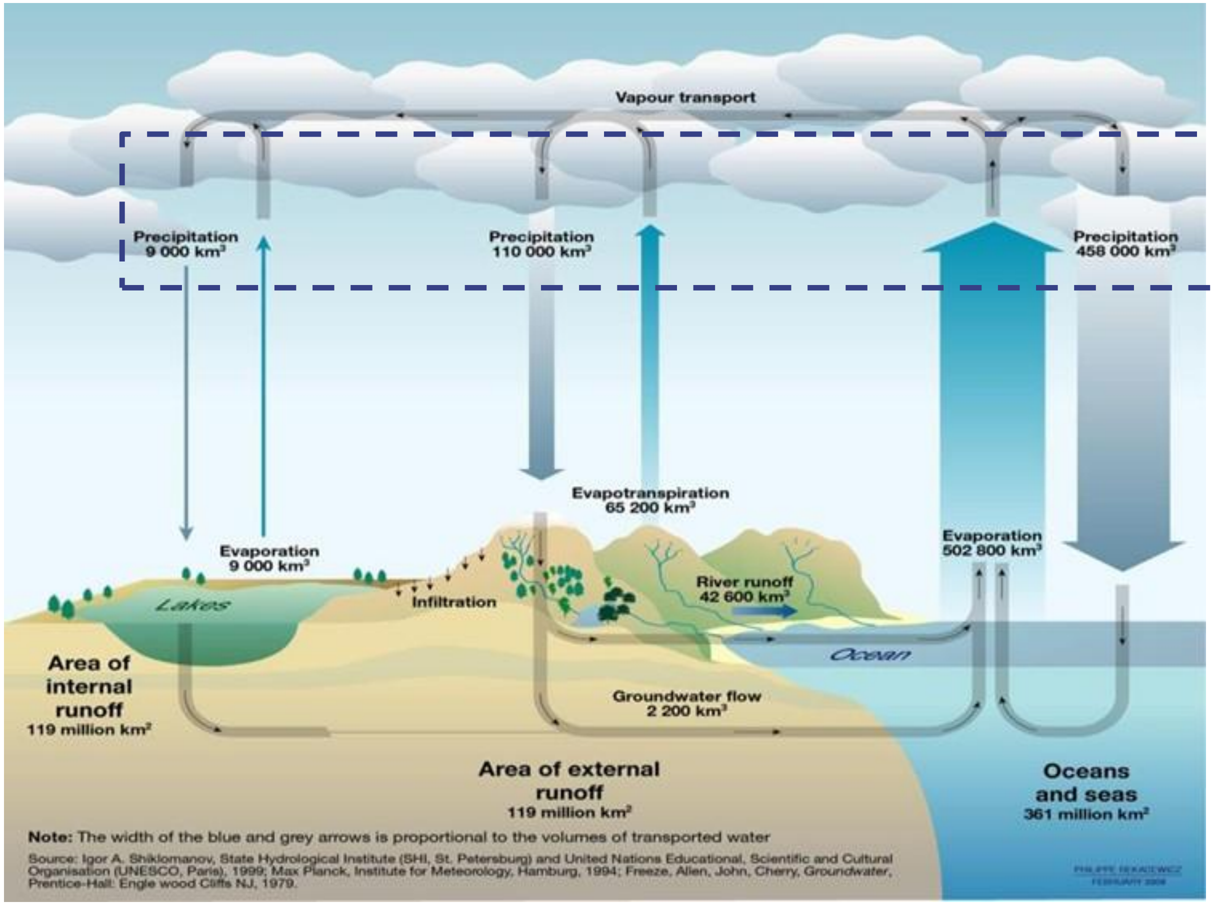
Shale resources are unevenly distributed around the globe, and most are located where freshwater is scarce. China’s shale gas is mostly located in densely populated regions with high-to-extremely-high water stress, where water use is dominated by agriculture. Hydraulic fracturing developments in the U.S. are located in medium-to-extremely-high water-stress regions. Water for hydraulic fracturing can be drawn from a variety of sources (surface water, groundwater, recycled flowback/produced water from previous frac operations). However, recent advances in frac’ing could result in 100% of freshwater being replaced with produced water. Well integrity is one of the main risks associated with shale-gas development, but it is not specific to frac operations. To address these risks, mitigation measures and industry standards have been developed and applied to ensure zonal isolation of wells through proper cementing & well casing practices, and to contain fracture propagation within the producing formations. Hydraulic fracturing increases conventional gas’s median life-cycle water consumption per unit of energy produced by 2-22%, depending on plant configuration.

Table of Contents

1. Water atlas – a global picture of the water cycle and resources

The natural water cycle provides a constant volume of freshwater every year

Hydrological Cycle schematic



Note: The width of the blue and grey arrows is proportional to the volumes of transported water

Source: Igor A. Shiklomanov, State Hydrological Institute (SHI, St. Petersburg) and United Nations Educational, Scientific and Cultural Organisation (UNESCO, Paris), 1999; Max Planck, Institute for Meteorology, Hamburg, 1994; Freeze, Allen, John, Cherry, *Groundwater*, Prentice-Hall: Engle wood Cliffs NJ, 1979.

Freshwater flow	577,000 km^3/year

- **Water exists in a variety of forms** (vapor/liquid/ice) at the surface or underground. Water flow is recycled through a coordinated hydrological cycle.
- There is **no creation of "new water":** each year ~577,000 km^3 of freshwater circulates through the water cycle. The **volume of freshwater** under various forms **remains roughly constant** in the natural hydrological cycle.

Note: Picture credits: UNEP (2008).
Source: UNEP (2008), "An Overview of the State of the World's Fresh and Marine Waters"

Water withdrawn is either “consumed” or “discharged”, with different consequences for local water stock

Water use classification and Impact on local availability

Withdrawal

Water taken from its source (lake, river, aquifer, etc.) for a specific use

Takes both fresh and non-fresh water stock and supply[1]

Proportion highly variable

Consumption

Water not returned to the immediate environment, often as a result of evaporation

Reduces either the quantity or quality of the water that is available to the local environment

Polluted discharged water is “in effect” consumed and can result in further pollution (thermal, toxic, chemical) of water body it is discharged into.

Discharge

Water returned in the same physical state to the local environment (not necessarily at the same temperature)

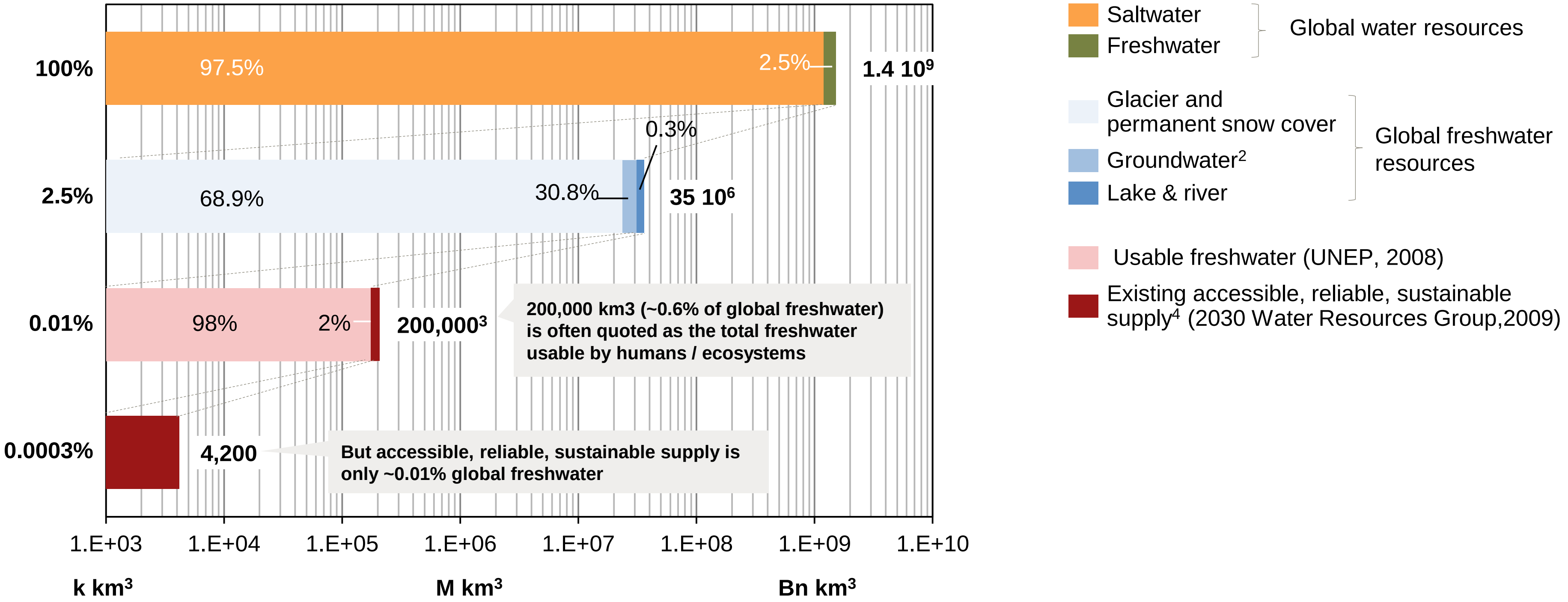
Releases freshwater (not polluted) then available for other uses/the environment

Note: Picture credits: The Weather Channel; National Geographic; Humboldt State University; 1 Non-fresh water incl: sea water, saline groundwater, municipal and industrial wastewater, oil and gas produced water and recycled injected water; Freshwater includes: surface and non-saline groundwater and desalinated salty water or treated wastewater.
Source:OECD (2012), “Environm. Outlook to 2050”; Aquastats (2012), “Disambiguation of water statistics”, Kenny et al. (2009), "Estimated Use of Water in the United States in 2005 USGS"

Accessible, reliable, and sustainable supplies of freshwater represent ~0.0003% of global water resources

Breakdown of global water resources

(% global water in km³, Log scale¹)



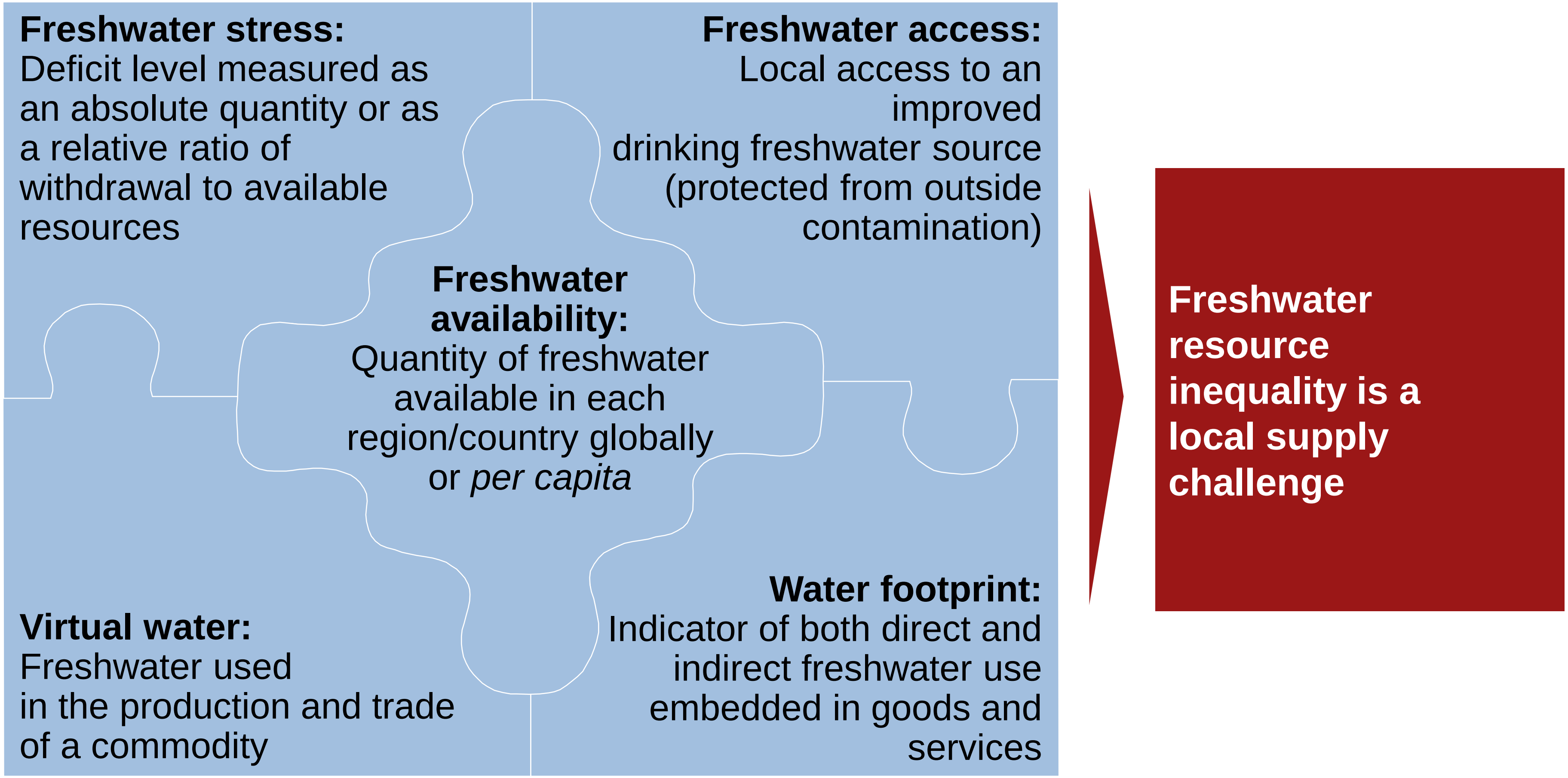
200,000 km3 (~0.6% of global freshwater) is often quoted as the total freshwater usable by humans / ecosystems

But accessible, reliable, sustainable supply is only ~0.01% global freshwater

1. The segments representing small percentages at the right-hand end of the first three bars have been enlarged for readability purposes; 2. Groundwater incl. shallow & deep groundwater basins up to 2,000 meters, soil moisture, swamp water and permafrost; 3. Renewable internal freshwater resources (internal river flows and groundwater from rainfall in a country), which amounted to 42,369 km3 worldwide in 2011 (World Bank database), represent another theoretical upper limit for the water that can be withdrawn from natural systems but in practice accessible, reliable, sustainable supply is far lower (~4,200km3); 4. Existing supply that can be provided at 90% reliability, based on historical hydrology and infrastructure investments scheduled through 2010; Net of environmental requirements, and excluding use of fossil (nonrenewable) groundwater reserves not sustainable in the long term.

Source: UNEP (2008), “An Overview of the State of the World’s Fresh and Marine Waters”; 2030 Water Resources Group (2009), “Charting our water future”; A.T. Kearney Energy Transition Institute analysis

5 dimensions of freshwater resource inequality highlight the local nature of its supply challenge



Freshwater stress: Deficit level measured as an absolute quantity or as a relative ratio of withdrawal to available resources

Freshwater access: Local access to an improved drinking freshwater source (protected from outside contamination)

Freshwater availability: Quantity of freshwater available in each region/country globally or *per capita*

Virtual water: Freshwater used in the production and trade of a commodity

Water footprint: Indicator of both direct and indirect freshwater use embedded in goods and services

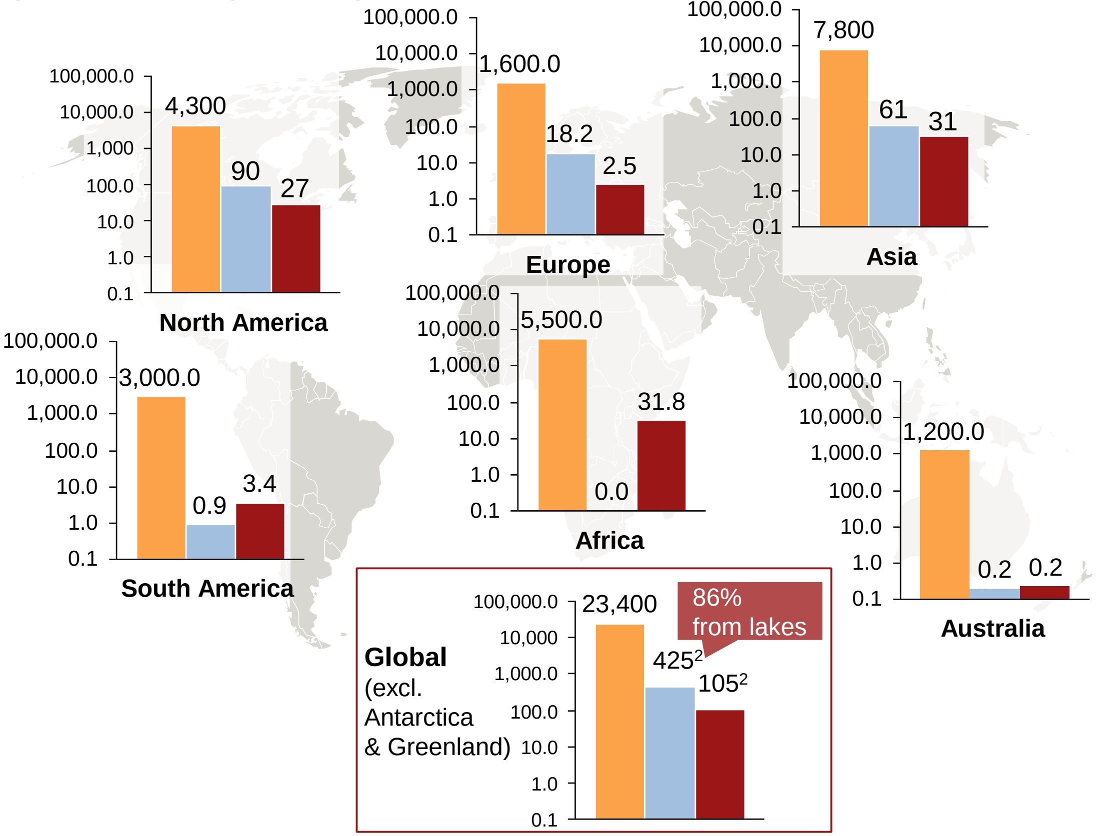
Freshwater resource inequality is a local supply challenge

Source: A.T. Kearney Energy Transition Institute analysis

Freshwater resources are unevenly distributed and divided into 3 main types

Map of available Freshwater by region and by type

(10^3 km^3, log scale)



🟧 Groundwater¹ 🟦 Glaciers and permanent ice caps 🟥 Wetlands, large lakes, reservoirs and rivers

Antarctica	21,600		**Antarctica & Greenland 68%**
Greenland	2,340		
Ground ice/permafrost	300	425	**Other glaciers/ ice ~1%**
Arctic islands	84		
Mountain glaciers	41		
Fresh groundwater	10,530		**Underground 30%**
Freshwater lakes	91	105	**Surface <1%**
Wetlands	12		
Rivers (as flows on Ø)	2		
In biological matter	1		
Atmospheric vapor (on Ø)	13		
Total freshwater (10^3 km^3)	**35,013**		

Excluding Antarctica and Greenland, groundwater dominates global freshwater resources

- 68% of all freshwater is in Antarctica and Greenland
- Groundwater resources account for 30% of all freshwater, although less than 1/2 of groundwater resources are fresh.
- The remaining 2% of freshwater resources are in other glaciers and in surface freshwater (~86% of surface freshwater is in lakes, mostly in Canada/ US, Africa and Asia; rivers account for ~2%)

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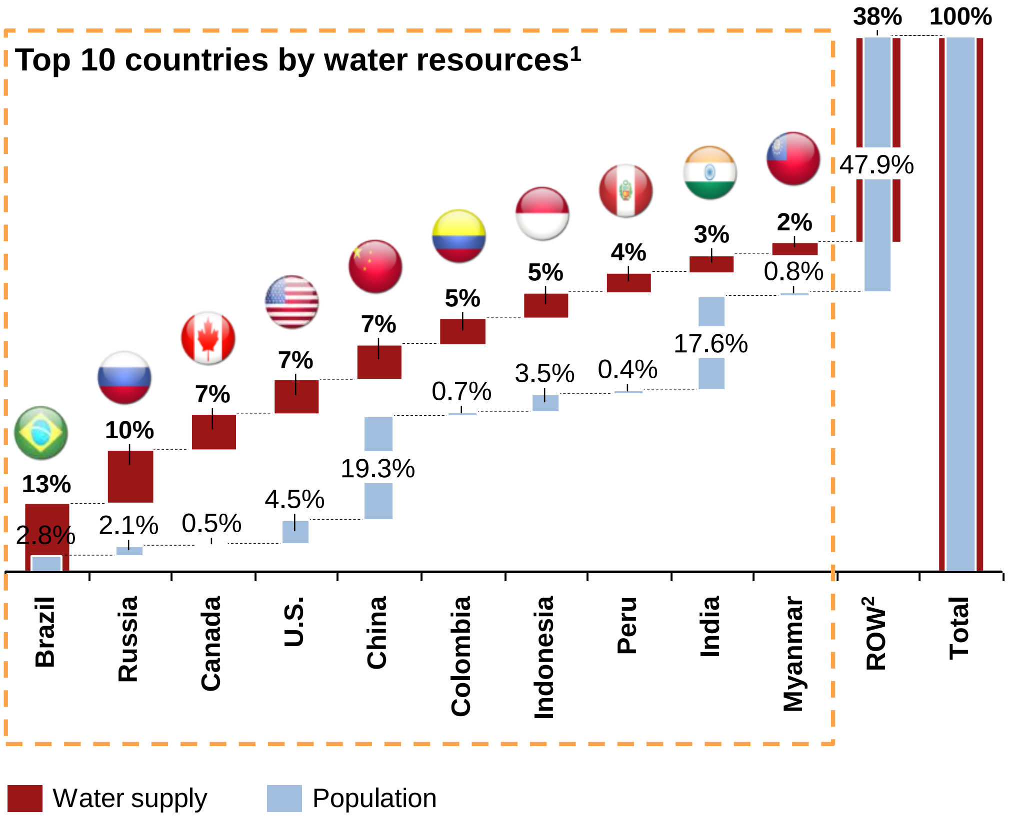
1. Global estimates indicate thatn ~55% of groundwater worldwide is saline and 45% fresh; 2. There is an inconsistency in the 2008 study between the global split by water type and the split by continent (glacier/ice and wetlands/lakes figures add up to 170 and 96 km³ in the split by continent).

Source: Adapted from Philippe Rekacewicz, UNEP/GRID-Arendal (2008), based on: Igor A. Shiklomanov, State Hydrological Institute, St. Petersburg and UNESCO, Paris (1999); World Meteorological Organisation (WMO); Intern. Council of Scientific Unions (ICSU); World Glacier Monitoring Service (WGMS); US Geological Survey (USGS); A.T. Kearney Energy Transition Institute analysis

10 countries share ~62% of freshwater resources and account for ~52% of global population

Freshwater resources per country (2012)

% of total renewable internal freshwater[1]



The uneven distribution of freshwater globally presents acute challenges at the local level:

- The 10 countries with the largest water reserves possess ~62% of global freshwater resources and account for 52% of the world population. The 80% (171) water-scarcest countries share only ~10% freshwater of supply yet account for 30% of the world population.
- The stark uneven distribution is evident at the regional/local levels, and presents significant risks. Examples of regions that exhibit such variations include:
  - The arid, drought-prone southwest U.S. compared with the country's relatively water-abundant northeast (great lakes region);
  - China's wet south and dry north regions.

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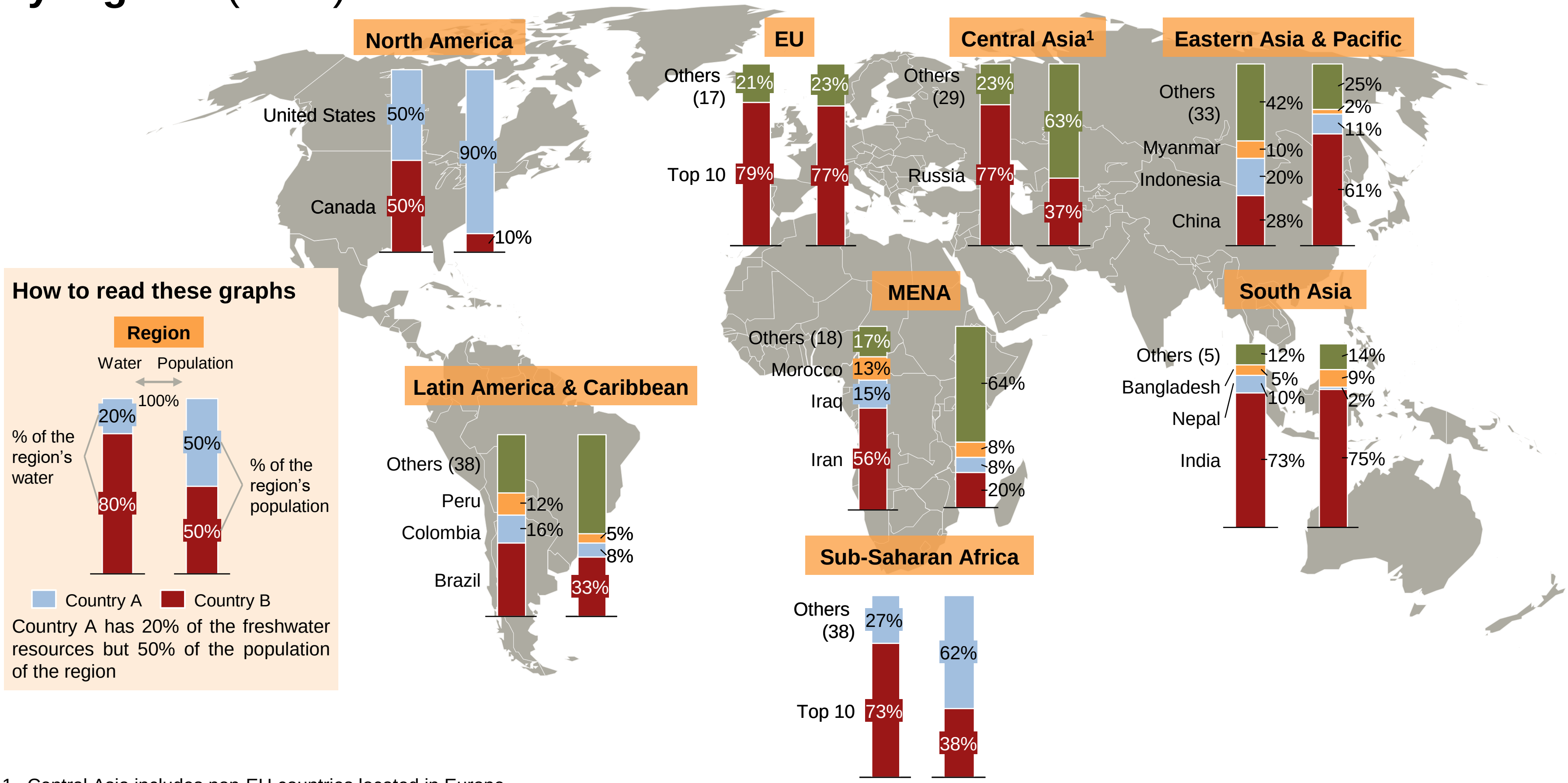
1. Renewable internal freshwater resources refer to internal river flows and groundwater from rainfall in each country. These resources amounted to 42,369 km3 worldwide in 2011, and ranged between 42,227 km³ and 42,982 km³ between 1992 and 2007; these figures represent a theoretical upper limit for the water that can be withdrawn from the natural systems but in practice is reduced to accessible, reliable, sustainable supply (see 2030 WRG 2009 report and slide 12); 2. ROW: Rest of the world.

Source: Goldman Sachs (2013), "Sustainable growth: Taking a deep dive into water"; World Bank World Development Indicators database (accessed 2014, data 2012); 2030 Water Resources Group (2009), "Charting our water future"; A.T. Kearney Energy Transition Institute analysis

In most regions, renewable freshwater distribution does not match demography

Renewable freshwater resources and Population breakdown by regions (2012) %



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1. Central Asia includes non-EU countries located in Europe.

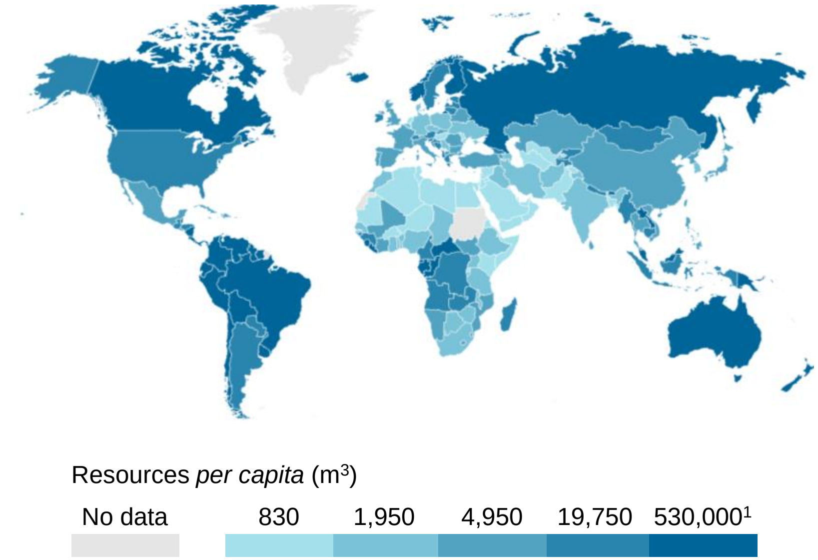
Note: Renewable internal freshwater resource flows refer to internal river flows and groundwater from rainfall in the country. It amounted worldwide to 42,369 km3 in 2011 and ranged between 42,227 and 42,982 between 1992 and 2007.

Source: World Bank World Development Indicators database (accessed 2014, data 2012); A.T. Kearney Energy Transition Institute analysis

Per capita imbalances are another indication of the local nature of freshwater inequality challenges (1/2)

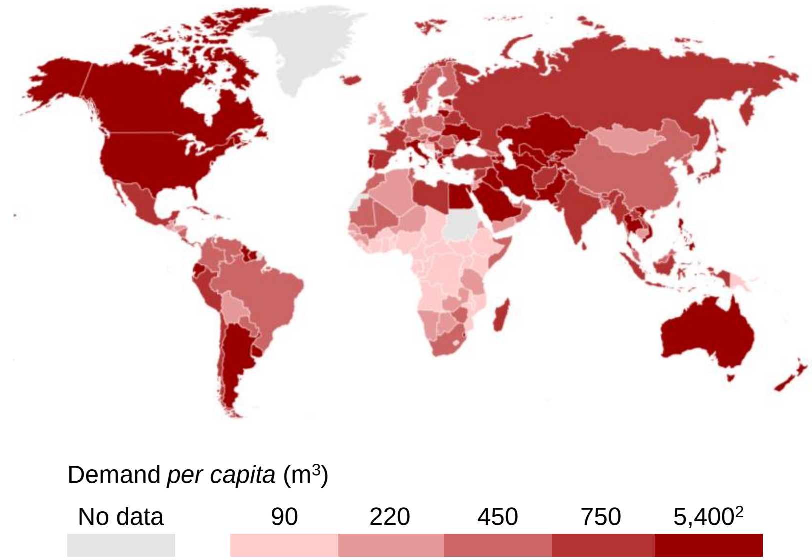
Water supply per capita (2012)

m³/capita



Water Demand per capita (2012)

m³/capita



Imbalances are exacerbated on a *per capita* basis. The top-10 water-rich countries have on average ~220 times more supply *per capita* than demand, whereas demand is on average ~6 times larger than supply in the 10 water-scarcest countries. **Many countries face severe freshwater availability challenges** due to extremely low levels of natural renewable freshwater (*e.g.* MENA), or a mismatch between population size and water supply (*e.g.* China/India have respectively 19.3%/17.6% of the population with 6.6%/3.4% of water supply). The extreme natural variability of rainfall geographically exacerbates these imbalances

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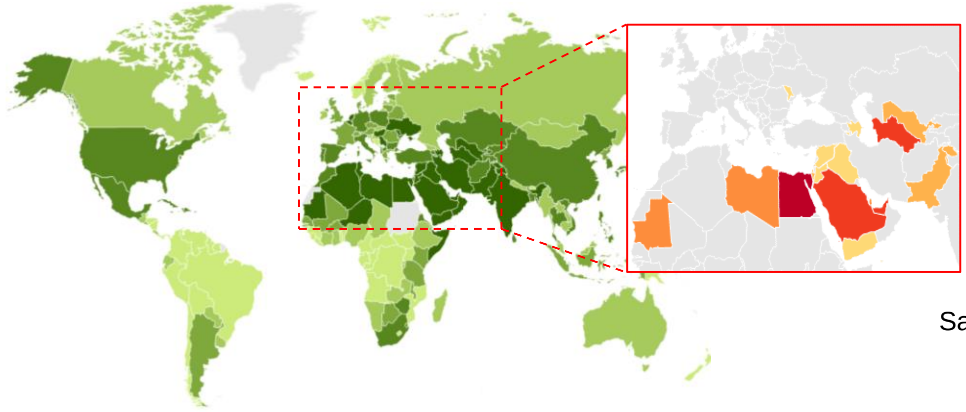
1. Iceland supply per capita; 2 Turkmenistan water demand per capita.

Source: World Bank World Development Indicators database (accessed 2014, data 2012); A.T. Kearney Energy Transition Institute analysis

Per capita imbalances are another indication of the local nature of freshwater inequality challenges (2/2)

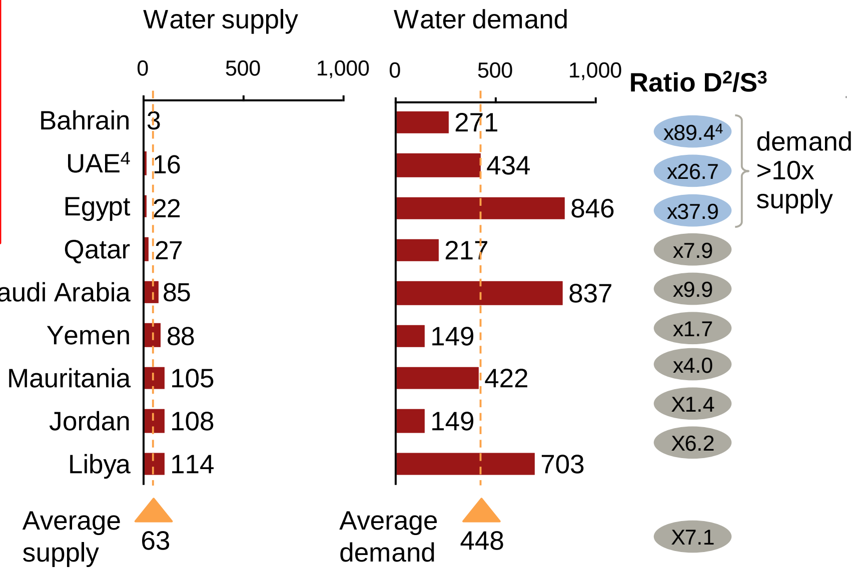
Demand/supply per capita & zoom on countries not self-sufficient[1]

%



Selected TOP water-scarce countries' Demand/supply *per capita* (2012)

m³/capita/year



153 countries are self-sufficient (88 with supply >10x demand per capita) but **18 are not (3 with demand >10x supply)**

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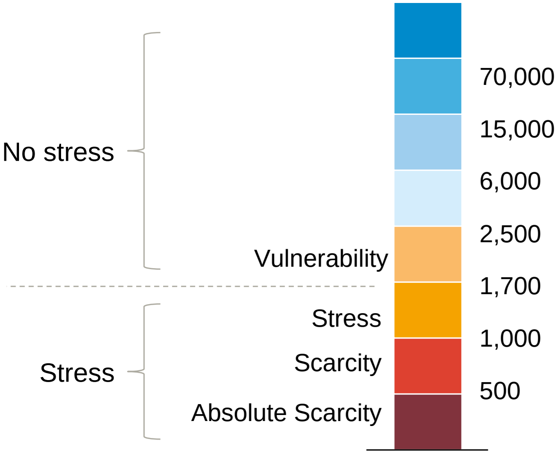
1. When D/S >100%; 2 D: Demand is the total freshwater withdrawal; 3 S: Supply is the total renewable internal freshwater resources (internal river flows and groundwater from rainfall) in the country; 4 UAE: United Arab Emirates; 5 D/S x89.4 corresponds to the 8935% maximum of the color scale in the map; 6 n.a.: not applicable.

Source: World Bank World Development Indicators database (accessed 2014, data 2012); A.T. Kearney Energy Transition Institute analysis

The two most common indicators for quantifying water stress are based on absolute quantity *per capita* and the relative withdrawn/available ratio

Water stress: Quantity per capita

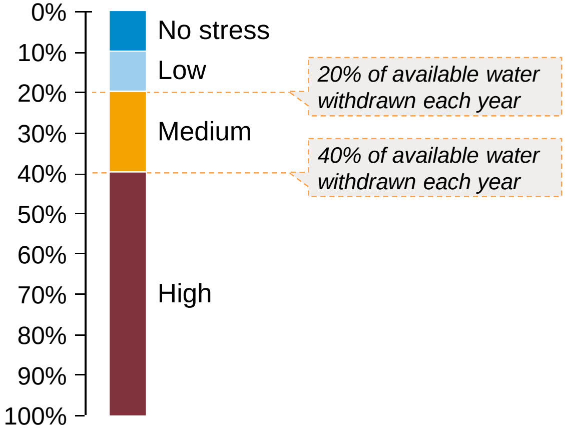
m^3/capita/year



The Falkenmark Indicator (FI) measures water stress as an absolute level of freshwater availability *per capita* in a given country.

Water stress: withdrawn / available Ratio

%



Water stress is otherwise often defined as a relative ratio of withdrawn to available freshwater in a given country. This indicator highlights how a country is using its resources: the more available freshwater is used, the more stress the country is under.

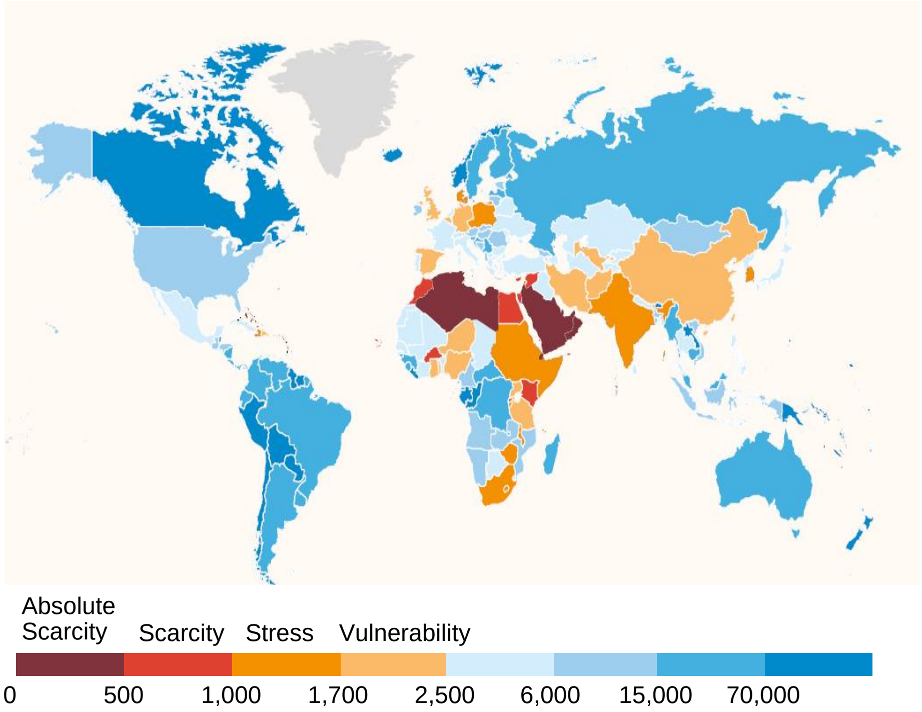
Both indicators have limitations because they do not take into account a country's ability to adapt to scarce supply (*e.g.* virtual water imports in the form of water-intensive commodities or effective supply management). The Falkenmark Indicator does not allow for differences in water-use patterns between countries, nor multiple in-stream uses. **Other indicators exist** (details in Chenoweth, 2008): weighted ones (*e.g.* social water scarcity index, water poverty index) and economic ones (*e.g.* index of structural water poverty: water-scarce countries able to pay for freshwater imports and alternative supply will not suffer from water poverty whereas some poor water-rich countries might, because infrastructure costs prevent them from accessing and leveraging existing freshwater resources).

Note: The conceptual graphic on the left is not to scale for readability purposes.
Source: UN-Water Task Force on indicators, monitoring and reporting (2009), "Monitoring progress in the water sector: a selected set of indicators"; UN (2012), "Managing water under uncertainty and risk"; Chenoweth (2008), "A re-assessment of indicators of national water scarcity"

64% of the global population is vulnerable to water stress, with MENA the worst-affected region

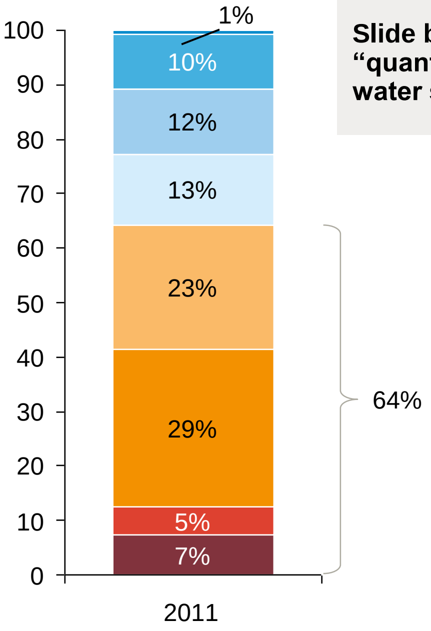
Water stress map in absolute quantity

Per Capita (2011)[1] M³/Capita/Year



Worldwide population breakdown by

Water stress quantity levels (2012) world population %



Slide based on "quantity *per capita* water stress" definition[2]

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1. The above picture and the population breakdown can worsen significantly if considered at the regional/local scale (e.g. arid Midwest and drought-prone California in the U.S.);
2. See left definition in slide 19.

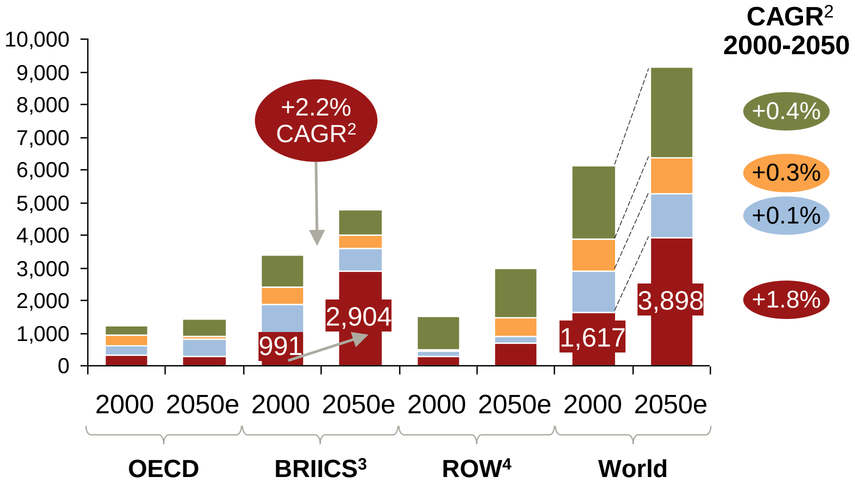
Note: Picture credits: UN water 2014.

Source: UN (2012), "Managing water under uncertainty and risk"; Chenoweth (2008), "A re-assessment of indicators of national water scarcity"; UN water (2014), "The United Nations world water development report 2014: Water and Energy"; World Bank World Development Indicators database (accessed 2014, data 2012); A.T. Kearney Energy Transition Institute analysis

The population and fraction of GDP under high water stress are forecast to double globally by 2050

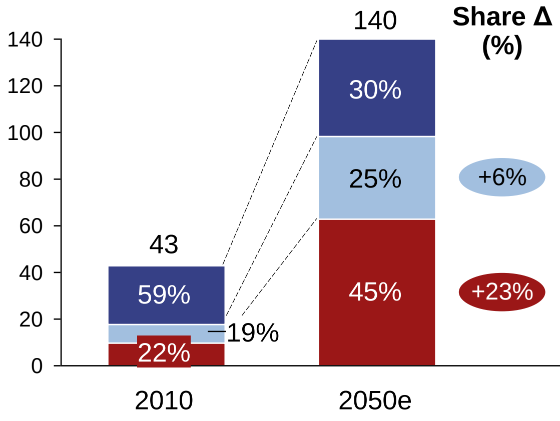
Population breakdown by water stress

people (M) Level[1]

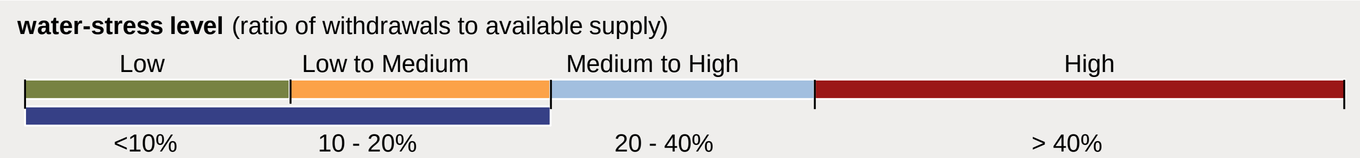


GDP breakdown by water-stress level

(2012) US$ Tn



Slide based on "withdrawn/ available ratio water stress" definition[5]



Between 2000 and 2050, the share of the population under high water stress is forecast to grow by 1.8% a year globally and by 2.2% a year in BRIICS countries.

World GDP distribution is expected to shift towards water-stressed regions as a result of rapid growth in regions with scarce resources. In addition, high-impact water-related disasters[6] (*e.g.* floods and droughts) will threaten businesses worldwide by disrupting water supply and distribution.

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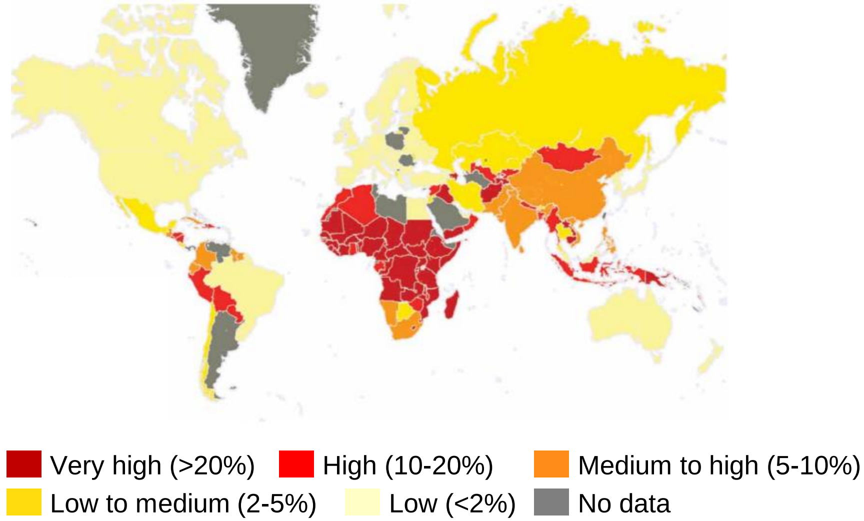
1. 2050 estimated data were taken from the baseline resource efficiency scenario; 2 CAGR: Compound annual growth rate; 3 BRIICS: Brazil, Russia, India, Indonesia, China and South Africa; 4 ROW: Rest of the world; 5 See right definition in slide 19; 6 See slide 41 for more details.

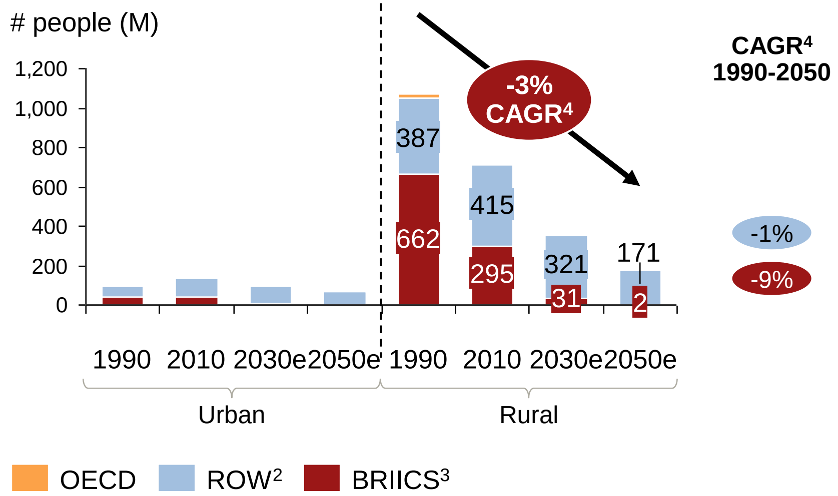
Source: OECD (2012), "OECD Environmental Outlook to 2050"; Bloomberg New Energy Finance (2012), "Water leadership forum results book"; A.T. Kearney Energy Transition Institute analysis

Even countries with available supply may experience limited access to freshwater

% of Population without access to an improved drinking-water source[1] (2010)



Urban & Rural population without access to improved water sources, 1990-2050



Freshwater scarcity can occur for reasons of accessibility, regardless of physical availability. Access to an improved drinking-water source can be limited in parts of countries where supply is sufficient. This can result from a lack of appropriate institutions, infrastructure, and/or investment, as is the case in Bolivia, Peru, Congo and Indonesia.

Reducing the number of people without access to improved water sources[5] is a major challenge in particular in rural areas of non-OECD countries.

Note: Picture credits: World Resources Institute (2013); 1 "Improved drinking-water source is defined as water which, by nature of its construction or through active intervention, is protected from outside contamination, in particular from contamination with fecal matter; Higher values indicate areas where people have less access to safe drinking water" (WRI, 2013); 2 ROW: Rest of the world; 3 BRIICS: Brazil, Russia, India, Indonesia, China and South Africa; 4 CAGR: Compound annual growth rate; 5 Access to an improved water source (see definition slide 42) does not always mean access to safe water as even sources of water that have been "improved" are frequently at risk of contamination by human and animal feces.

Source: World Resources Institute (2013), "Aqueduct Global Maps 2.0"; OECD (2012), "OECD Environmental Outlook to 2050"

Commodities' water footprints have important local implications

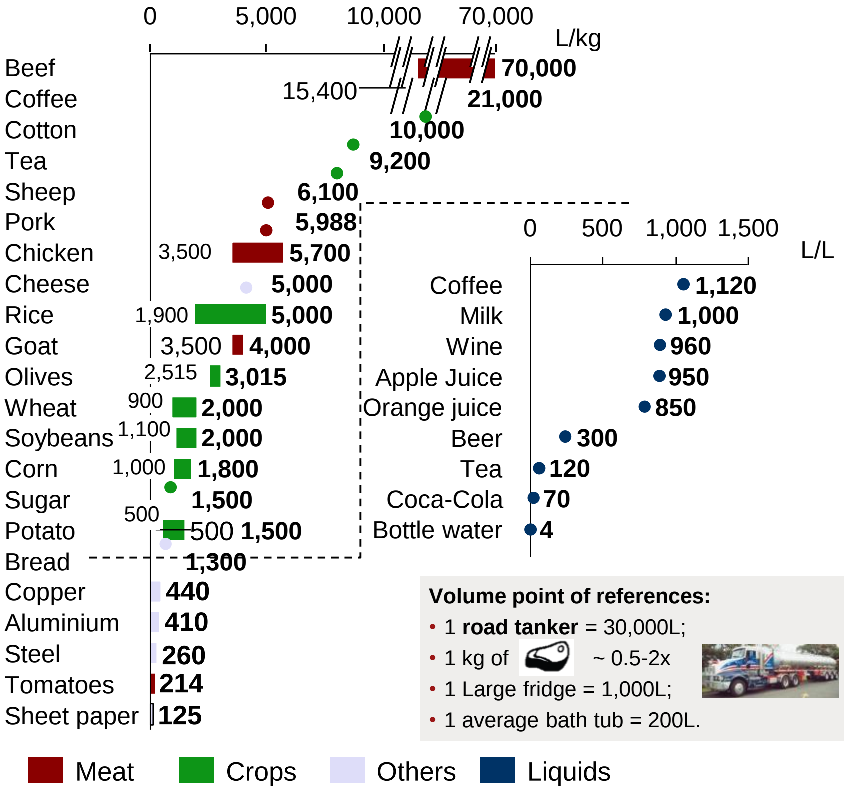
Definition of water footprint

Water footprint is a measure of direct and indirect use of water

- The water footprint of a product (good or service) is the quantity of freshwater consumed, both directly and indirectly, throughout the product's supply chain. Note that ~90% of our water use is due to the food we eat (Tony Allan).
- It is a consumption-based metric, attributing the quantity of freshwater use to the consumer rather than the producer. Water footprint examples:
  - Producing **1kg of beef** requires the consumption of 15,400-70,000L of water (~0.5-**2 road tankers***);
  - Producing 1kg of milk, wine, or apple juice consumes ~1,000L of water (4-5 bathtubs).
- Water footprint is often described as comprising 3 components: **green[1]**, **blue[1]**, and **grey water[1]** each with distinct ecological and social characteristics:
  - Green: freshwater unavailable for other land uses;
  - Blue: freshwater extracted and transported;
  - Grey: freshwater polluted throughout the supply chain.
- Contextualized analysis of their relative impacts[2] exists. Other assessments go **beyond the volumetric approach** by including the **level of stress of local water resources and water quality**[3].

example of Water footprint

L/kg, L/L



Volume point of references:

- 1 **road tanker** = 30,000L;
- 1 kg of 🥩 ~ 0.5-2x
- 1 Large fridge = 1,000L;
- 1 average bath tub = 200L.

---

1. Green water is the amount of precipitation and soil moisture directly consumed in an activity (e.g. growing crops); Blue water is the amount of surface groundwater consumed in an activity (growing crops or manufacturing an industrial food); Grey water is the water needed to assimilate pollutants from a production process back into water bodies at levels that meet governing standards (Hoekstra, 2011). This should not be confused with wastewater reused directly at a site, which is often also referred to as grey water or greywater. Grey water is an indicator of water quality, while Green and Blue water are measures of consumptive water use; 2. Called water-footprint sustainability assessment in the literature; 3. e.g. Veolia water impact index.

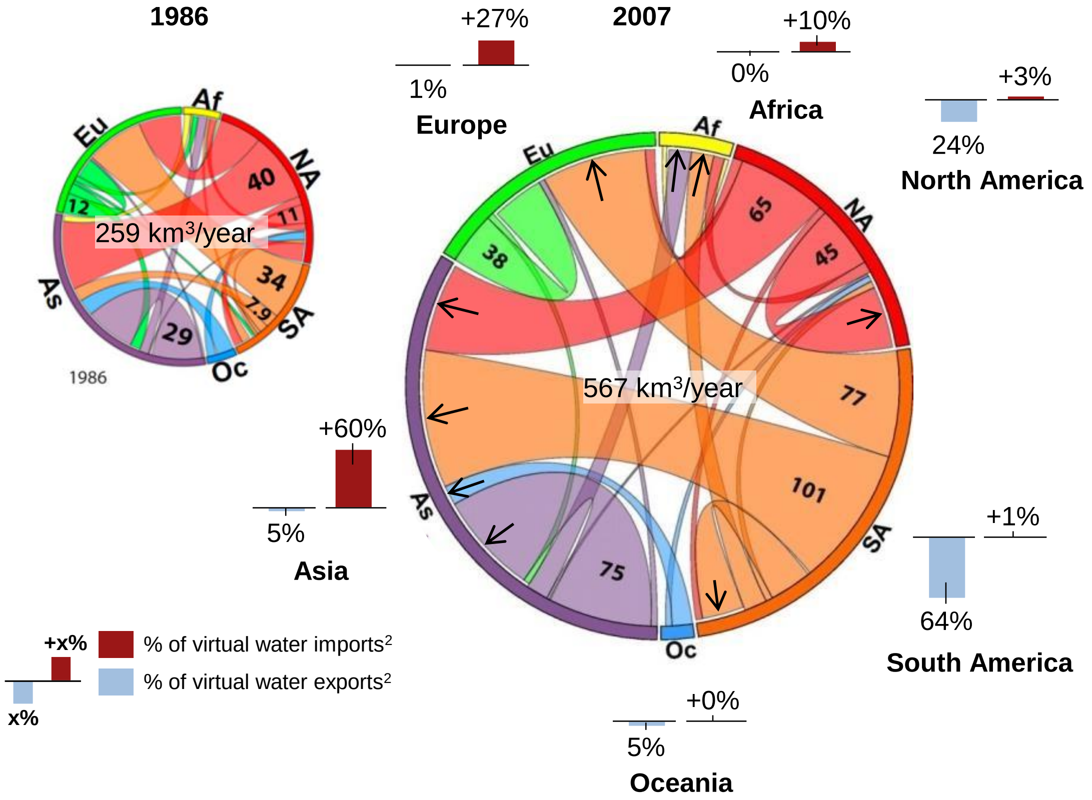
Note: Picture credit: www.tieman.com.au;

Source: Hoekstra et al (2011), "The water footprint assessment manual: Setting the global standard"; Gleick (2014 & 2009), "The world's water, The Biennial report on freshwater resources"; http://www.waterfootprint.org/; Tony Allan (2011), "Virtual Water"

Virtual water reveals hidden global water trade via water-intensive products

Examples of virtual water trade flows[1]

km^3/year, % of virtual water imports/exports



- **Total** regional **water trade** consists of **physical and virtual water flows** over a certain period.
- **Virtual water generally refers to the freshwater embodied in the production and trade of a commodity or product.** International virtual water trade therefore allows the **indirect transfer** of freshwater resources between regions through commodities, goods**,** and services (*e.g.* food and feed crops, livestock and dairy based products).
- Dalin et al. recent analysis indicates that, **for 58 food commodities,** Asia and South America are the largest importer and exporter of virtual water, respectively. **The total volume of virtual water traded in 2007 was 567 km^3/year,** equivalent to ~22% of global freshwater withdrawal for agriculture.

---

1. Dalin's study focused on the virtual water trade networks associated with the trade of 58 food commodities made from five major crops (barley, corn, rice, soy and wheat) and three livestock products (beef, pork and poultry). These commodities account for about 60% of global calorie consumption; 2 based on international trade only (excluding intraregional trade), amounting to ~300 km3/year; values approximated by using scale of graph when actual figures not provided.

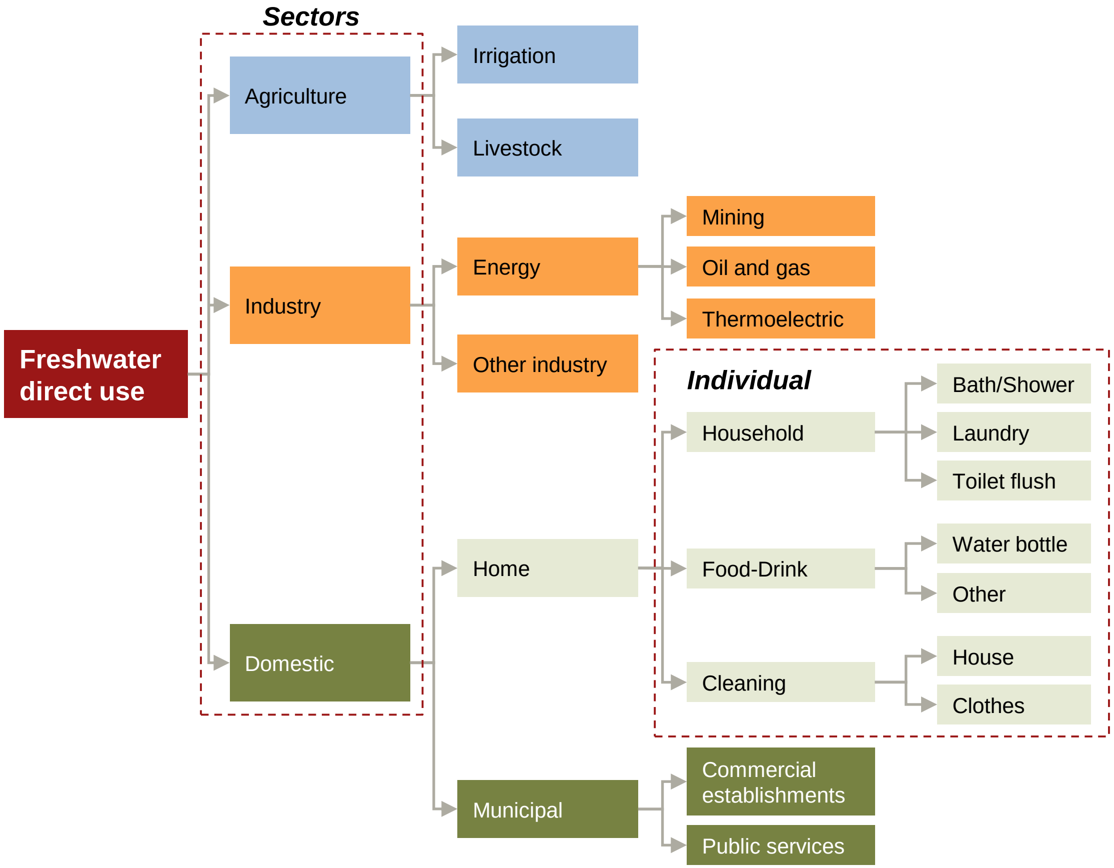
Note: Picture credits: Dalin et al. (2012); Color code refers to exporting regions; Virtual water is an active area of research, with no publicly available and comprehensive analysis & database.

Source: Dalin et al. (2012), "Evolution of the global virtual water trade network"; Black and King (2009), "The Atlas of Water"

2. Current freshwater uses and future supply – demand mismatch

Freshwater is used in a wide range of economic and domestic activities

Direct freshwater uses[1] by sector (Illustrative)



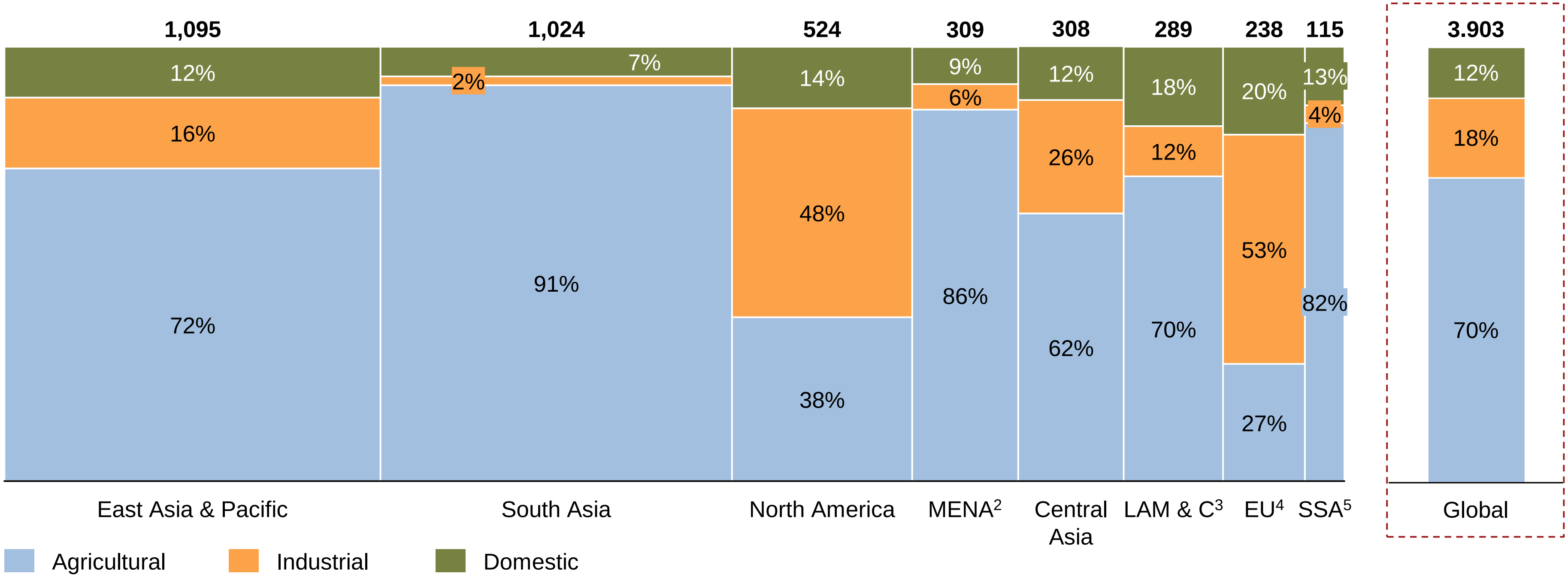
- **Freshwater use[1] at the sector level (agriculture, industry, domestic) is much larger than individual direct use but domestic consumers' indirect uses have important repercussions on each sector.**
- Domestic consumers' food and energy-consumption habits/choices indirectly influence global freshwater use.
  - *Agriculture:* water use is increased by the choice of water-intensive products and imports of water-intensive commodities not produced locally/all year round.
  - *Industry:* both the quantity and technology choice/supply mix of the energy consumed drastically affects water use.
  - *Domestic:* municipal services set quality standards for drinking water and the local environment (water bodies, green space…) that indirectly affect freshwater use. Local/federal regulations can also limit indoor and outdoor household consumption, especially in drought conditions (hosepipe use etc…).

Note: 1. In this FactBook, "water use" at the sectorial level means consumption and withdrawal, but consumption only at the individual/product level.
Source: A.T. Kearney Energy Transition Institute analysis

Agriculture accounts for 70% of global freshwater withdrawal

Freshwater withdrawal[1] by region and sector (2012)

km³ / year, %



Industry dominates in North America/Europe

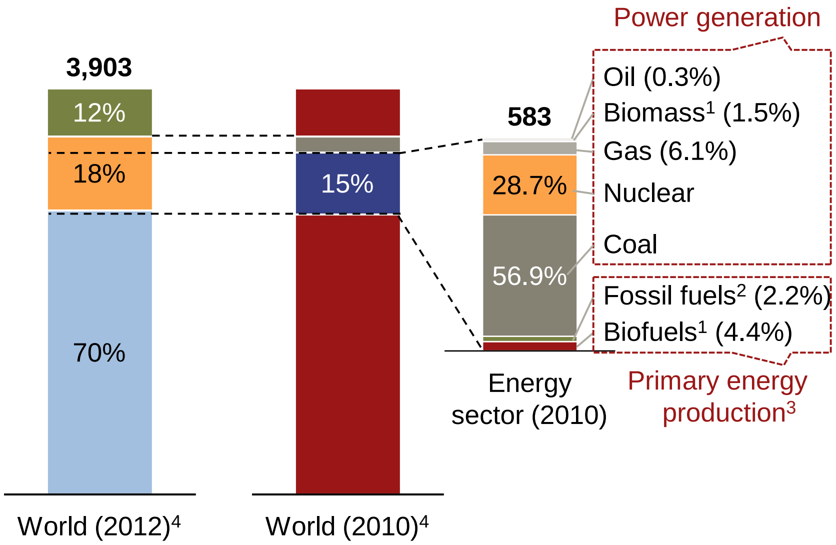
- Sub-Saharan Africa, MENA[2], and South Asia use 82-91% of their freshwater for agriculture.
- Europe and North America's industrial freshwater withdrawal are, respectively, 2 and 1.3 times larger than their agriculture withdrawal.

Note: 1. "Withdrawals also include water from desalination plants in countries where they are a significant source. Withdrawals can exceed 100% of total renewable resources where extraction from non-renewable aquifers or desalination plants is considerable or where there is significant water reuse"; World Bank online. 2. MENA: Middle East & North Africa; 3. LAM & C: Latin America & Caribbean; 4. EU: European Union; 5 SSA: Sub-Saharan Africa.

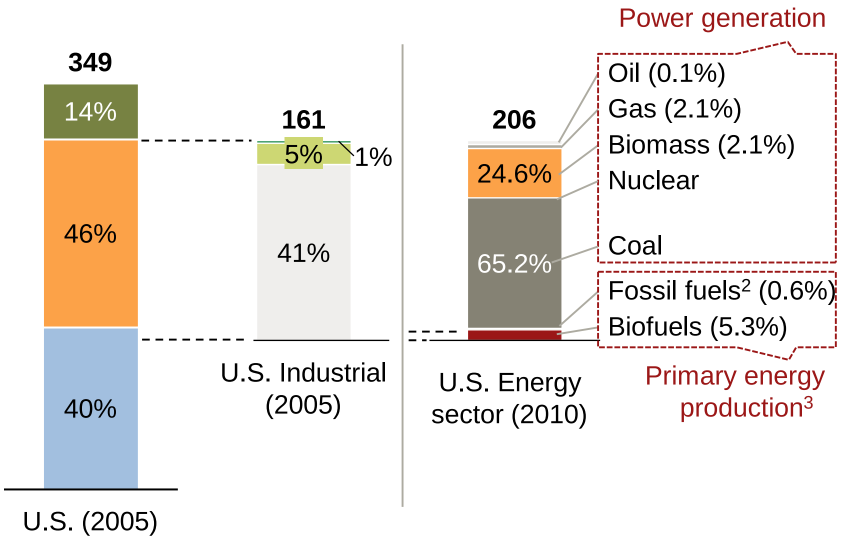
Source: World Bank World Development Indicators (accessed 2014, data 2012); A.T. Kearney Energy Transition Institute analysis

Energy can represent a major fraction of water withdrawal in highly industrialized countries

GLOBAL FRESHWATER WITHDRAWAL BY SECTOR (2012 & 2010) %, km^3



U.S. FRESHWATER WITHDRAWAL BY SECTOR (2005, 2010) %, km^3



▨ Other industry ▨ Energy sector ▨ Not applicable ▨ Agricultural ▨ Industrial ▨ Domestic ▨ Mining ▨ Other industrial ▨ Thermoelectric

- In 2012, 70% of freshwater worldwide was withdrawn for agriculture and 18% for industrial purposes. The IEA estimates that, **in 2010, 15% of global freshwater was withdrawn for the energy sector**
- In industrialized countries **energy can represent up to 40% (*e.g.* U.S.) of water withdrawal**

---

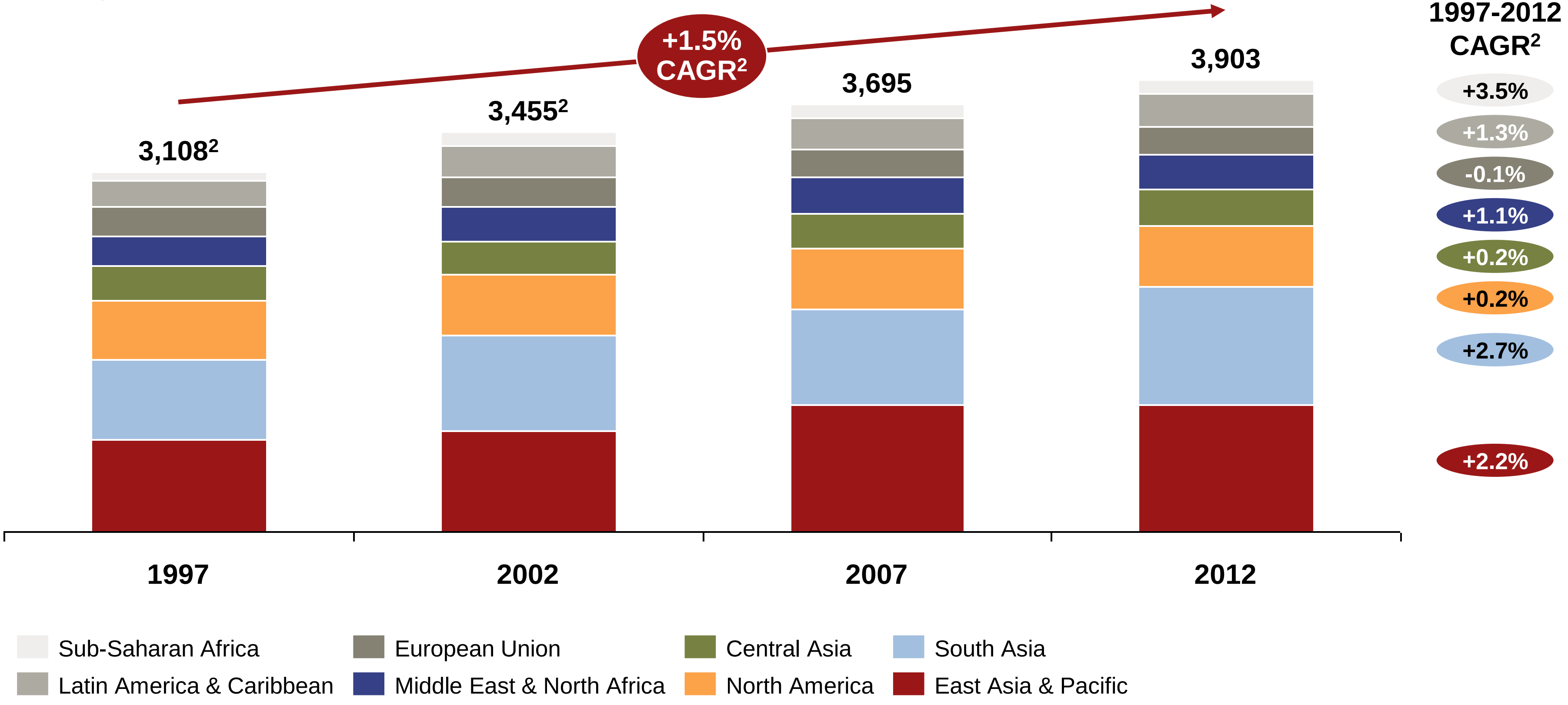
1. Biomass & biofuel withdrawals represent about 1% of global 2010 freshwater withdrawals; 2. Fossil fuel primary energy production (World: 13 km^3, U.S.:28 km^3) consists of oil (World: 9.6 km^3), coal (World: 8 km^3) and gas (World: 5 km^3, where unconventional gas is 0.3 km^3 ~ 0.008% of global 2010 freshwater withdrawals); 3. Primary energy production consists of resource extraction, irrigation, fuel refining & processing and transport (IEA); 4. Breakdown data were only available for the Agricultural/Industrial/Domestic sector in 2011 and for the Energy sector in 2010, but global figures for both years are around 3890 km^3.

Source: World Bank World Development Indicators (accessed 2014, data 2012); U.S. Geological Survey water.usgs.gov website; IEA (2012), "World Energy Outlook 2012 - Chapter 17 Water for Energy"; UN water (2014), "The United Nations world water development report 2014: Water and Energy"; A.T. Kearney Energy Transition Institute analysis

Global freshwater withdrawal grew by 1.5% per annum between 1997 and 2012, with significant regional variations

Freshwater withdrawal[1] by region (2012)

km³ / year



1. Withdrawals also include water from desalination plants in countries where they are a significant source. Withdrawals can exceed 100% of total renewable resources where extraction from non-renewable aquifers or desalination plants is considerable or where there is significant water reuse; 2 East Asia & Pacific consolidated total withdrawal data were not available and have therefore been estimated by subtracting the sum of all other regions from the estimated world total; 2. CAGR: Compound annual growth rate.

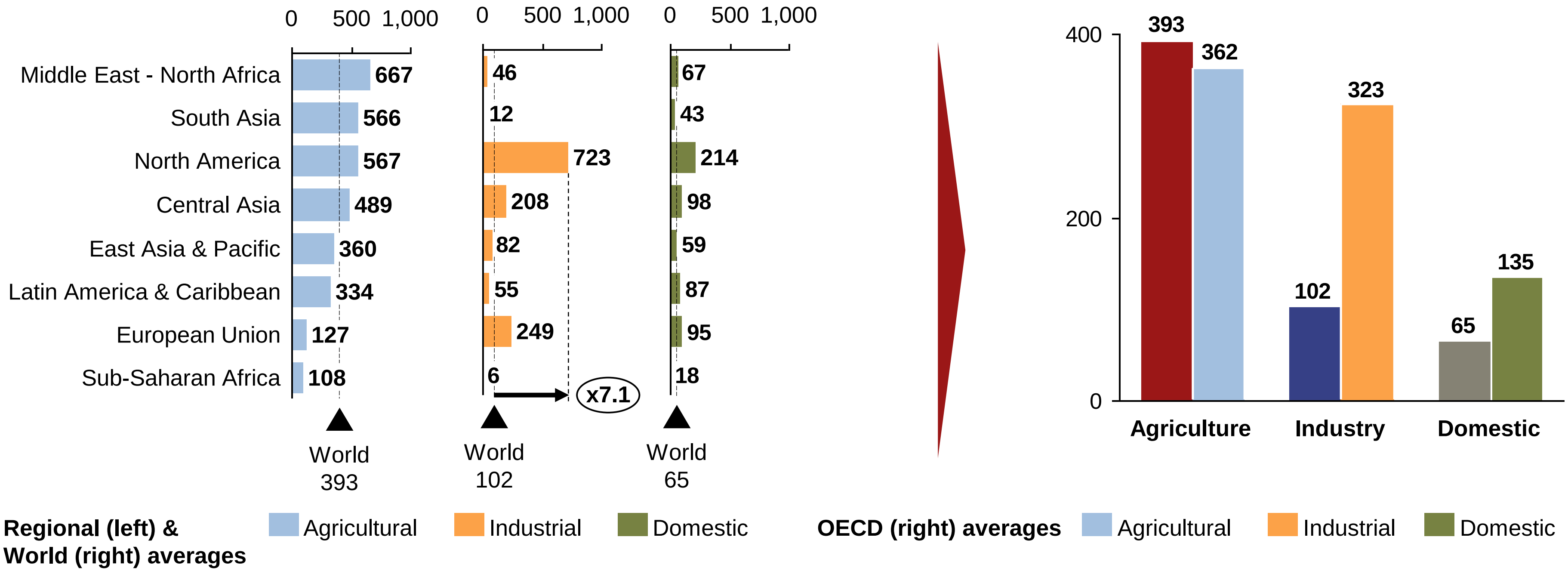
Note: In the 1997-2012 period, the world population increased by 2% per year, indicating that water withdrawal per capita has increased

Source: World Bank World Development Indicators database (accessed 2014, data 2012); A.T. Kearney Energy Transition Institute analysis

Per capita sectorial withdrawals are highly variable and highlight varying degrees of industrialization

Regional and Global withdrawal by Sector (2012)

m³/capita/year



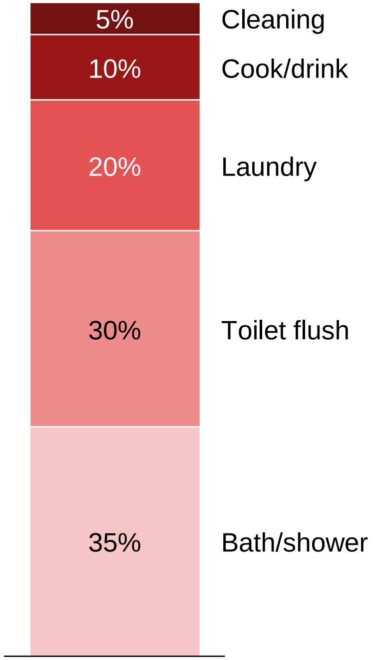
***Per capita* freshwater withdrawals by economic sector vary considerably between developed and developing regions, both at the regional and at the macro level.**

- OECD averages for industrial and domestic withdrawals are, respectively, 3 and 2 times higher than the world average, reflecting regional variations in industrialization.
- In particular, North America's industrial and domestic water withdrawal are largely above the world average**.**

Source: World Bank World Development Indicators (accessed 2014, data 2012); Black and King (2009), "The Atlas of Water"; A.T. Kearney Energy Transition Institute analysis

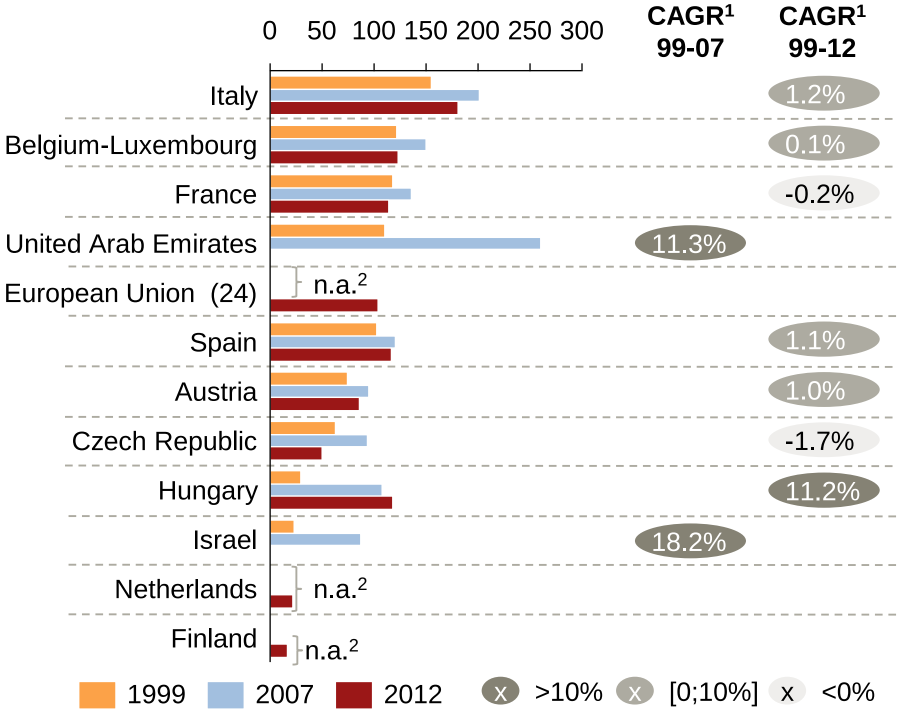
Homes in industrialized countries consumed ~85% of freshwater directly in bathing, toilet flushing and laundry

Typical Industrialized Home Water use Pattern (2008) %



Drinking water and cooking account for just 10% of direct freshwater use in an industrialized home, excluding:
- Outdoor watering uses;
- Indirect freshwater consumption in the supply of food and materials (*e.g.* virtual water see slide 24 & 23).

Per-Capita Bottled Water Consumption L/capita/year



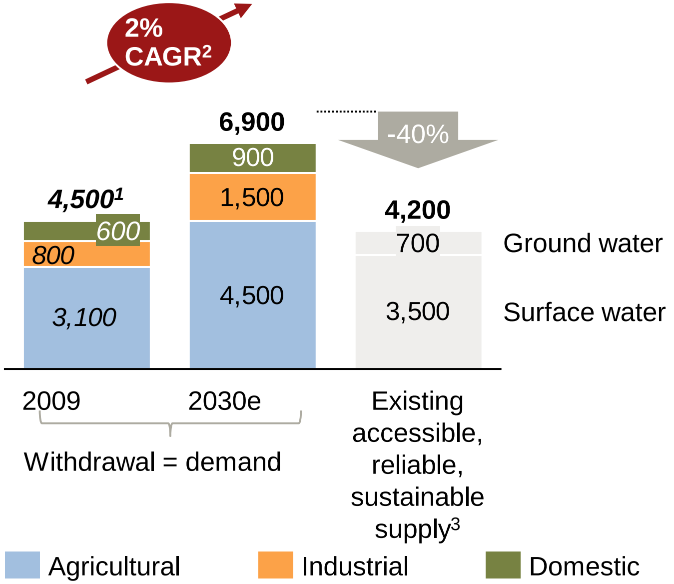
- ***Per capita*** **consumption of bottled water is highly heterogeneous** both in absolute quantity and growth dynamics.
- **Different growth drivers exist:**
  - Illness prevention in developing countries (growing market);
  - Perceived health benefits in developed countries (shrinking market).

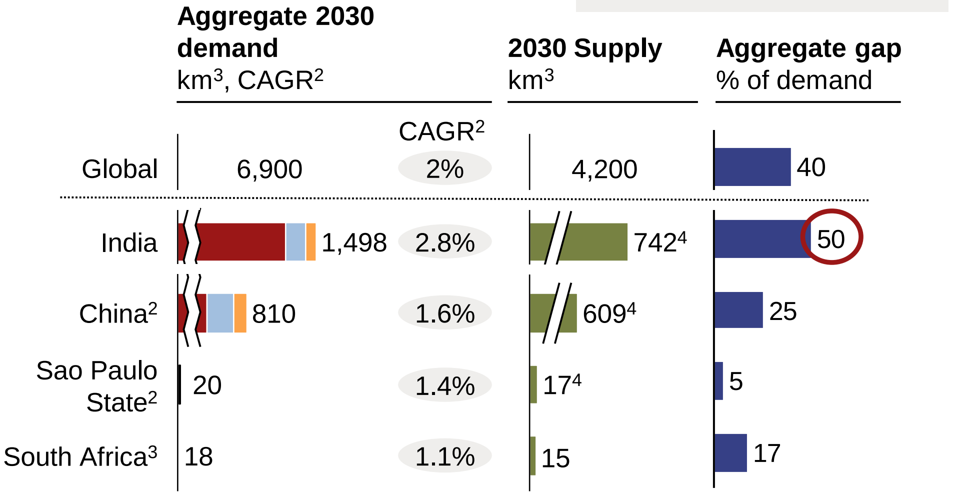
1. CAGR: Compound annual growth rate; 2. n.a.: Not available.
Source: Black et al (2009), "The Atlas of Water"; Credit Suisse (2009), "Water: The pressure is rising"; European federation of bottled water (efbw.eu/); Pacific Institute (worldwater.org/water-data/)

The gap between global freshwater supply and demand is expected to reach ~40% by 2030, but water challenges are local in nature

Global and regional withdrawal in 2030 VS. existing accessible, reliable supply[1] (2009) km³

Gap driven by
Supply ↓ Demand ↑





- The **supply-demand mismatch depicted above is driven both by reductions in freshwater supply and increasing demand**. Failure to address this gap fully could lead to serious consequences (detailed in slides 36 and 37).
- **The global 40%-gap figure is an aggregation of numerous local gaps, some of which are even worse**. For instance, it is forecast that India's 2030 gap will be ~50%, and that 1/3 of the population of developing countries will live in basins where the deficit exceeds 50%. **There is therefore no single freshwater crisis, as different regions/countries face very different water challenges and generalizations should thus be taken with caution.**

---

1. The withdrawal figure for 2009 presented in this study is higher than the World Bank figure presented in previous slides. The authors could not reconcile data differences as only the latter database is publically available; 2. CAGR: Compound annual growth rate; 3. Existing supply which can be provided at 90% reliability, based on historical hydrology and infrastructure investments scheduled through 2010, net of environmental requirements; fossil/non-renewable groundwater reserves have not been considered, as they are not sustainable in the long term; 4. Figures slightly changed for consistency purpose with slide 64.

Source: 2030 Water Resources Group (2009), "Charting our water future"

Various factors can reduce freshwater supply by affecting its quantity and quality, as well as its location and reliability

Supply ↓

Causes of reductions in freshwater supplies/stocks

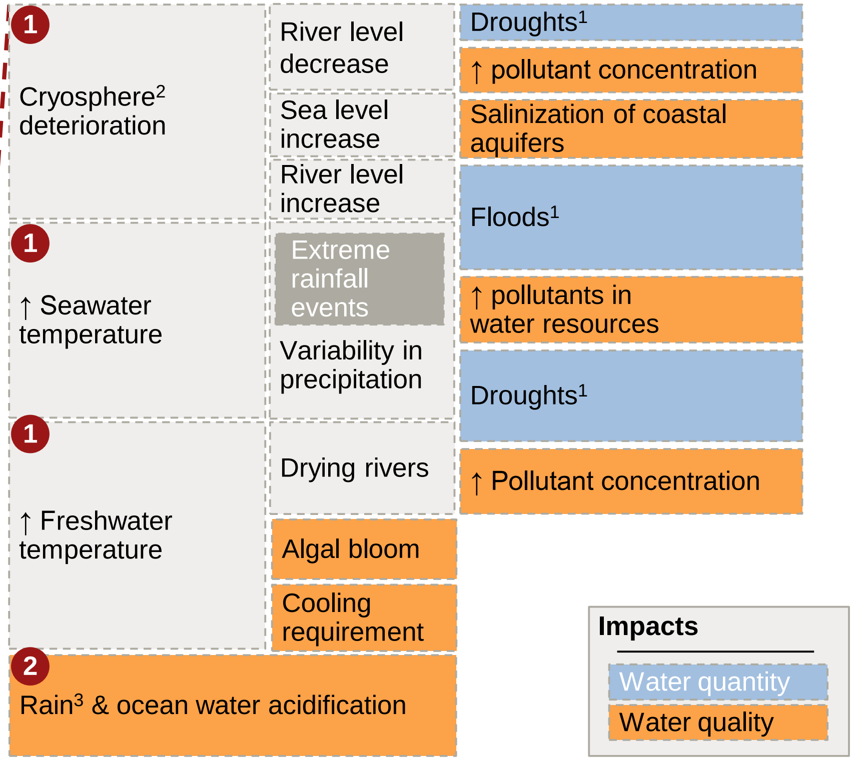
Overuse reduces natural water stocks. Over-exploitation depletes natural reservoirs (groundwater and surface) by pumping at a faster rate than the rate of replenishment. The depletion of groundwater levels is well documented. One example of surface-water depletion is the decline in the Aral Sea. This was once the world's fourth-biggest inland sea, but, by 2007, overuse had resulted in a 90% loss of its original volume. It is now split into three separate lakes, two of which are too saline to support most aquatic life. Low water prices in some countries (China and India in particular) are among the causes of this kind of poor water-resource management.

Water pollution[1] from agricultural, industrial and domestic wastes, leaks, and/or run-off **significantly** reduces **freshwater supply**.

Global warming and an increasing concentration of CO_2 affect both the quality and quantity of water supply. Glacial river flow is the most severely affected during the dry season, as its supply comes mainly from glaciers (*e.g.* 70% of the Ganga). As a result, there is no river when there is no glacier. In addition, the contrast in precipitation between wet and dry regions increases; and extreme rainfall events are very likely to increase in frequency and intensity (IPCC, 2014).

All these factors also affect the location of water supply and the reliability/timing of its retrieval.

Impact of Increase in (①) temperature and (②) CO2 atmospheric concentration



① Cryosphere[2] deterioration

River level decrease

Droughts[1]

↑ pollutant concentration

Sea level increase

Salinization of coastal aquifers

River level increase

Floods[1]

① ↑ Seawater temperature

Extreme rainfall events

↑ pollutants in water resources

Variability in precipitation

Droughts[1]

① ↑ Freshwater temperature

Drying rivers

↑ Pollutant concentration

Algal bloom

Cooling requirement

② Rain[3] & ocean water acidification

Impacts

Water quantity

Water quality

---

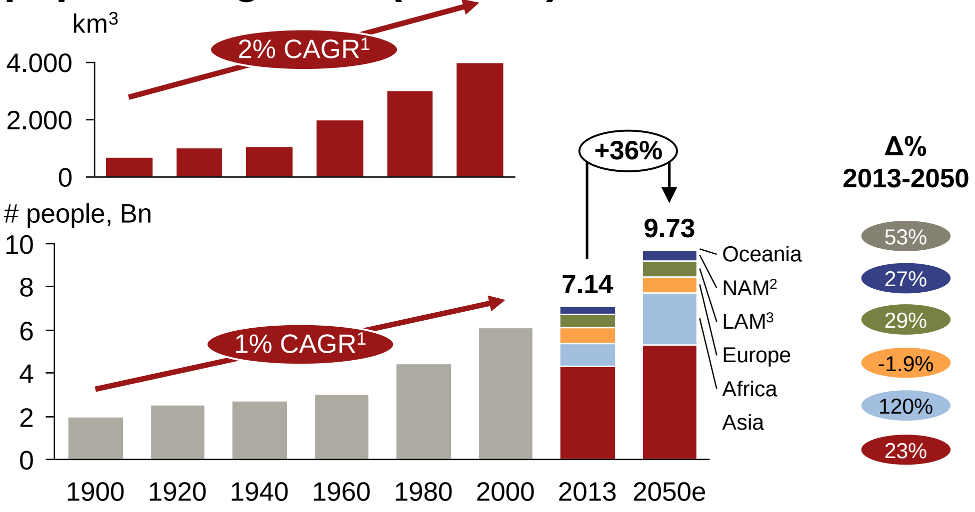
1. See slides 40 and 41 for more details; 2. Represents all water in solid form on the Earth (e.g. ice, snow); 3. Acidity in rainwater could also be caused by atmospheric transportation and deposition of nitrogen and sulfur compounds.

Source: Black and King (2009), “The Atlas of Water”; Gleick (2008-2009), “The world’s water, The Biennial report on freshwater resources”; UNEP (2007), “Global Environmental Outlook”; OECD (2012), “Environmental Outlook to 2050”; Credit Suisse (2009), “Water: The pressure is rising”; IPCC (2014), “AR5 Summary For Policymaker”

Water demand has grown twice as fast as the population since 1900

Demand ↑

Freshwater demand (TOP) and population growth (bottom)



Water demand growth is driven by several trends, including population growth, which is widely expected in regions with the scarcest water resources: **~90% of the projected 2.59 Bn population growth by 2050 is forecast to occur in Africa and Asia, which are** already experiencing high-to-extremely high levels of local water stress.

Other freshwater demand trends

Economic growth will increase freshwater demand. **Urbanization also increases local demand and can result in worsening access to water, with significant negative social consequences[4] (*e.g.* urban slums).** Growth in urban population within a limited area requires a high and rapid surge in additional connections to the supply network[5], which puts pressure on local resources.

Increases in demand for food (+ changing diet), feed[6], fiber and biofuels lead to significant increases in freshwater demand and competition for freshwater.

- An expansion of the middle class in emerging economies generate additional demand for water-intensive products (meat, cotton). Note that ~30% of the food produced is lost/wasted along the value chain.
- Intensification of agricultural production and increasing irrigation can create competition for supplies, and will require drastic increases in water productivity.
- Biofuels compete with food for land and freshwater resources. As a result, any significant increase in biofuels production could exacerbate freshwater shortages, directly and indirectly, in areas where supplies are scarce.

---

1. CAGR: Compound annual growth rate; 2. NAM: North America; 3. LAM: Latin America; 4. Worsening freshwater access can have (rapid) dramatic consequences in poor, densely populated urban areas like slums, where social unrest, violence and/or control by non-state groups are often caused, and/or exacerbated by a water shortage; 5. The convenience of urban water network connections makes consumption straightforward for urban consumers, resulting in higher domestic freshwater use and growth in overall demand; 6. Crops grown for livestock; Note - a WBCSD report came out as this FactBook was being published: WBCSD (2014), “Co-optimizing solutions water and energy for food feed and fiber”.

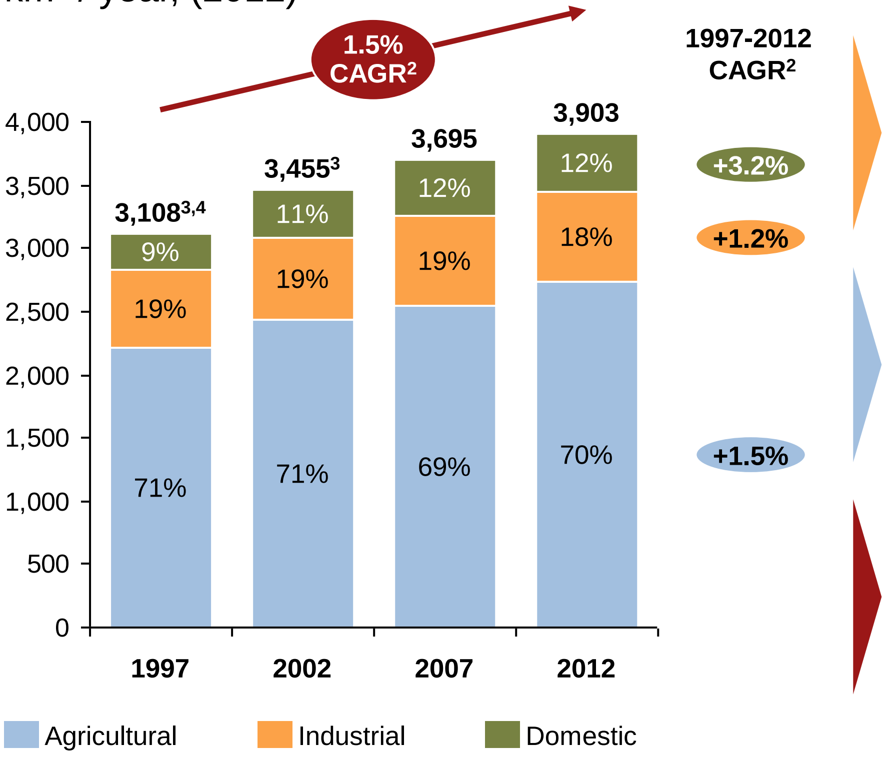
Source: Credit Suisse (2009), “Water: The pressure is rising”; Population Reference Bureau (2013), “2013 World Population Data Sheet”; Kilcullen (2014), “Water wars” presentation at global water summit, Paris; FAO (2008), “Coping with water scarcity - an action framework for agriculture and food security”

Water demand dynamics indicate that the domestic sector is the fastest-growing worldwide and that each sector exhibits significant regional variations

Demand ↑

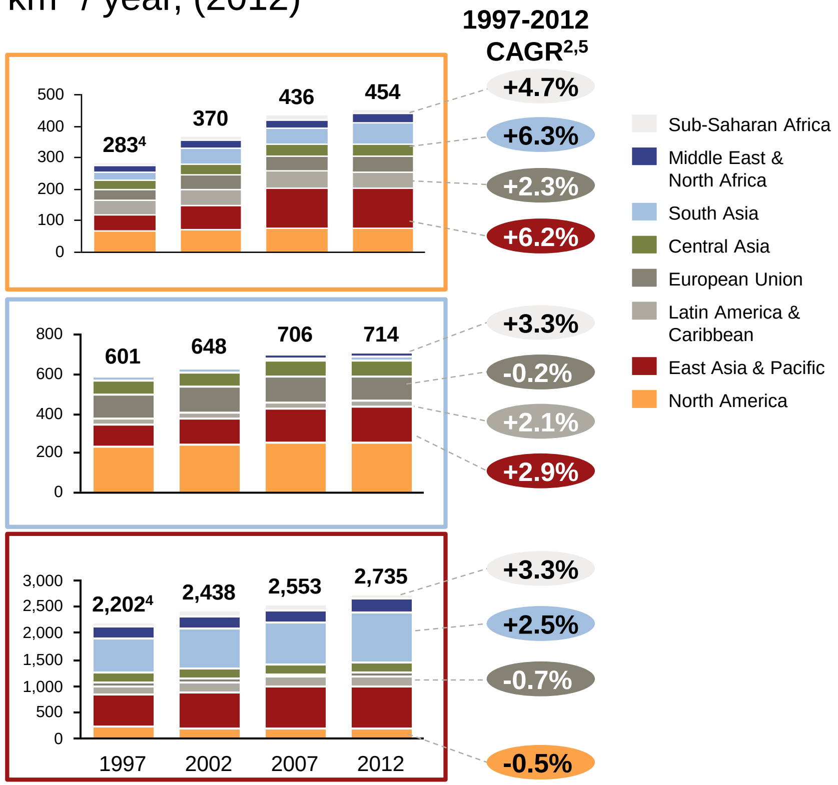
Freshwater withdrawal- by sector

km³ / year, (2012)



Sectorial Withdrawal by region

km³ / year, (2012)



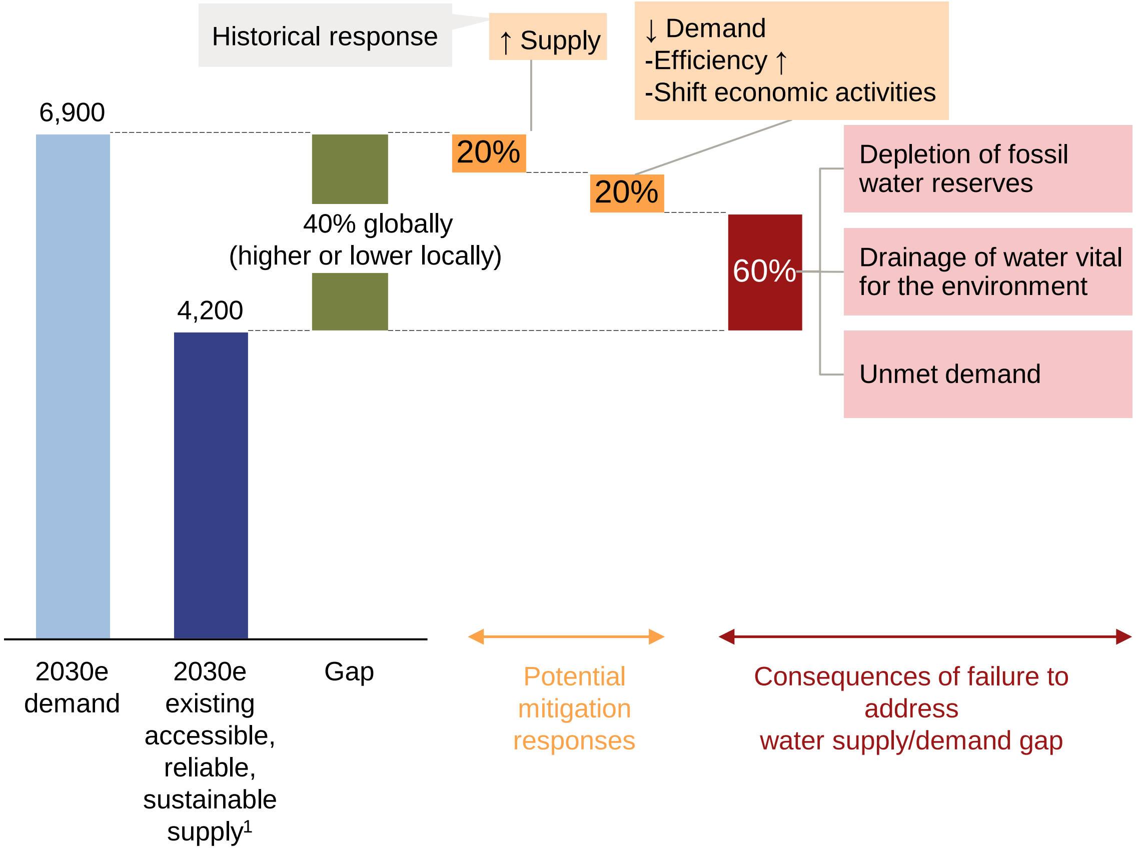
1. Withdrawals also include water from desalination plants in countries where these are a significant supply source. Withdrawals can exceed 100% of total renewable resources where extraction from non-renewable aquifers or desalination plants is considerable or where there is significant water reuse; 2. CAGR: Compound annual growth rate; 3. East Asia & Pacific consolidated total withdrawal data were not directly available, and have been estimated by subtracting the sum of all other regions from the estimated world total; 4. Breakdowns for % sectorial withdrawal in 1997 do not add up to 100% leading to a total of 3,108 km3 (21 less than the cumulative worldwide total); 5. All CAGR not represented are > 0 and < 2%.

Source: World Bank World Development Indicators database (accessed 2014, data 2012); A.T. Kearney Energy Transition Institute analysis

60% of the water gap may remain unaddressed, potentially leading to depleted non-renewable supply, drained environments and/or unmet demand

2030 global water supply-demand gap and potential responses & consequences

(2009) km^3 / year, % (2009)



- **Business-as-usual water management is unlikely to close the gap** without having a significant negative impact on local fossil-water resources and ecosystems, or leaving demand unmet, putting local populations and industries at risk.
- **Different mitigation options exist:**
  - **Increase natural[2] (and alternative[3]) supply.** Increasing natural supply has historically been the preferred option but low-cost supplies have already been largely exhausted;
  - **Decrease demand by**
    - **Increasing water productivity** across all sectors either by increasing the **efficiency** of water use (same output with less water) or increasing production using the same water;
    - **Shift towards less water-intensive economic activities** (e.g. rely more on agricultural imports to reduce withdrawal).

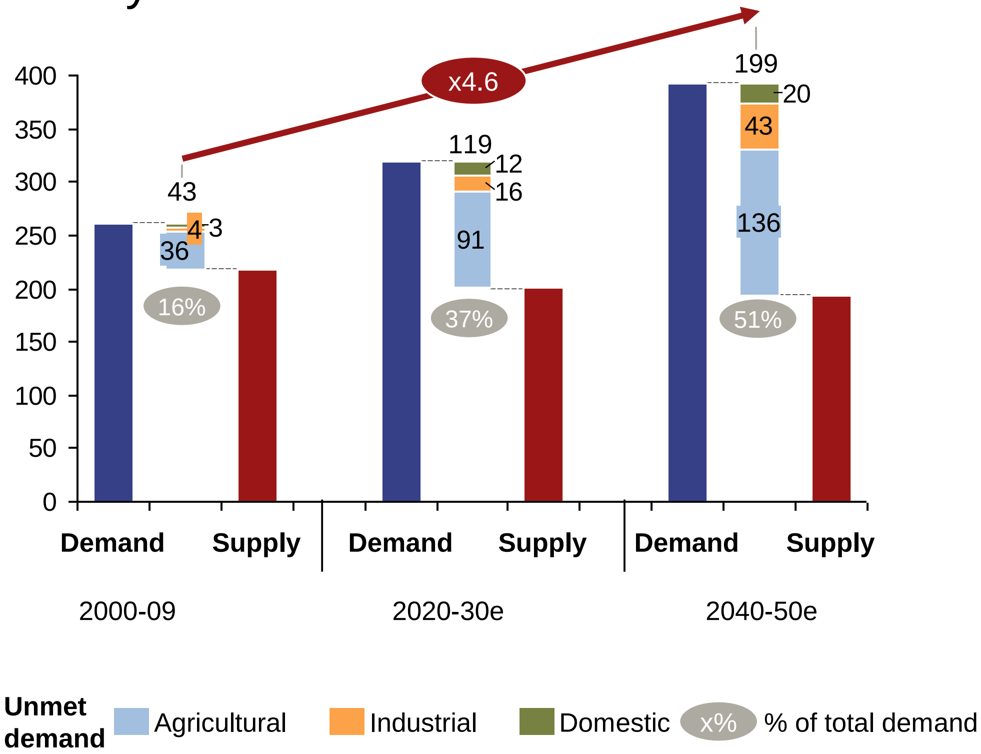
1. Existing supply that can be provided at 90% reliability, based on historical hydrology and infrastructure investments scheduled through 2010, net of environmental requirements; fossil/non-renewable groundwater reserves are not included, as they are not sustainable in the long term; 2. This applies to water-rich countries with limited infrastructure but that have the potential to convert untapped existing water resources into available, accessible, and reliable supply; 3. Including desalination and wastewater treatment.

Source: 2030 Water Resources Group (2009), "Charting our water future"

Unmet demand in MENA region may quadruple in the next 40 years, reaching half of total demand

Mena Water Supply vs demand Scenario (2011)

km^3 / year



- Un**met water demand**, resulting from the mismatch between supply and demand**, is already severe in MENA[1]:**
  - Unmet water demand in Bahrain, Jordan and the UAE2 currently ranges between 76% and 90%3.
  - Iraq, Iran and Saudi Arabia cumulatively account for ~70% of MENA's current unmet demand.
- **This mismatch is expected to worsen because of** rising demand and (potentially) decreasing supply. The graph plots the average climate scenario (one of 3 scenarios4) from the Future Water report, commissioned by the World Bank. The scenario assumes that:
  - Extensive growth **in irrigated agriculture,** and in domestic and industrial water needs, drive up demand.
  - Rainfall supply decreases slightly, albeit to uncertain levels.
- The **consequences of unmet water demand** include weaker economic **growth, adverse impacts on human health,** inability to grow food domestically (with impacts on local economies), resulting in greater reliance on **food imports, and environmental destruction.**

---

1. MENA: Middle East & North Africa; 2. UAE: United Arab Emirates; 3. These demand over supply percentages, taken from the Future Water report, do not refer to the exact same quantity as those reported by the World Bank ratio in section 1; 4. Taken as representative of outputs from 9 different Global Circulation Models, ranked from wettest to driest.

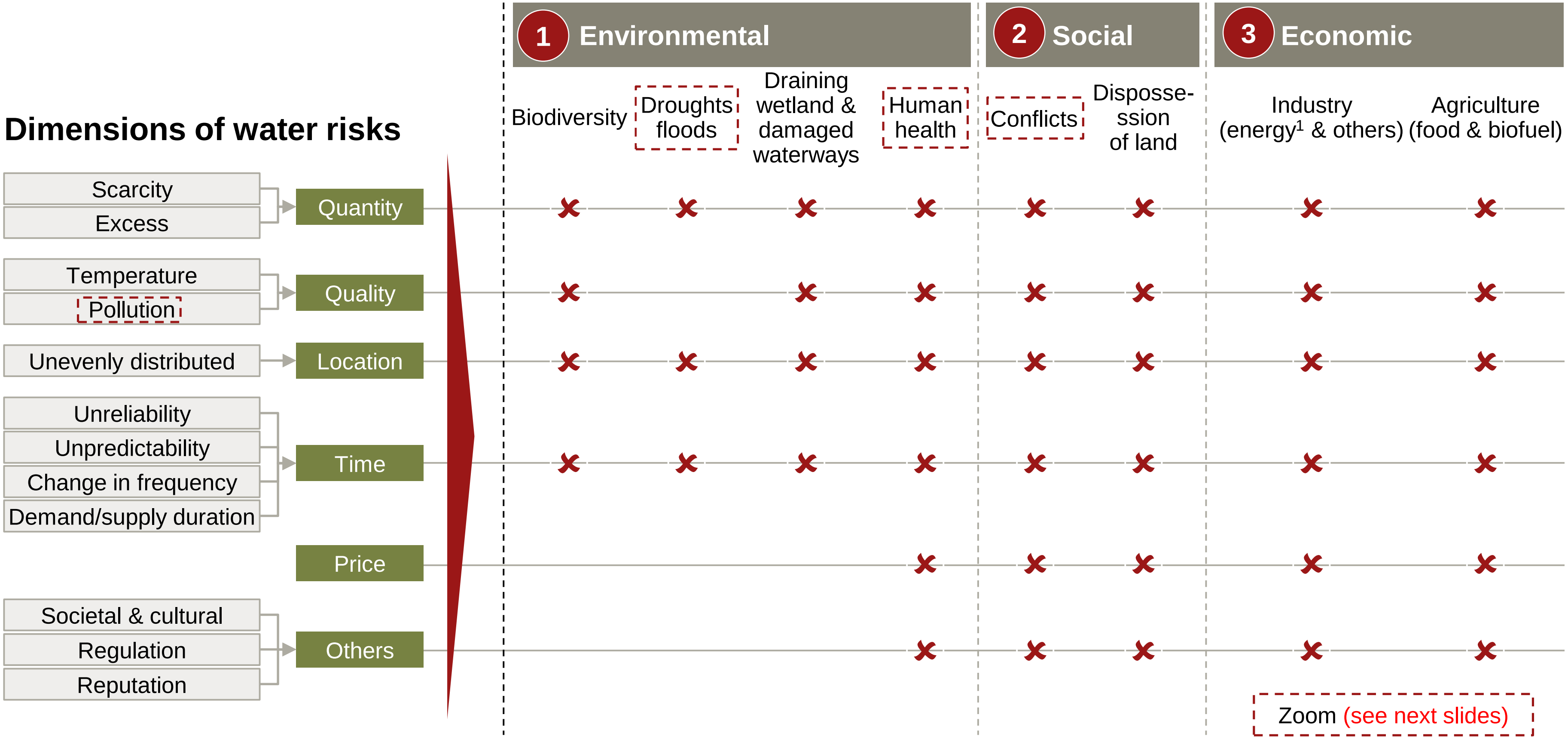
Source: Future Water (2011), "Middle-East, Northern Africa Water Outlook"; A.T. Kearney Energy Transition Institute analysis"

3. Water risks: multi-dimensional and high-impact

Almost all water risks are multi-dimensioned and have environmental, social, and economic impacts

Main dimensions of water-risk challenges

Illustrative



Dimensions of water risks

Sub-dimensions	Dimensions	1 Environmental: Biodiversity	1 Environmental: Droughts floods	1 Environmental: Draining wetland & damaged waterways	1 Environmental: Human health	2 Social: Conflicts	2 Social: Dispossession of land	3 Economic: Industry (energy[1] & others)	3 Economic: Agriculture (food & biofuel)
Scarcity Excess	Quantity	✗	✗	✗	✗	✗	✗	✗	✗
Temperature Pollution	Quality	✗		✗	✗	✗	✗	✗	✗
Unevenly distributed	Location	✗	✗	✗	✗	✗	✗	✗	✗
Unreliability Unpredictability Change in frequency Demand/supply duration	Time	✗	✗	✗	✗	✗	✗	✗	✗
	Price				✗	✗	✗	✗	✗
Societal & cultural Regulation Reputation	Others				✗	✗	✗	✗	✗

Zoom (see next slides)

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1. Detailed in part 6.

Source: Goldman Sachs (2013), "Sustainable Growth: Taking a Deep Dive into Water", OECD (2013), "Water and climate change adaptation"; Societe Generale (2013), "Mining and water risk, clear or muddy waters ahead"; UN (2012), "Managing water under uncertainty and risk"; A.T. Kearney Energy Transition Institute analysis

Various types of pollution can impair the quality of freshwater and reduce its supply

Main causes of water pollution

(worst-offending sectors)

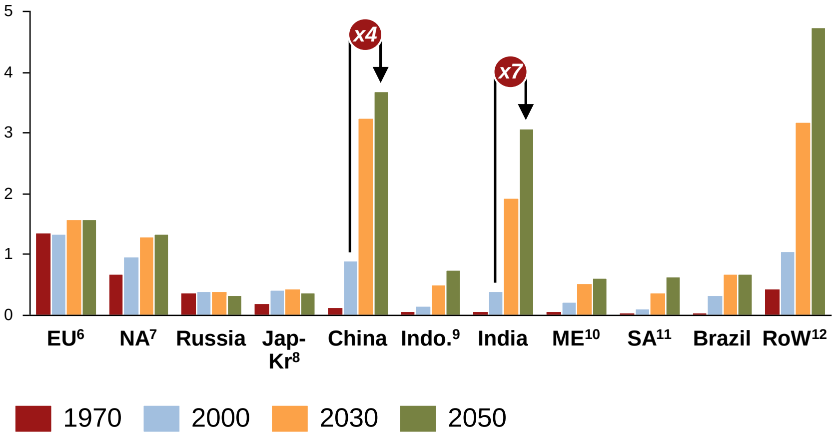
- **Eutrophication** (agriculture and domestic wastewater):
  - Can affect all surface-water bodies and coastal zones;
  - Results from an excess of nutrients[1] in water, leading to harmful algal blooms and oxygen depletion. Common nutrients are nitrogen, phosphorus and potassium[2].
- **Toxic contamination** (industry and agriculture):
  - Mostly occurs in freshwater sources;
  - Caused by the release of anthropogenic toxic compounds[3] or mobilization of naturally occurring ones[4].
- **Micro-pollutants** (domestic and agriculture):
  - Affect freshwater sources;
  - Sources include cosmetics, medicines, cleaning agents, residues from pesticides and antibiotics.
- **Acidification** (industry):

Over the long term, an increasing concentration of atmospheric CO_2 will mostly affect the oceans.[5]

Water pollution can make water not only unfit for human consumption, but also for industrial and agricultural use, and for ecosystems.

Nutrient effluents from wastewater

Mt of N/year



Nutrient effluents from wastewater are expected to increase significantly in China and India in the next 40 years. Algal blooms affect the domestic (*e.g.* drinking water) and industrial (*e.g.* cooling) use of freshwater. When algae decompose they also remove oxygen from the water, causing major losses to biodiversity and activities such as fishing[13].

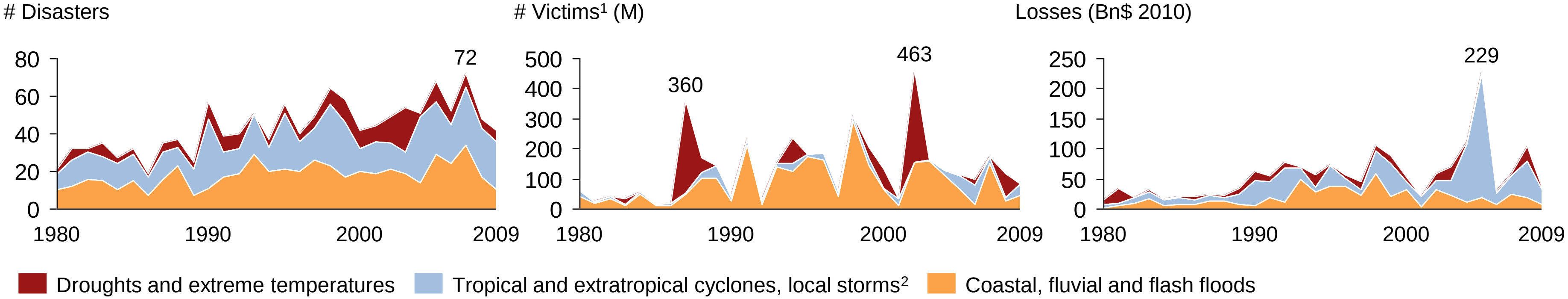
---

1. Components necessary for an organism to grow; the most consumed nutrients are carbon, hydrogen, nitrogen, oxygen, phosphorus, and sulfur; 2. Mostly from agriculture fertilizers, which drain from fields, animal waste and human sewage; 3. From poorly/non-treated waste gases and liquids; 4. E.g. arsenic in groundwater; 5. And then affects rivers and lakes through the hydrological cycle; 6. EU: European Union; 7. NA: North America; 8. Jap-Kr: Japan-Korea; 9. Indo.: Indonesia; 10. ME: Middle East; 11. SA: South Africa; 12. ROW: Rest of the world; 13. Algae have high Biochemical Oxygen Demand, a measure of the amount of dissolved oxygen required/consumed by polluting micro-organisms to feed on organic material, grow and reproduce. This removes oxygen from water and damages biodiversity.

Source: OECD (2012), “Environmental Outlook to 2050”; UNEP (2010), “UNEP Emerging Issues: Environmental Consequences of Ocean Acidification: A Threat to Foot Security”

Droughts, storms and floods have environmental, social, and economic consequences and impact all dimensions of water risks

Global Water and weather-related disasters



Disasters

Victims[1] (M)

Losses (Bn$ 2010)

Droughts and floods are caused by water quantity (scarcity or excess), **supply location and reliability/timing.** The resulting stresses from floods and droughts, as well as **storms[2],** impact water quality and price, and can result in societal/cultural shocks, and regulatory procedures and lawsuits. All three have **severe economic impacts, potentially with millions of victims[1].** For instance, in 1983, drought and resulting famine led to more than 400,000 fatalities in Ethiopia and Sudan. In 2002, drought in India, and floods and storms in China, resulted in 450 million victims[1]. In 2005, Hurricane Katrina and the flooding it caused in the U.S. led to economic damage amounting to 140 Bn$. Between 1980 and 2009, storms accounted for nearly 45% of all weather-related disasters, floods ~40%, and droughts 15%. About 2/3 of the victims can be attributed to floods, 25% to droughts and about 12% to storms. **Each disaster type has different causes**:

- **Droughts**: poor land utilization and poor management of water stocks can cause long periods of water deficit;
- **Storms[2]**: combined persistence, over sufficiently long periods, of specific conditions (pre-existing weather disturbance, warm tropical oceans, moisture, light winds) can produce the violent winds, waves, torrential rains, and floods associated with storms (NOAA);
- **Floods**: unusually heavy, prolonged rain, and/or rivers rising (due to rapid seasonal ice-melt and/or poor natural soil or artificial drainage).

Note: NOAA: National Oceanic and Atmospheric Administration; 1. Victims refer to people affected or killed by incident; 2. Hurricanes, typhoons and cyclones refer to the same phenomenon occurring in different geographical areas: Atlantic and Northeast Pacific; Northwest Pacific; South Pacific and Indian Ocean respectively.

Source: OECD (2012), “Environmental Outlook to 2050”; UN (2012), “Managing water under uncertainty and risk”; Black et al (2009), “The Atlas of Water”; National Oceanic and Atmospheric Administration website (http://oceanservice.noaa.gov/facts/cycslone.html)

Water-related diseases result in hundred thousands of fatalities that are avoidable both via sanitation and improvements in water supply

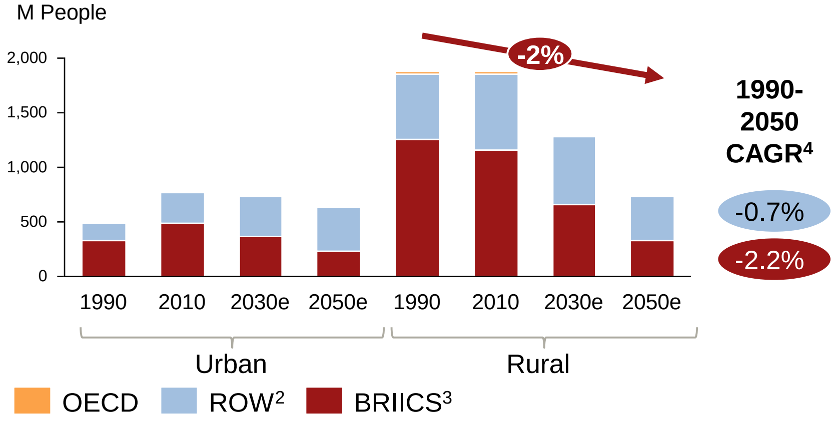
Impact of main water-related diseases & assessment of routes of transmission

Disease	2002 annual global fatalities attributable to water, sanitation and hygiene	Pathways / Vectors	% of total burden[1] avoidable if pathway controlled
Diarrhoea	1,523,000	Water supply	94
Malnutrition	863,000	Water supply, sanitation, hygiene, water resources management	50
Malaria	526,000	Water resources management	42
Dengue	18,000	Water supply, sanitation	95
Schistosomiasis	15,000	Water supply, sanitation, water resources management	100
Japanese encephalitis	13,000	Water resources management	95
Intestinal nematodes	12,000	Sanitation	100

Water supply, sanitation and hygiene are linked to several water-related diseases:

- Directly, when bacteria/pathogens develop/are transmitted through water.
- Indirectly, when poor management presents an adequate environment for mosquitos and other vector insects.

Number of people without access to basic sanitation facilities (2012)



Two factors are vital in reducing water-related diseases:

- *Access to basic sanitation*, meaning access to toilet facilities for the safe disposal of human excreta (*e.g.* flush or pour-flush to piped sewer system). Access to sanitation is currently ~2.4 times worse in rural than in urban areas. It is expected to improve at ~2% per annum (1990-2050) in all rural regions, mostly driven by urbanization in BRIICS countries[3] and higher incomes.
- *Access to an improved water source,* meaning piped water, public taps, standpipes, protected dug wells, protected spring or rainwater collection; unimproved water sources are unprotected wells or springs, water carts and tanker trucks.

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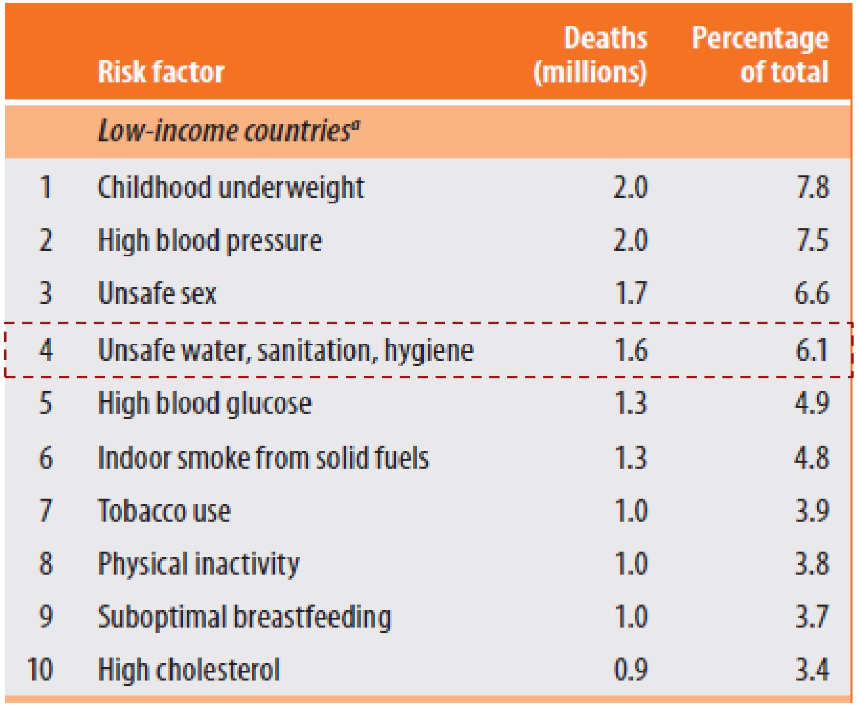
1. The burden of a disease includes death, illness and disability caused by the disease; 2. ROW: Rest of the world; 3. BRIICS: Brazil, Russia, India, Indonesia, China and South Africa; 4. CAGR: Compound annual growth rate.

Source: WHO (2008), "Safer Water, Better Health"; WHO (2006), "Preventing Disease Through Healthy Environments"; Black & King (2009), "The Atlas of Water"; OECD (2012), "Environmental Outlook to 2050"; WHO/UNICEF Joint Monitoring Programme (2008), "Millennium Development Goal Assessment Report"; A.T. Kearney Energy Transition Institute analysis

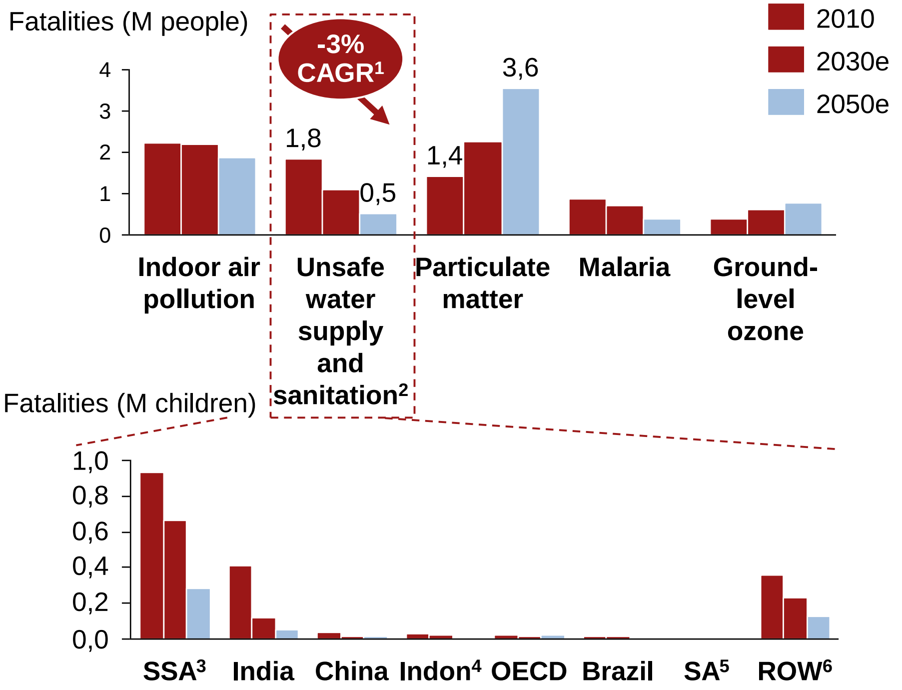
Water presents a high risk of fatality in low-income countries, particularly in children

Ranking of causes of Fatality For low-income countries (2004)



	Risk factor	Deaths (millions)	Percentage of total
	Low-income countries[a]		
1	Childhood underweight	2.0	7.8
2	High blood pressure	2.0	7.5
3	Unsafe sex	1.7	6.6
4	Unsafe water, sanitation, hygiene	1.6	6.1
5	High blood glucose	1.3	4.9
6	Indoor smoke from solid fuels	1.3	4.8
7	Tobacco use	1.0	3.9
8	Physical inactivity	1.0	3.8
9	Suboptimal breastfeeding	1.0	3.7
10	High cholesterol	0.9	3.4

Premature Fatalities due to various environmental factors



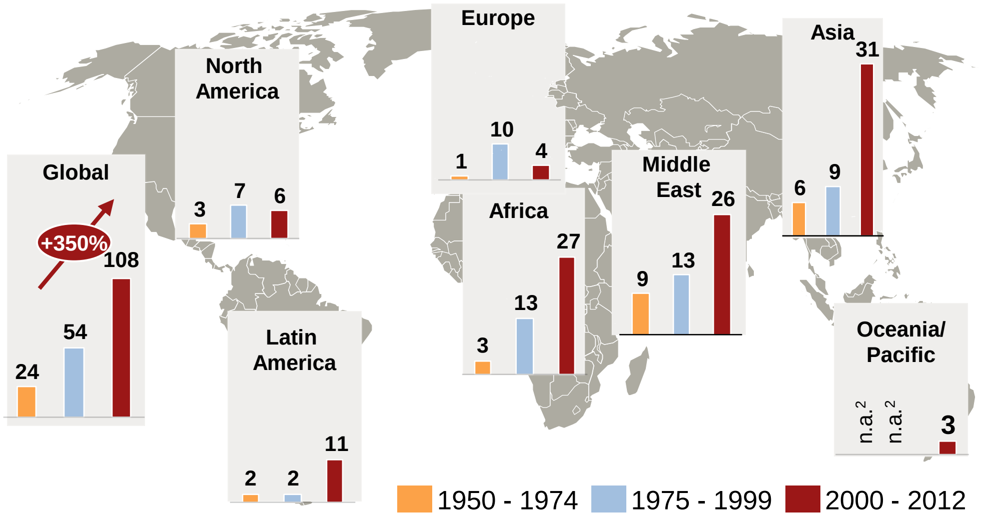
- Unsafe water supply and sanitation was the 4th worst fatality risk in low-income countries in 2004.
- **Lack of access to** adequate **water supply and sanitation** resulted in 2010 in **1.8 million children fatalities.** Greater access to improved water supply and basic sanitation facilities is expected to reduce child mortality from diarrhea, which has a greater impact on children under 15 than HIV, AIDs, malaria, and tuberculosis combined.

Note: Picture credits: WHO (2009); 1 CAGR: Compound annual growth rate; 2 Premature child mortality only; 3 SSA: Sub-Saharan Africa; 4 Indon: Indonesia; 5 SA: South Africa; 6 ROW: Rest of the world.
Source: OECD (2012), "Environmental Outlook to 2050"; WHO (2009), "Global Health Risks: Mortality and Burden of Disease Attributable to selected major risks"

Freshwater has been the cause of or played an integral part in numerous conflicts

Number of water-related conflicts 1950 – 2012 by region[1]

of conflicts



Water conflict examples:

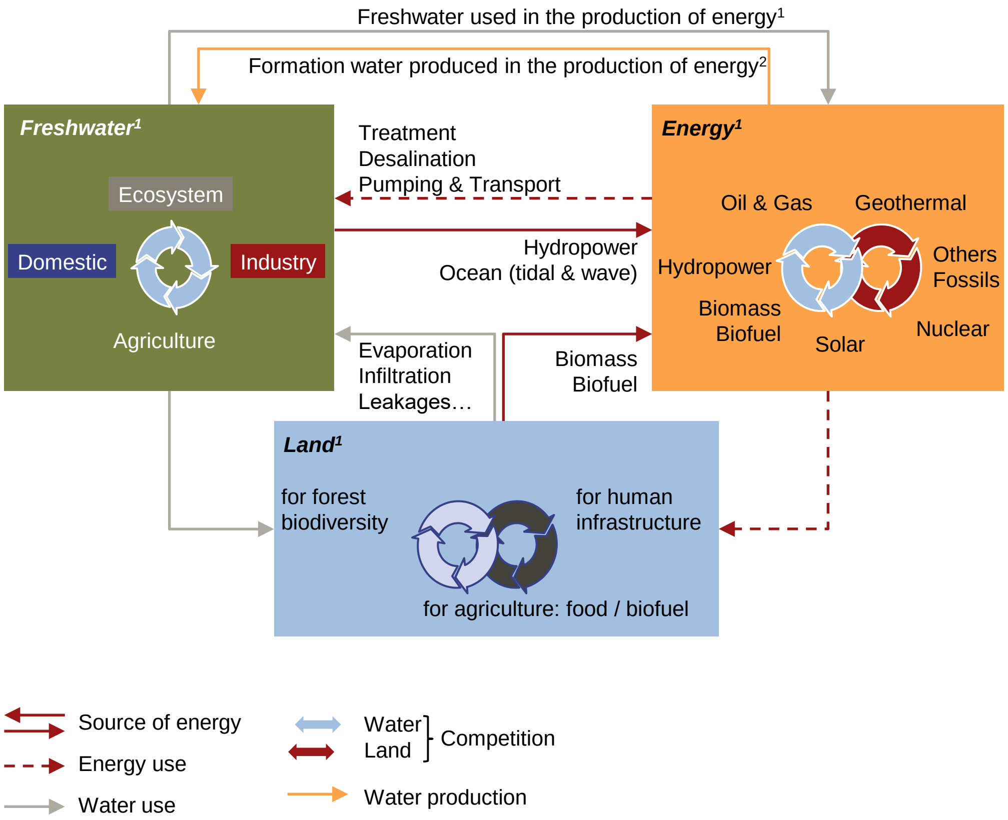
- Water-development dispute, **1958**, **Egypt**, **Sudan**: Egypt sent an unsuccessful military expedition into disputed territory amidst pending negotiations over the Nile waters; Nile Water Treaty signed when pro-Egyptian government elected in Sudan.
- Water as a military tool/target & terrorism, **2003–2007, Darfur**, **Sudan**: The ongoing civil war in the Sudan has included violence against water resources. Bombings destroyed water wells. Water wells were intentionally contaminated as part of a strategy of harassment against displaced populations.
- Water used as a military weapon, **2006, Sri Lanka**: Tamil Tiger rebels cut the water supply to government-held villages in northeastern Sri Lanka. Sri Lankan government forces then launched attacks on the reservoir, declaring the Tamil actions to be terrorism
- Water as a development dispute & military target, **2012, Sudan/South Sudan**: Violence breaks out at water points. >10 refugees die every day because of water shortages at refugee camps in South Sudan.
- Water as a military target & military tool, **2014, Sudan** : Fighting displaces thousands and leaves many dead. A water pipeline to the UN compound is targeted and destroyed.

- **Water conflicts are thousands of years old** (the first reported dates back to ~2400BC in Mesopotamia).
- **The number of reported conflicts[1] has increased by 350% worldwide** in the last 6 decades. Today, **most** of the conflicts occur **at a sub-national level**. **Freshwater is** at the **root of numerous conflicts** at different levels, **as a:**
  - **Source of conflict**: limited supply and/or access to it, has provoked numerous disputes, motivated by need for economic and social development;
  - **Conflict target for** nations or as a means of coercion by non-state groups;
  - **Military, terrorist or political tool**: water resources or systems can be used as a weapon or as a political tool by state or non-state agents.
- According to the Food and Agricultural Organization, more than **3,600 treaties related to international water resources have been completed** to date. But their **lack of enforcement measures and conflict resolution mechanisms are recognized weaknesses**. Surprisingly, a 2006 UNDP report indicated that only 1/3 of 145 transboundary agreements focus on water utilization volume allocation.

Note: See UNESCO special series on Water and conflict resolution. 1 In the late 1980s, the Pacific Institute initiated a project to track events related to water and conflicts and updated it continuously since; 2 n.a.: Not available.
Source: Gleick and Heberger (2012), ''Water and Conflict: Events, Trends and Analysis (2011-2012)"; UNDP (2006), "Beyond scarcity: Power, poverty and the global water crisis".
http://www.worldwater.org/conflict; http://www.un.org/waterforlifedecade/transboundary_waters.shtml

Water, energy and land are closely interrelated and resource competition is expected to increase

Water-Energy-Land nexus



Freshwater used in the production of energy[1]

Formation water produced in the production of energy[2]

Freshwater[1]

Ecosystem

Domestic

Industry

Agriculture

Treatment
Desalination
Pumping & Transport

Hydropower
Ocean (tidal & wave)

Evaporation
Infiltration
Leakages…

Biomass
Biofuel

Energy[1]

Oil & Gas

Geothermal

Hydropower

Others
Fossils

Biomass
Biofuel

Solar

Nuclear

Land[1]

for forest
biodiversity

for human
infrastructure

for agriculture: food / biofuel

Source of energy

Energy use

Water use

Water } Competition
Land

Water production

- **Challenging compromises will need to be made globally and locally**. For instance, by 2030, increases in water scarcity could result in annual losses in global grain production of ~30%, at a time when food production needs to increase by 70-100%. And the fastest-growing regional economies will witness a sharp rise in energy/industrial water demand which is problematic because they are currently allocating on average 60-90% water to agriculture. How to **square these circles** will be a **key challenge in** the **decades to come.**
- **Water and energy** are closely interrelated (see section 6) and their **relationship is and will remain under stress.** *E.g.* strong demand for one can impact or limit supply of the other, particularly where there is competition for energy or water resources. The availability of water can therefore constrain the development of the energy sector, and vice versa. Water is also a potential source of energy.
- In addition, both require extensive **land resources**: *e.g.* growth in agricultural output results in significant increases both in water and in energy consumption.

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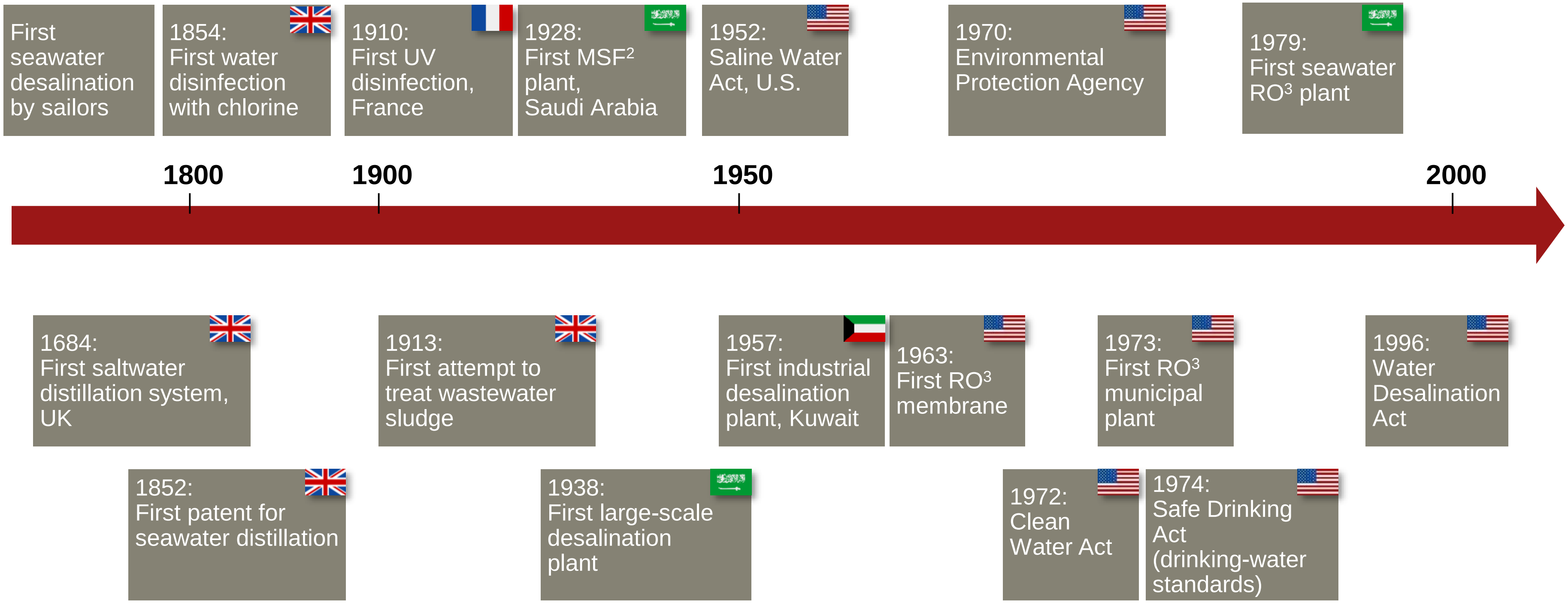
1. Each subsection competes with the others for freshwater supply, contributing to global stress; 2. Oil and gas companies produce a large quantity of saline formation water during the exploration and production of a field. Mature depleted fields require either water or gas injection to maintain production (enhanced oil/gas recovery).

Source: European report on development (2012), "Confronting scarcity: Managing water, energy and land for inclusive and sustainable growth"; World economic forum (2011), "Water security, the water-food-energy-climate nexus"; A.T. Kearney Energy Transition Institute analysis

4. Value chain and technologies

Water treatment and desalination are old processes but most of their technological development occurred after the 1950s

Timeline[1]



First seawater desalination by sailors

1854: First water disinfection with chlorine

1910: First UV disinfection, France

1928: First MSF[2] plant, Saudi Arabia

1952: Saline Water Act, U.S.

1970: Environmental Protection Agency

1979: First seawater RO[3] plant

1684: First saltwater distillation system, UK

1913: First attempt to treat wastewater sludge

1957: First industrial desalination plant, Kuwait

1963: First RO[3] membrane

1973: First RO[3] municipal plant

1996: Water Desalination Act

1852: First patent for seawater distillation

1938: First large-scale desalination plant

1972: Clean Water Act

1974: Safe Drinking Act (drinking-water standards)

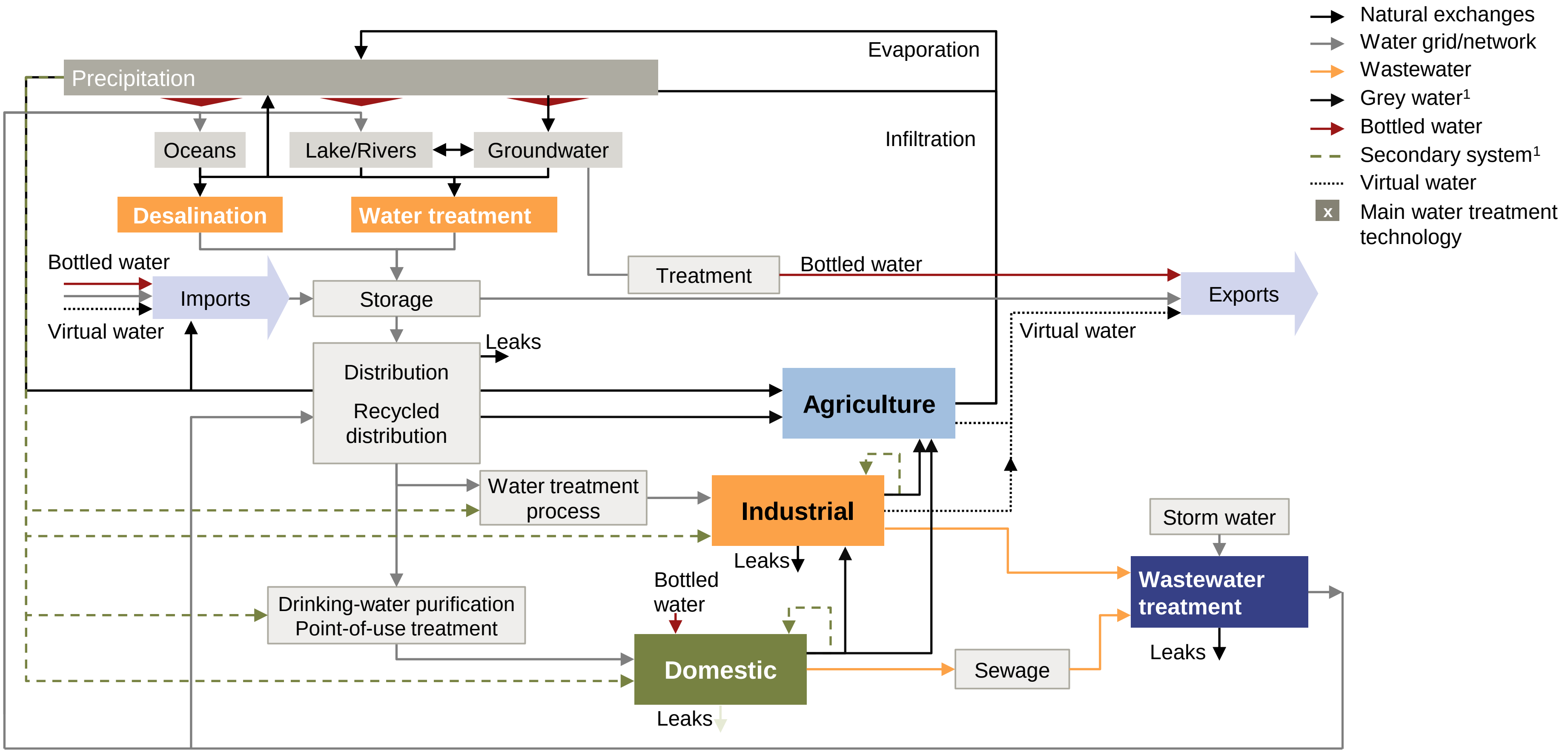
---

1. The scale of the time interval is not respected for visibility purpose;
2. MSF: Multi-Stage Flash (thermal); 3 RO: Reverse Osmosis (membrane).

Source: Cooley et al. (2006), "Desalination with a grain of salt"; Al-Mutaz (1995), "A comparative study of RO and MSF desalination plant"; Dessouky and Ettouney (2002), "Fundamentals of salt water desalination"; U.S. national archives (online); A.T. Kearney Energy Transition Institute analysis

The water value chain is complex and fragmented among various industries

Water value chain

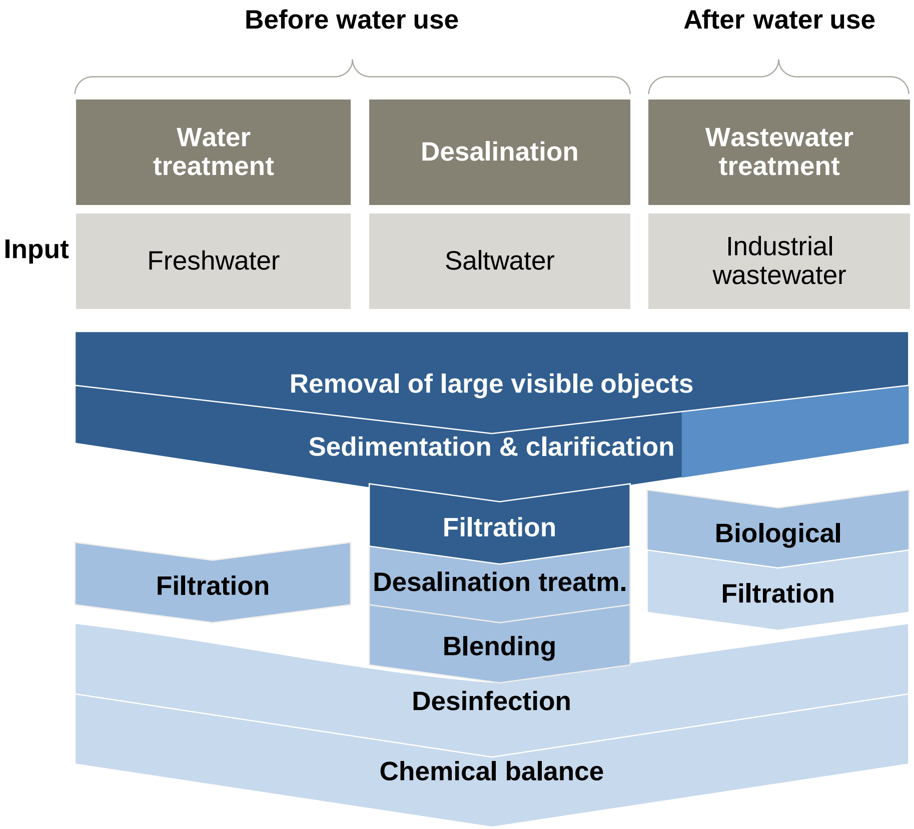


Nota: Water-demand management is not represented here, but is becoming an increasingly important element in the water value chain;

1. Greywater: wastewater generated from domestic or industrial processes, reused internally in a secondary system (large dotted line) or externally by another process (e.g. irrigation).

Source: SAM (2010), "Water: a market of the future"; UNEP (2012); "Measuring water use in a green economy

Water treatment, desalination, and wastewater treatment share many of the same processes, but often use different terms



Before water use | **After water use**

	Water treatment	Desalination	Wastewater treatment
Input	Freshwater	Saltwater	Industrial wastewater

Removal of large visible objects

Sedimentation & clarification

Filtration

Biological

Filtration

Desalination treatm.

Filtration

Blending

Desinfection

Chemical balance

🟦 **Pre-treatment** is a preliminary mechanical or chemical process that involves:

- Coarse screening to remove debris that could damage the treatment facility's equipment.
- Forcing high-flow water through a (grit) chamber to separate grit (gravel, sand) from the remaining matters treated further down the process chain.
- Chemical addition to prepare water for further treatment.

🟦 **Primary treatment** is a mechanical process based on the decantation of organic and inorganic materials and the removal of floating materials in primary settling tanks (clarifiers). It can remove ~60% of total suspended solids and up to 65% of oil and grease. Removing organic matter can reduce Biochemical Oxygen Demand (BOD)[2] by 25-50%.

🟦 **Main/secondary[3] treatments differ in each value chain.** Wastewater biological removal of residual organics is achieved by adding micro-organisms to an aerated tank. These metabolize waste, grow and settle at the bottom of the tank, at which point they are disposed of. This process can remove up to 90% of organic matter and reduce BOD[2] by up to 85%.

⬜ **Post/tertiary[3] treatment** involves the implementation of advanced final processes before water use. These consist of:

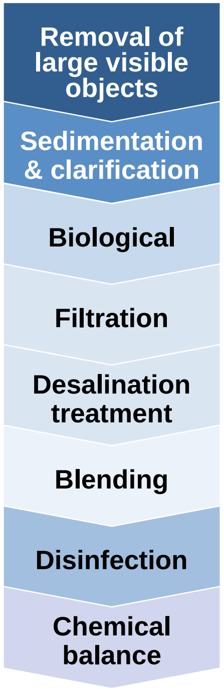
- Ultraviolet, chloramine, ozone or chlorine disinfection, followed by
- Chemical balancing, which involves remineralization, and the neutralization of common pollutants (nitrogen or phosphorus) or specific industrial/treatment ones, and of the pH balance.

Note: The implementation of the various processing stages and the degree of treatment are determined by regulations on effluent quality.

1. Mixing saltwater and freshwater lowers the concentration of salt to meet consumer requirements. Blending can also be done before the desalination step by lowering input concentration and thus facilitating desalination; 2. Biochemical Oxygen Demand (BOD) is the amount of dissolved oxygen required by micro-organism to degrade organic material used for growth and reproduction. It indicates the waste's capacity to remove oxygen from water and is commonly expressed in milligrams of oxygen consumed per liter during a 5-day incubation. Therefore, removing micro-organisms/organic matter reduces oxygen demand, making more oxygen available for ecosystems. BOD is a useful measure for assessing the effectiveness of treatment processes; 3. Wastewater terminology.

Source: IEA-ETSAP and Irena (2012), "Water desalination using renewable energy"; California water plan (2013); The World Bank (online) "Sanitation, hygiene and wastewater resource guide"; FAO document repository (1992), "Wastewater treatment and use in agriculture"

3 types of treatment technologies are used at various stages of the value chains



Removal of large visible objects

Sedimentation & clarification

Biological

Filtration

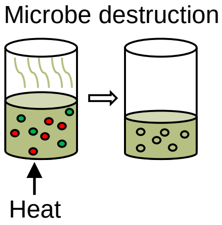
Desalination treatment

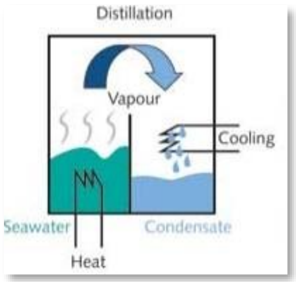
Blending

Disinfection

Chemical balance

Thermal

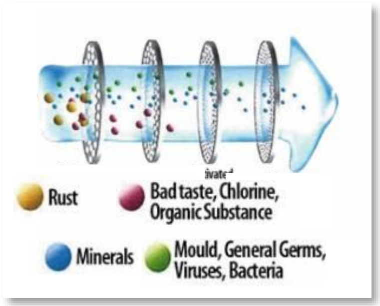




Boiling water is the oldest process **for disinfecting** organically polluted water (**intestinal diseases, microbes**, viruses…), but it cannot remove chemical toxins.

Vaporizing water, then condensing it, **leaves** some **dissolved molecules/matter behind**. This process is used in **desalination** to **produce freshwater by vaporizing saline feed-water.**

Membrane/screen



Specific molecules can be physically separated using screens and pressure differences. Semi-permeable membranes retain dissolved molecules that exceed the size of its pores, letting smaller ones and water pass through. This process is used in:

- **Desalination** to remove salt.
- **Water treatment** to retain small pollutants.
- **Wastewater treatment** to separate the floc (mass created by chemically flocculated waste).

Biological - Chemical

Different processes are used to:

① **Chemically** facilitate electrical (coagulation) and physical (flocculation) agglomeration, by increasing floc weight and thus **enhancing decantation**.

② **Biologically reduce Biochemical Oxygen Demand (BOD)**[1] by controlling population of micro-organisms.

③ **Chemically disinfect** and **balance the water** by eliminating hazardous agents.

Note: Picture credits: Waterworld (online); Konia (online); bbdr (online);

[1] See Biochemical Oxygen Demand (BOD) definition slide 40 and 49.

Source: IEA-ETSAP and Irena (2012), "Water Desalination Using Renewable Energy"; FAO Water Reports (2010), "The Wealth of waste"; WHO (2011), "Safe Drinking-water from Desalination"

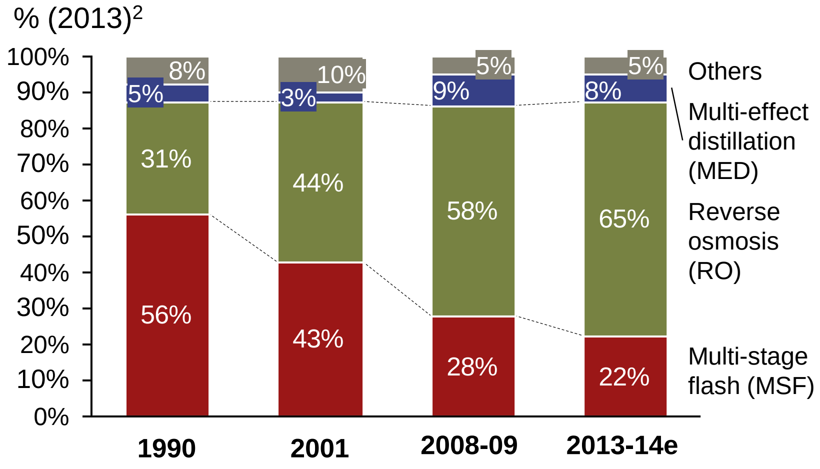
Desalination is currently performed by membranes or thermal technologies

Process description

Desalination is a saltwater[1] treatment process that removes **dissolved salt** and other chemicals, creating an alternative supply of freshwater or lower-salinity water. It can reduce salt content to varying degrees for different purposes: low-purity[1] uses (agriculture, industry cleaning or cooling); drinking-water; or high-purity water for specific industrial processes. Two main treatment technology groups exist:

- **Membrane,** in which a pressure-driven process, reverse osmosis (RO), is the main technology: a high-pressure pump forces water molecules through special semi-permeable membranes, overcoming natural osmotic pressure and leaving larger molecules behind, including salt.
- **Thermal,** in which multi-stage flash (MSF) and multi-effect distillation (MED) are the two dominant technologies:
  - In MSF, feed water is boiled and some of it vaporizes -or flashes. The process is repeated with the remaining water, in an environment of gradually decreasing pressure, enabling flashing to continue throughout the next stages;
  - In MED, feed-water vapor flows into steam tubes. These heat the remaining water during the following stages (or effects), in which successively decreasing pressures also facilitate evaporation

Global installed desalination capacity by technology



- RO and MED desalination technologies have grown significantly over the past 10 years, mainly as a result of recent advances in RO pretreatment technologies, RO's relatively low energy consumption and the lower energy requirements of MED compared with MSF.
- "Others" include newer/under development desalination technologies, such as electrodialysis, forward osmosis, or carbon nanotube.

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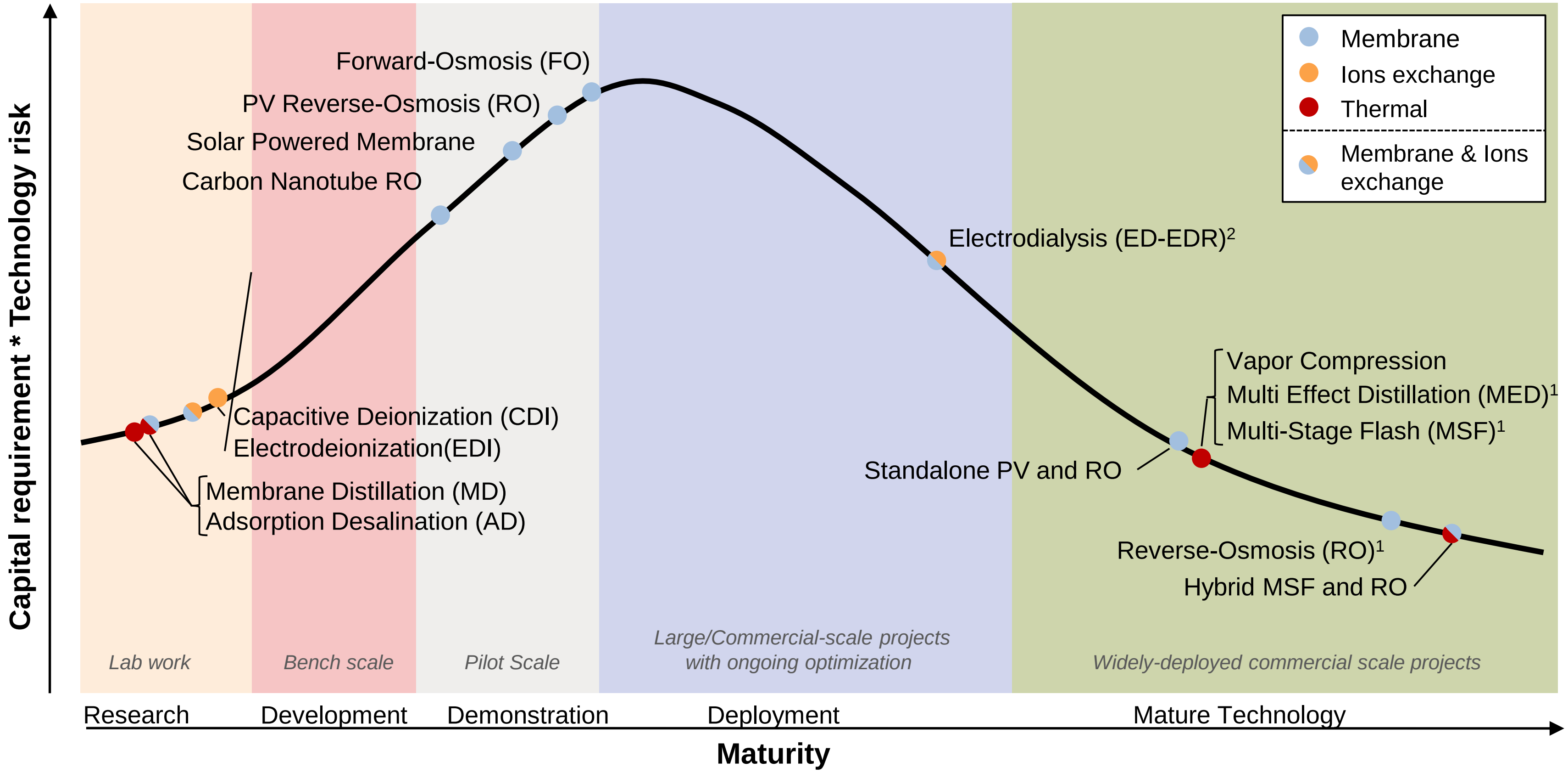
1. Saltwater includes brackish (1,500-15,000ppm), seawater (15,000-50,000ppm) and brine (40,000-300,000ppm); Low-purity water refers to water with high Total Dissolved Solid (TDS) and vice versa; 2. Cumulative installed capacity, from Bashitialshaaer et al. (2013) and GWI reference therein.

Source: Bashitialshaaer et al. (2013), "China desalination cost compared to long-term estimation"; California Water Plan Update 2013; IEA-ETSAP and Irena (2012), "Water Desalination Using Renewable Energy"; Credit Suisse (2009), "Water: The pressure is rising"; GWI (2011), "Global water market 2011"

Desalination technologies exist at all maturity stages

Technology maturity curve



1. According to World bank, MSF has reach its technological maturity while Multi Effect Distillation (MED) and Reverse-Osmosis (RO) have the potential for additional technological development. These three technologies are here ranked according to their market share; 2. Mature but not widely used.

Source: Colorado School of mines (2009), “An Integrated Framework for Treatment and management of produced water”; Memorandum (2013), “scwd2 Regional seawater desalination project”; World bank (2012), “Renewable energy desalination: an emerging solution to close the water gap in the Middle East and North Africa”; A.T. Kearney Energy Transition Institute Analysis

The main desalination technologies are suited for different applications

Desalination: Removal of large visible objects → Sedimentation/ Clarification → Filtration → **Desalination Treatment** → Blending → Disinfection → Chemical Balance

		Capex	Opex	Energy use	Installed capacity[1] (Mm³/d)	Plant size & output range per unit[2] (m³/d)	Operational complexity	Input water quality constraints			Output quality potential
								Seawater	Brackish water	Pre-treatment	
Membrane	**Reverse-osmosis**	○	○	○	43.1	Largest plants [0-240,000]	●	✓	✓	Yes	✓
Thermal	**Multi-stage flash**	●	●	●	19.2	Large plants [0-78,700]	○	✓	✗	No[3]	✓✓
	Multi-effect distillation	◐	◐	◐	5.7	Small plants [0-37,850]	◐	✓	✗	No	✓✓

● Highest ◐ Medium ○ Lowest

1. IEA-ETSAP (2011), figures calculated from market share and total installed capacity (77 Mm3/day); 2. A plant can be composed of one or multiple units; 3. Additional cooling is required for MSF treatment.

Source: IEA-ETSAP and Irena (2012), "Water Desalination Using Renewable Energy"; Credit Suisse (2009), "Water: the pressure is rising", GWI (2011); "Global water market 2011"; Pacific Institute (2006), "Desalination with a grain of salt"; Fichtner (2011), "MENA regional water outlook, part II, Desalination using renewable energy, task 1&2";
A.T. Kearney Energy Transition Institute Analysis

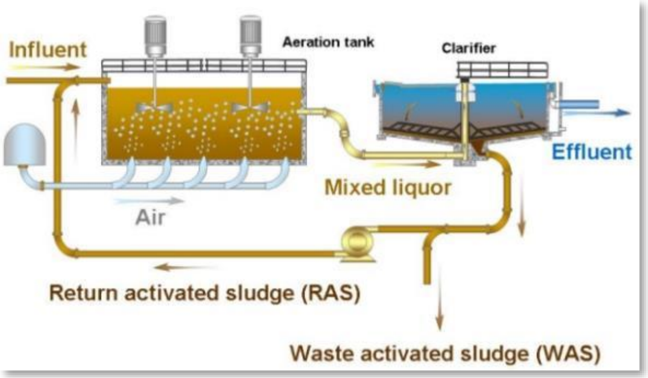
Wastewater treatment involves the biological processing of the combination of the influent and activated sludge

Process description

- Wastewater
- Removal of large visible objects
- Sedimentation/ Clarification
- **Biological**
- **Activated Sludge**
- Filtration
- Disinfection
- Chemical Balance

In the activated sludge[1] process, micro-organisms degrade organic waste under aerobic conditions. The micro-organisms grow, clump together and eventually settle **at the bottom of the tank** (clarifier). Activated sludge is used to clear organic and suspended solids from the influent[1] and reduce Biochemical Oxygen Demand[2]. Some of the sludge is reused (RAS in illustration), while the rest is disposed of (WAS) and can be digested to produce biogas. The treatment can be performed by different technologies, including:

- Conventional activated sludge process (in the illustration).
- Sequencing batch reactor with a one-tank settling system only.
- Membrane biological reactor, in which a membrane replaces the settlement process.



Technology	Pros	Cons
Activated sludge process	Very efficient process Low Capex and Opex	Difficulty to adjust to variations in waste composition Large space requirement (secondary clarifier or tank)
Sequencing batch reactor	Reliable remote operations and maintenance One tank: small space requirement	High energy consumption Sludge needs to be disposed of frequently
Membrane biological reactor	Does not need tertiary treatment Higher flow rate than settling method Small space requirement	Higher capital and operational cost for same throughput than the other two High energy consumption

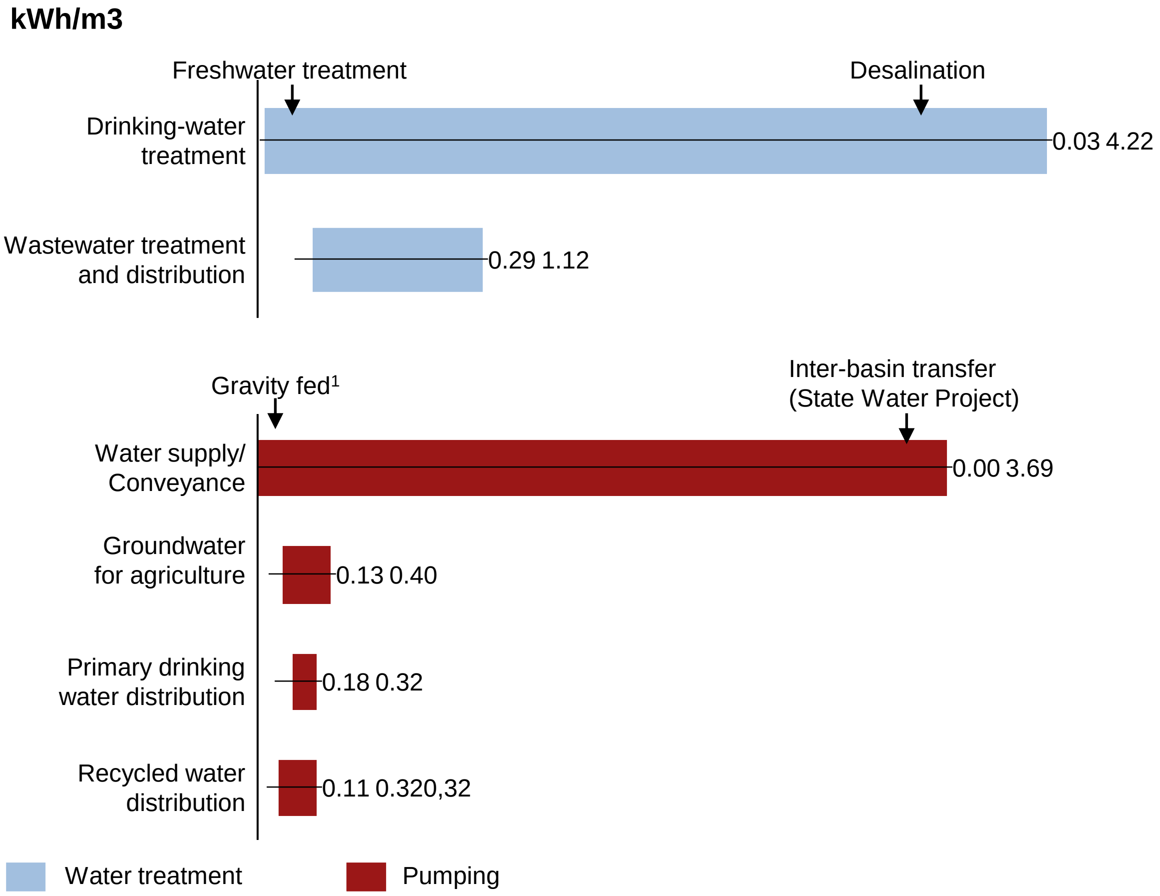
Note: Picture credits: ewisa (online);

1. “Activated sludge refers to a mass of micro-organisms cultivated in the treatment process to break down organic matter into carbon dioxide, water, and other inorganic compounds” World Bank (online); 2. See slide 40 and 49.

Source: GE power and water (online), membrane bioreactor; EPA (2007), “Wastewater management fact sheet, membrane bioreactors”; Pipeline (2003), “Explaining the activated sludge process”; The World bank Sanitation Hygiene and Wastewater (SHW) resource guide (online)

Energy is a key requirement in water systems

Example of energy intensity in water treatment (top) and pumping (bottom), in California



The energy intensity of water treatment is mainly determined by the quality of input water and the desired output quality.

- Treatments of water with high salinity (*e.g.* seawater, produced water from oil & gas operations) or large amounts of organic material (*e.g.* municipal wastewater) require a large amount of energy.
- Increased use of treated, non-freshwater supply will thus lead to an increase in energy requirements.
- Desalination can be 100 times more energy-intensive than freshwater treatment.

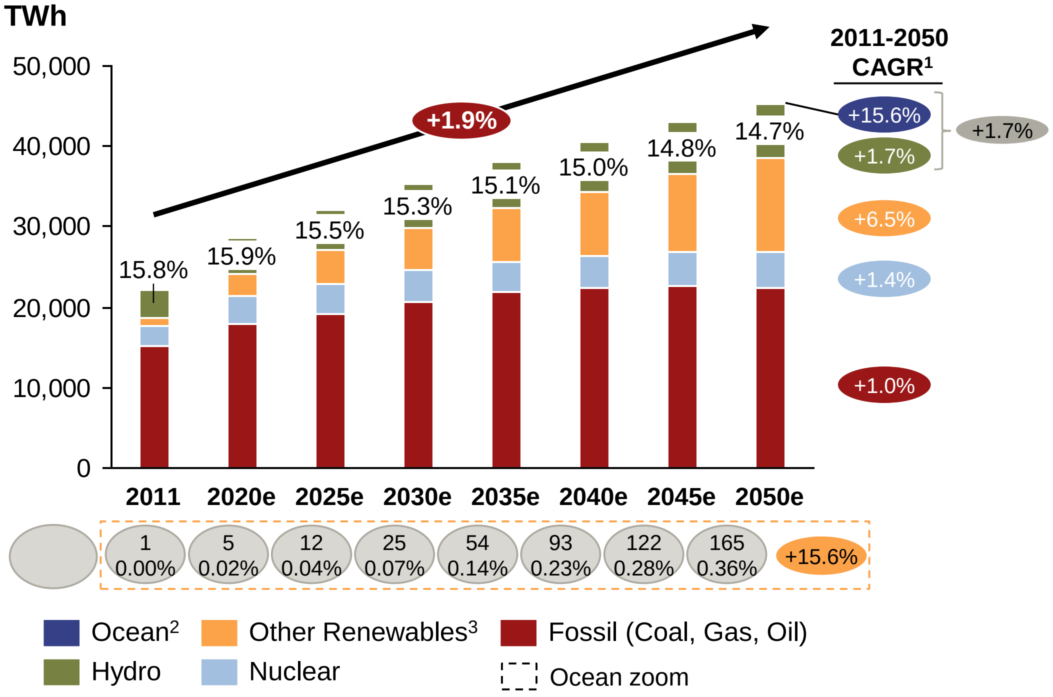
The energy intensity required for water pumping can vary significantly, depending on the difference in elevation between the source and the target location. *E.g.* inter-basin transfer can be 10 times more energy intensive than local distribution (*e.g.* gravity-fed) or groundwater pumping.

1. Gravity fed: water supply technology using gravity to transport water.

Source: DOE (2014), “The Water-Energy Nexus: Challenges and Opportunities”; WaterAid (2013), “Gravity-fed schemes”

Hydropower is among the main contributors to global electricity production, but marine power’s contribution remains very small

Gross global electricity generation (2014)



Projected data are based on the 4DS, or New Policies, scenario, which assumes recent government policy commitments will be implemented even if they have not yet been backed up by firm measures.

- **Methods of generating electricity from water** include hydropower, wave power and tidal power.
- **Hydropower contributes more than nuclear power to the global electricity mix**. Other renewables are expected to surpass hydropower by 2035. China, Brazil (80% of power generation), Canada (60%), the US, and Russia are the world leaders in hydropower.
  - 2009 global installed capacity was 1,007 GW (ETP 2012). Total technical potential is estimated to be 3,721 GW (NREL 2011), in Africa 92% of the hydropower capacity is still underdeveloped;
  - Small hydropower installed and potential capacity are 75 and 173 GW respectively;
  - IEA Energy Technology Perspectives indicates that hydropower’s contribution increased from 3252 TWh in 2009 (IEA 2012) to 3490 TWh in 2011 (IEA 2014).
- **Electricity production from ocean** (wave and tidal) is forecast to remain **below 0.5% of the global mix until 2050.**

---

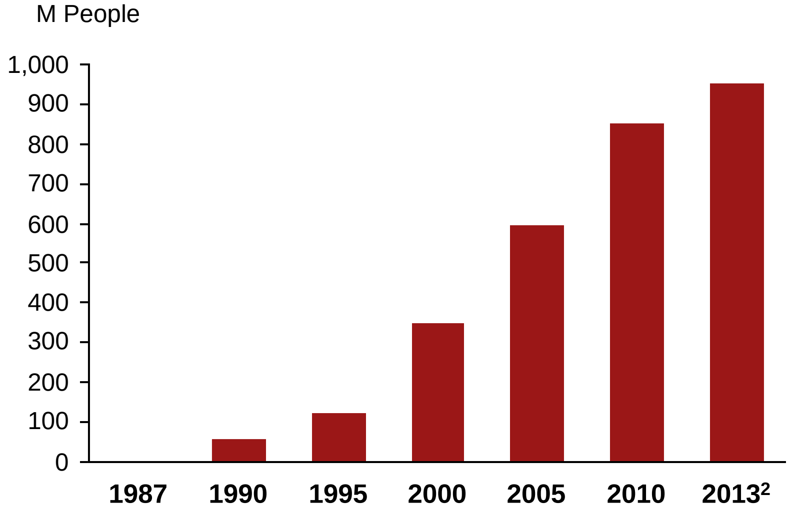
1. CAGR: Compound annual growth rate; 2. Wave and tidal; 3. Include solar (photovoltaic and concentrating solar power), wind (onshore and offshore), biomass and geothermal. The 2DS scenario includes a growth rate per annum for other renewable of +7.8%.

Source: IEA (2012, 2014), “Energy Technology Perspectives”; National Renewable Energy Laboratory (NREL) (2011), “Chapter 5: Hydropower”, “Chapter 6: Ocean Energy”; UNIDO and ICSHP website www.smallhydroworld.org/; A.T. Kearney Energy Transition Institute analysis

5. Water market trends and promising solutions

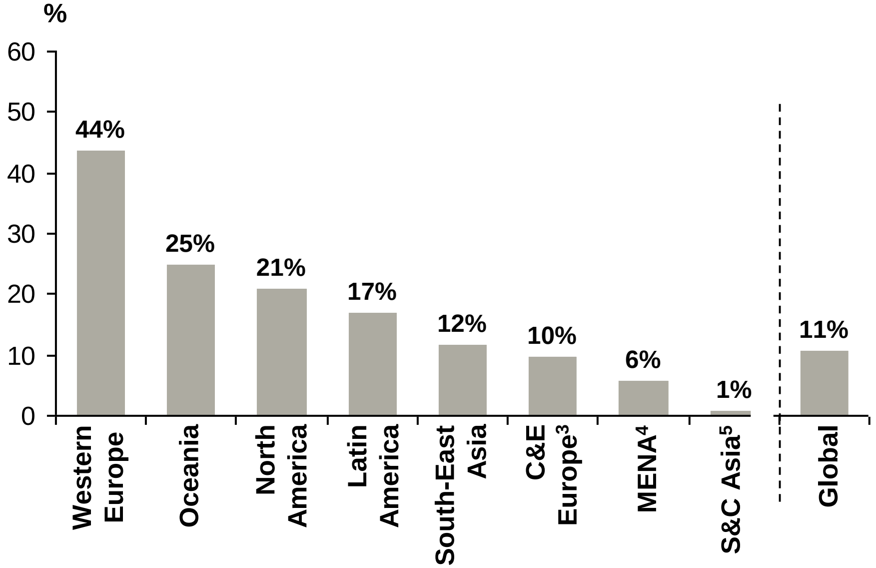
Privatization of the water sector has increased in the past two decades. Western Europe has the highest degree of water-sector privatization

Cumulative number of people served by Private sector participation contracts[1]



The number of people served in water (& sewerage) by the private sector increased rapidly from 1990 to 2010 (and, more recently, at a slower rate)**. It now stands at almost 1 billion people.** Between November 2012 and November 2013, an additional 33.5 million people in China and 11.9 million in India switched to private-sector service providers.

Proportion of population served by the private sector (2008)



Private-sector penetration in 2008 was high in Western Europe, Oceania and North America but still small in Asia & MENA[4]. A few countries, such as the Netherlands, Sweden, Switzerland and Japan, maintained 100% public management, while others, such as the UK[6], France and Spain, were pioneers in opening their water-services market to the private sector.

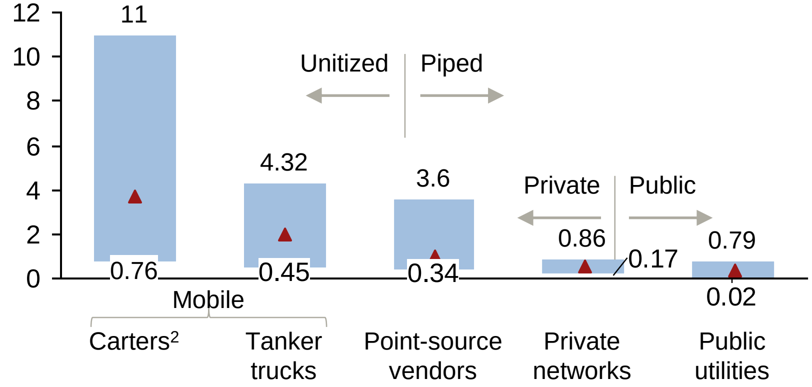
1. Private sector participation contracts are divided into categories: operating/management, lease contracts, concessions, and outright asset privatization. For more details, see GWI 201 Data of LHS graph was reproduced manually; 2. Up to end of October 2013; 3. C&E Europe: Central and Eastern Europe; 4. MENA: Middle East and Africa; 5. S&C Asia: South and Central Asia; 6. UK: United Kingdom.

Source: Crédit Suisse (2009), “Water: The pressure is rising”; GWI (2013), Volume 14, Issue 11; GWI (2011), “Global Water Market”

Water prices vary by distribution channel and geography

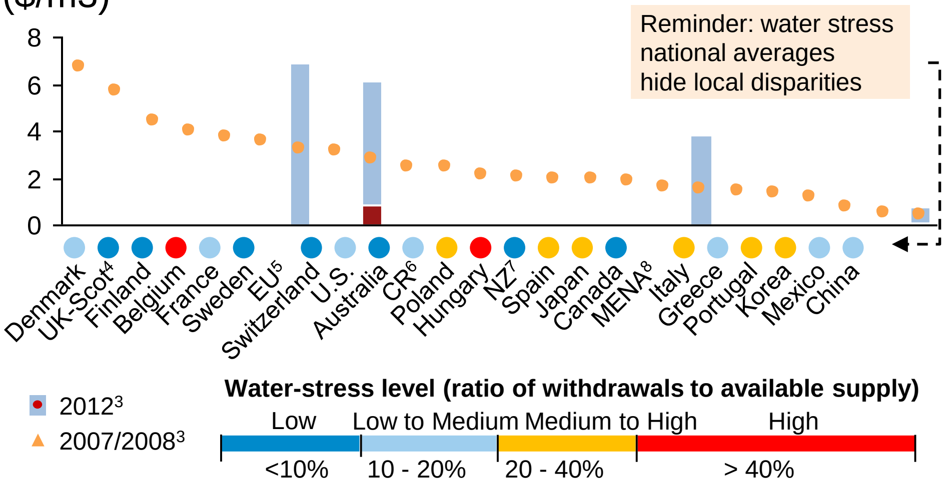
Small-scale Water-supply tariff by distribution channel[1]

($/m3 (2005))



Water tariff ranges by geography

($/m3)



Reminder: water stress national averages hide local disparities

Water tariffs vary according to the distribution channel. Prices fall as volumes and thus economies of scale in production and sales increase. Public and private utilities can also charge less by incorporating government subsidies.

Municipal and household **prices differ significantly by country**. Despite rising costs[9], **water remains heavily subsidized. Low water prices,** not reflecting real costs[10], **encourage wastage and over-extraction.** Some **water-scarce countries charge** a lot **less** for water (free in India, cheap in China and Mexico) than water-rich ones (UK[11], Denmark).

Note: Note that water value and water price (~infrastructure + delivery cost) can be significantly different depending on the stakeholders considered.

1. Based on data from 47 countries and 93 locations taken from the literature review; 2. Carters are vehicles/equipment used to obtain water from suppliers, wells and boreholes, and unimproved / untreated sources (springs, rivers, and lakes) and deliver it for different uses to homes unconnected to water infrastructure; 3. 2012 municipal water price and 2007/2008 household unit price of water and wastewater services including taxes; 4. UK-Scot: United Kingdom-Scotland; 5. EU: European Union; 6. CR: Czech Republic; 7. NZ: New Zealand; 8. MENA: Middle East & North Africa; 9. Resulting from more stringent quality standards and rising production cost; 10. Average water prices for the agricultural sector are about 0.10 $/m³ versus 0.60-3.00 $/m³ for industrial and household use. In many OECD countries, farmers only pay operational and maintenance costs for water supply, and not a share of capital costs for infrastructure; 11. UK: United Kingdom.

Source: Kariuki and Schwartz (2005), “Small-Scale Private Service Providers of Water Supply and Electricity A Review of Incidence Structure Pricing”; BNEF (2012), “Water leadership forum results book”; OECD (2012), “Environmental outlook to 2050”; Goldman Sachs (2013), “Sustainable Growth: Taking a Deep Dive Into Water”

Solutions to the water crisis involve either a reduction in demand or an increase in supply

Potential Measures to address water challenges

- 🟩 x Domestic
- 🟧 x Industrial
- 🟦 x Agricultural
- ☐ x All 3 sectors
- ⬚ Detailed next slides

Addressing water challenges

- **↓ Demand**
  - **↑ Efficiency**
    - Better plumbing, leakage control | Efficient faucet sensor & toilet[1] | Low flow tap
    - Smart pump and valve | Less water-intensive crop; genetically modified crops (drought resistant…)
    - Increase yield; advanced irrigation technique & better crop stress management
  - **↑ Recycling**
    - Water reuse | Toilet, Faucet, laundry machine[2]
  - **↓ Pollution**
    - Industrial waste cleaning | Agricultural contamination reduction[3]
    - Water quality monitoring: unpolluted water is immediately reused/recycled and not disposed in sewage
  - **Regulation**
    - Metering, maximum water-use standards, pressure & data management | Irrigation scheduling
  - **Substitution**
    - Economic activities switching to less water-intensive ones | Virtual water imports
  - **↑ Water price**
    - Water pricing (tiered tariffs[4]), decrease subsidies
- **↑ Supply**
  - **Infrastructure**
    - Existing supply improvement: rehabilitation of old/inefficient infrastructure
  - **Alternative supply**
    - Desalination | Wastewater treatment | Rainwater harvesting | Produced water
    - Storm water capture
  - **Transportation**
    - Short (plumbing), medium (pipe), long (canal) range water import
  - **Storage**
    - Dam/reservoirs, municipal reservoirs, aquifer recharge

Many water-scarce countries have developed mitigation strategies but remain focused on expanding supply

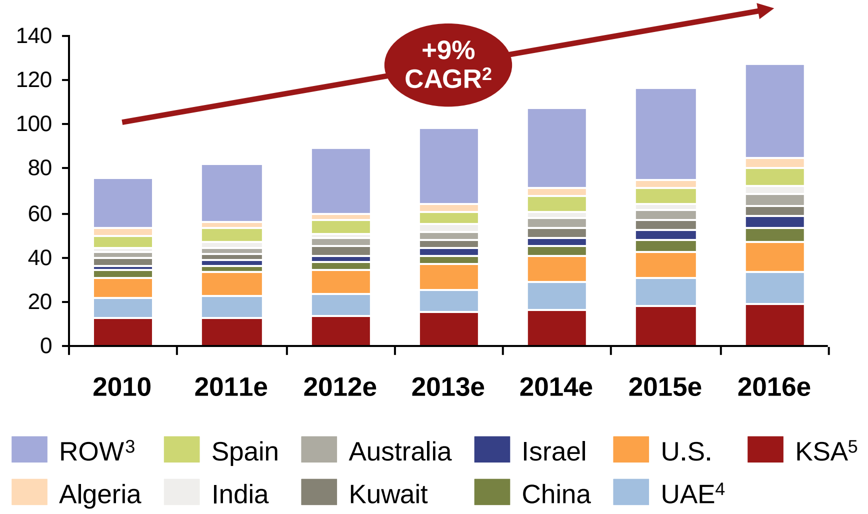
1. On/off and flow sensors; 2. Secondary system using grey water depending on feed-water quality requirements (drinkable, clean water or not…); 3. Nutrients leaching from agriculture fertilization infiltration and/or runoff can cause eutrophication; 4. Tiered pricing consists of charging more for consumption beyond a certain threshold. This system rewards low-consuming homes and penalizes over-users; Note - a WBCSD report came out as this FactBook was being published: WBCSD (2014), "Co-optimizing solutions water and energy for food feed and fiber".

Source: UNESCO (2009), "Water in a changing world"; 2030 Water Resources Group (2009), "Charting our water future"; Crédit Suisse (2009), "Water: The pressure is rising"; FAO document repository (1996), "Control of water pollution from agriculture"

Desalination is a promising solution for increasing freshwater supply and is expected to grow mostly in the Middle-East and North Africa region

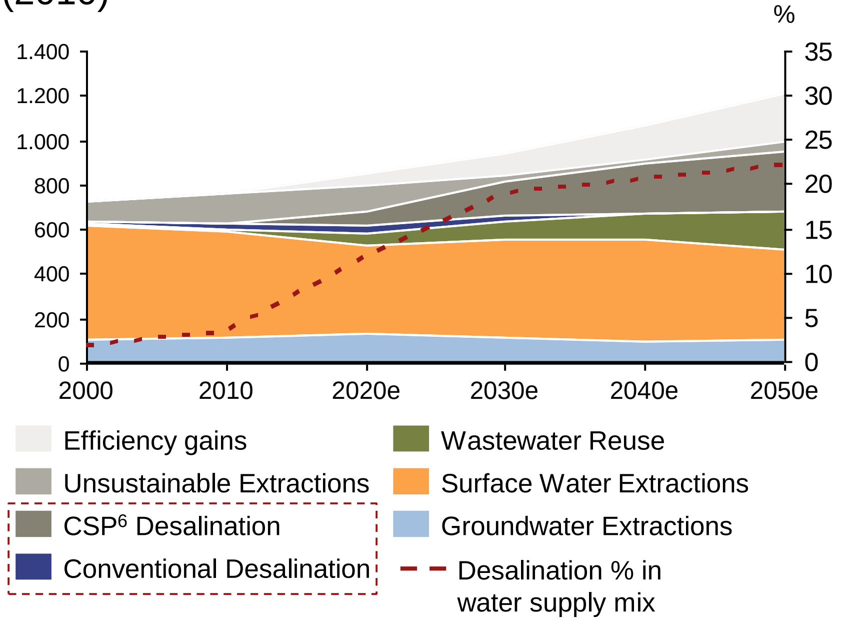
Installed desalination (Conventional + Renewable) capacity by geography[1]

(2010)



Possible scenario for Mena[7] water Supply by technology

(2010)



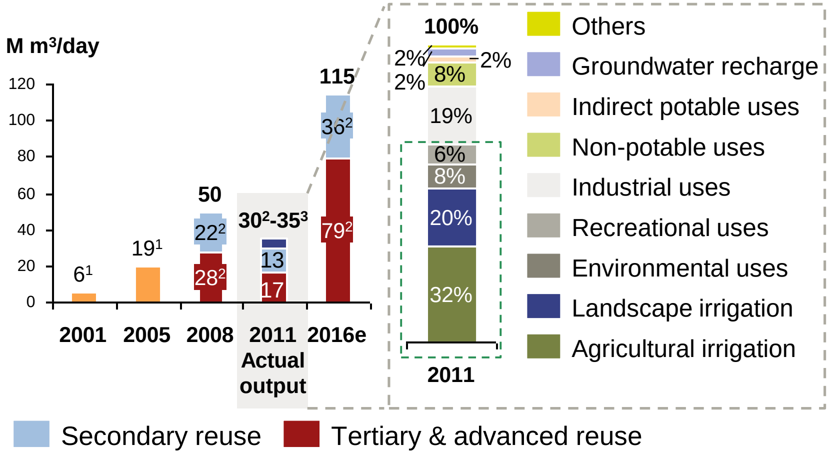
- **Desalination** currently produces about 25-30 km³/year, which represents about 0.6-0.8% of global freshwater withdrawal.
- The market for desalinated water is expected to grow both in developed and developing countries, with **54% of the global growth expected in MENA[7].**
- **Desalination's share of MENA[7] water supply is expected to grow significantly in the next 40 years.** IEA (2012) highlights the desalination potential of CSP and Fichtner (2011) scenario projects it to be the largest contributing desalination type in 2050 in MENA[7].

1. Data were manually reproduced from (IEA-ETSAP and Irena ,2012); 2 CAGR: Compound annual growth rate; 3 ROW: Rest of the world;
4. UAE: United Arab Emirates; 5 KSA: Kingdom of Saudi Arabia; 6 CSP: Concentrating solar power; 7 MENA: Middle East & North Africa.

Source: IEA-ETSAP and Irena (2012), "Water desalination using renewable energy"; Fichtner (2011), "Use of desalination and renewable energy to close the water gap"

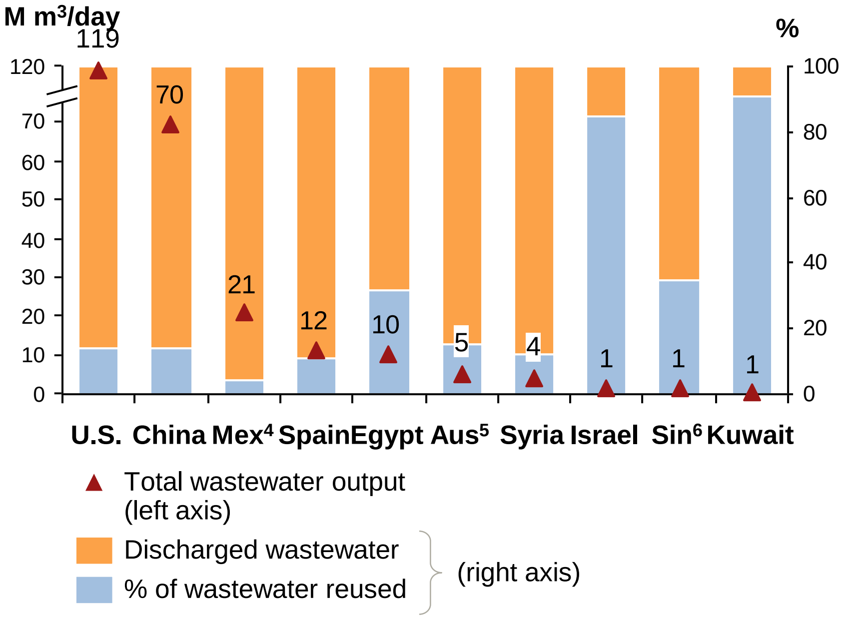
Water reuse accounts for 0.3% of global freshwater withdrawal and has some advantages over desalination, but is not generally applied to high-value uses

Water-reuse capacity (left 2009 & 2011) **& application market share** (right 2011)



- **The reused-water market (supply - in the graph on the left), currently provides 30 M m^3/day (10.7 km^3/year - 0.3% of global withdrawal), and has high growth potential.** Water reuse is defined as the "use of reclaimed water for beneficial purposes with no loss of control between collection and application. Reclaimed water in this sense is defined as water which has been treated in order to meet a specific water quality standard" (GWI).
- **66%** of **produced/reused-water utilization (** ⬚ **in the graph on the right) is not focused on high-value reuse** (to meet industry and/or domestic demand) and will thus not **reduce water demand,** as agricultural demand for additional water is almost unlimited.

Water reuse as % of wastewater output (2011)



- **Reuse has advantages over desalination and could even affect the growth of desalination if distribution issues are addressed**[7]**:** It requires less energy per m^3 of water produced and is considered more environmentally friendly.
- Water reuse infrastructure/activities, ranging from wastewater collection, physical, biological and advanced treatment to reused water distribution, are much broader than in the desalination market (supplying/operating plants).

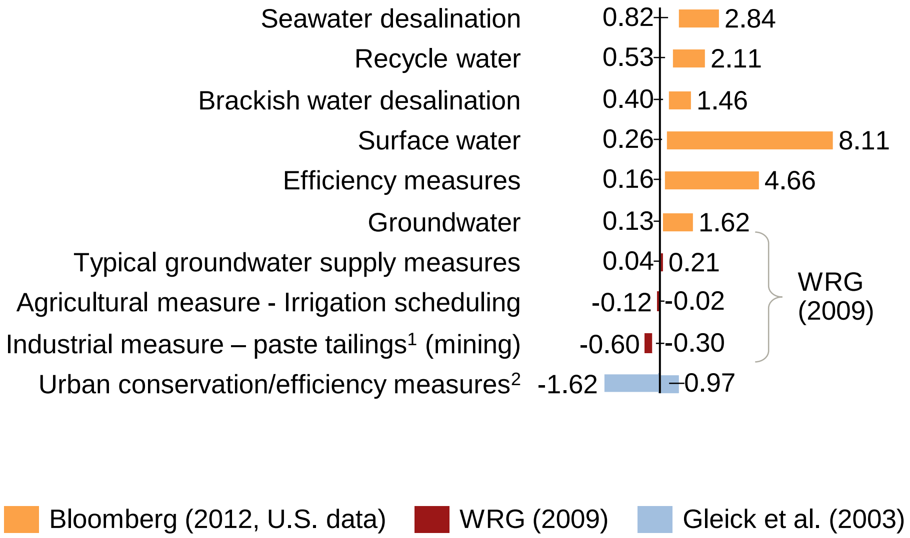
1. 2009 Crédit Suisse data; 2. 2011 GWI data; 3. GWI report announces a current actual output of ~30 Mm^3/day but the sum of the wastewater reused from the right graph for the cited countries is equal to 35.5 Mm^3/day; 4. Mex: Mexico; 5. Aus: Australia; 6. Sin: Singapore; 7. *e.g.* if direct potable reuse were to become widely accepted/implemented.

Source: GWI (2011), "Global Water Market 2011"; Crédit Suisse (2009), "Water: The pressure is rising"

Cost estimates for different solutions vary significantly, and demand efficiency measures are generally cheaper than desalination/treatment supply ones

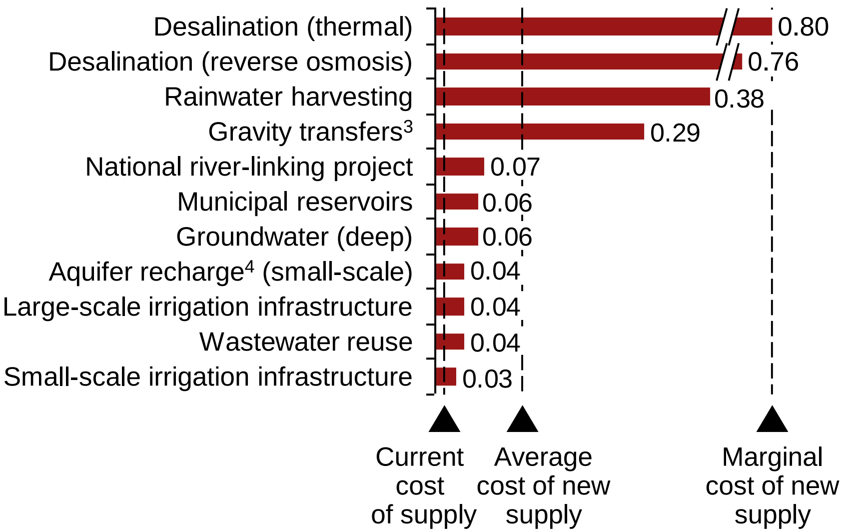
Global Water supply & demand costs

Literature range examples \$/m³



India: example of water supply costs

\$/m³ (2009)



- **Cost estimates** of solution levers for increasing supply and reducing demand **vary significantly in the literature**. Costs will be specific to local settings and the chosen technology.
- To meet growing freshwater demand, **most countries have focused** on **increasing supply**, usually **with energy-intensive methods such as desalination**. However desalination capacity, even with forecast efficiency improvements, is still significantly more costly than traditional water supply infrastructure, which is, in turn, often more expensive than efficiency measures5 (e.g. agricultural irrigation scheduling).

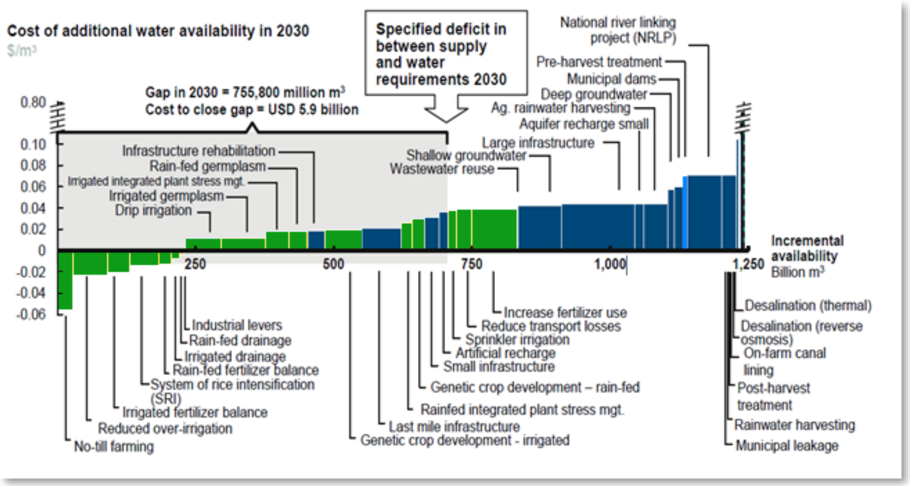
---

1. Process for recycling water in conventional mining;
2. Include commercial, industrial, and institutional sector conservation/efficiency measures;
3. "Interlinking of water management to transfer water resources from surplus basins to other basins by gravity";
4. Rainwater and artificial recharge of aquifers with collected water;
5. These efficiency measures can result in net cost savings (when operating savings of the measures outweigh annualized capital costs).

Source: 2030 Water Resources Group (2009), "Charting our water future"; Bloomberg New Energy Finance (2012), "Water leadership forum results book"; Gleick et al. (2003), "Waste Not, Want Not"

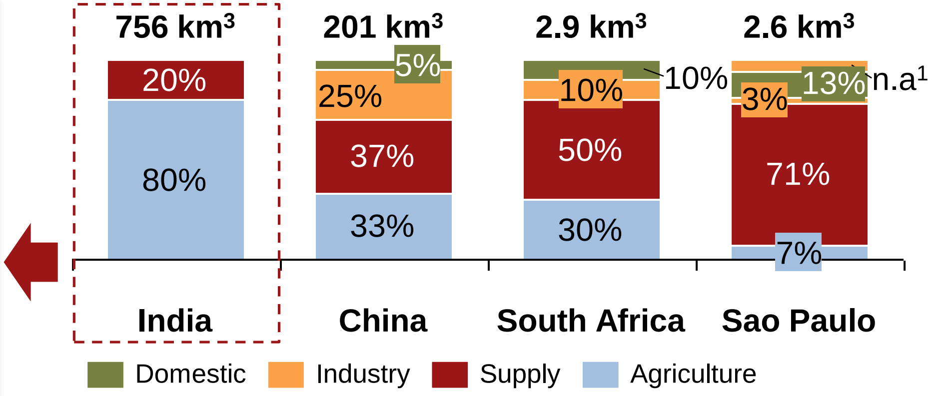
Solutions for closing the 2030 water supply-demand gap will be geographically specific

Water Availability cost curve - India



Solution levers mix to close the 2030

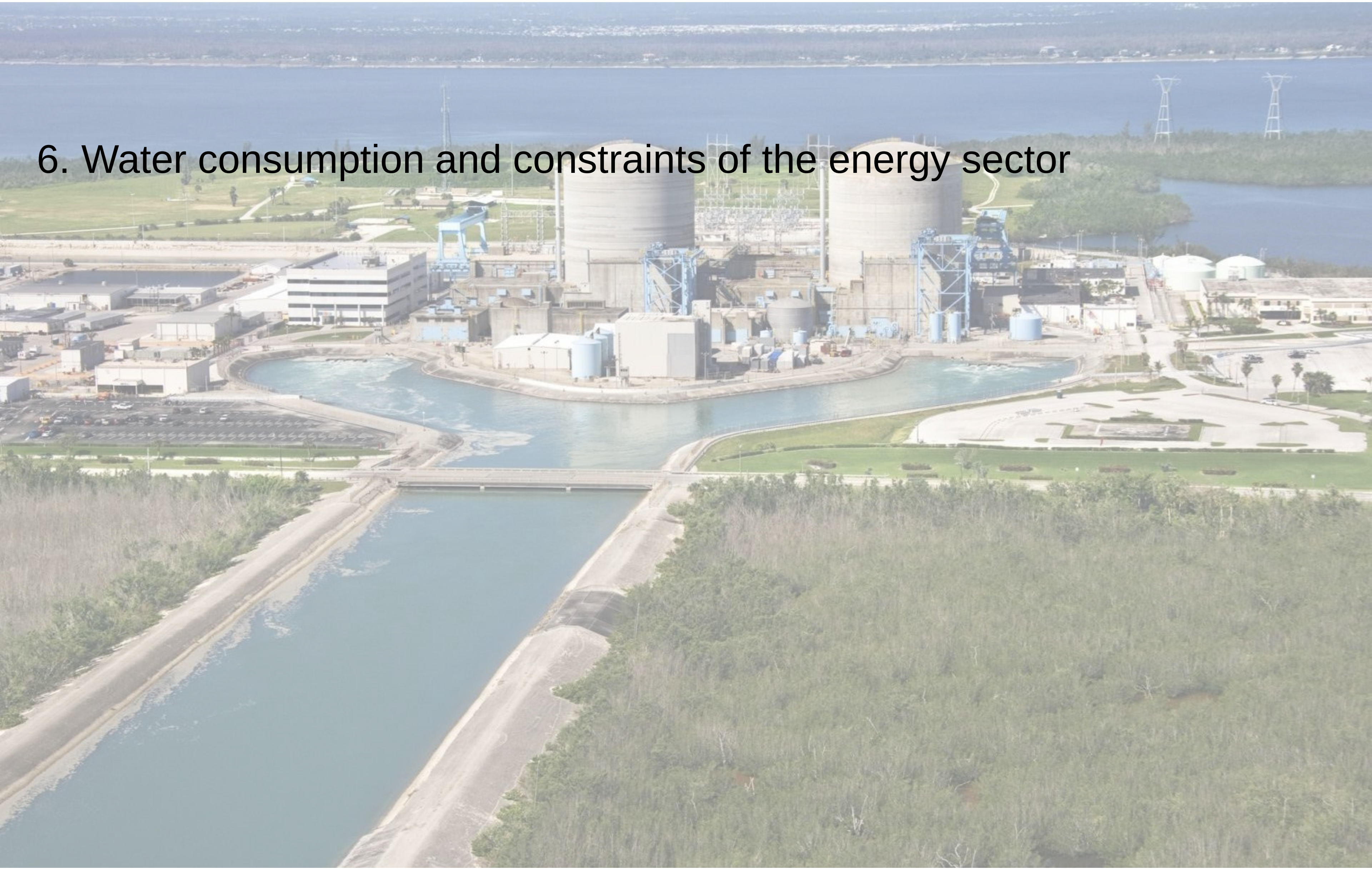
Volume gap



How to read this graph
These 100% columns indicate the mix of solution levers needed to close the 2030 gap (grey area in the LHS cost curve). The first bar, for India, corresponds to the cost curve to the left. Cost curves corresponding to the other bars are available in the study mentioned in the reference below.

The portfolio of solution levers for filling the 2030 gap will vary drastically from one location to another. The Indian cost curve shows that 80% of the 756 km3 missing by 2030 could come from improving the efficiency of water use in agriculture. China's solution for closing its gap would require ambitious, water-conscious "new build" in the rapidly growing industrial and urban sectors, as well as water-saving regulatory reforms. Case studies of both South Africa and Sao Paulo illustrate the extensive supply infrastructure required to close these two countries' gaps. Further details on each case study and on technical measures are available in the report.

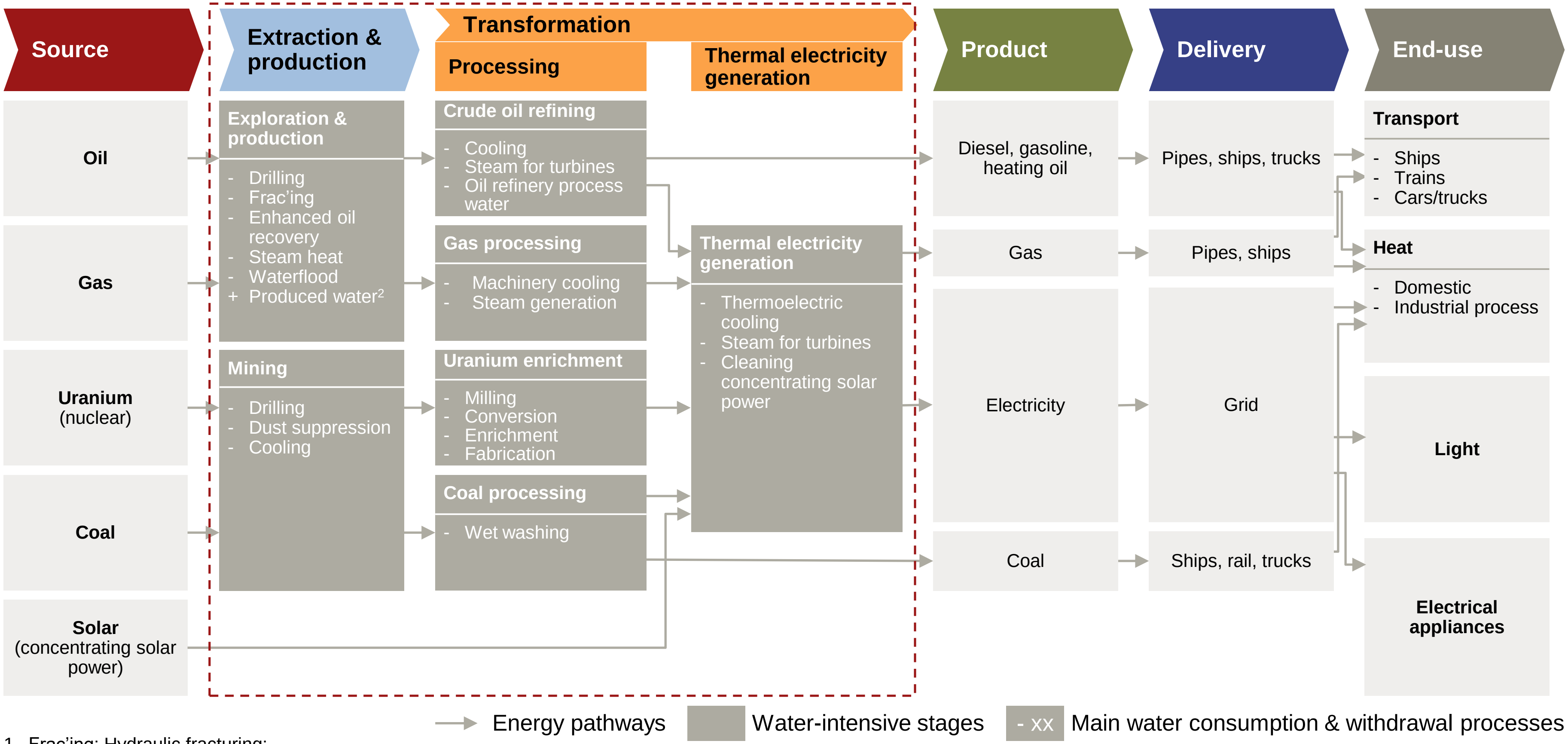
Note: Picture credits: 2030 Water Resources Group; Cost curves and detailed discussion on each 4 case studies above are available in the 2030 Water Resources Group study.
1. n.a.: Not available.
Source: 2030 Water Resources Group, (2009), "Charting our water future"



6. Water consumption and constraints of the energy sector

Freshwater is necessary at different stages of oil, gas, nuclear, coal and concentrating solar power energy systems

Main water-intensive stages in the life cycles of various energy systems[1]



Source
- **Oil**
- **Gas**
- **Uranium** (nuclear)
- **Coal**
- **Solar** (concentrating solar power)

Extraction & production

Exploration & production
- Drilling
- Frac'ing
- Enhanced oil recovery
- Steam heat
- Waterflood

+ Produced water[2]

Mining
- Drilling
- Dust suppression
- Cooling

Transformation

Processing

Crude oil refining
- Cooling
- Steam for turbines
- Oil refinery process water

Gas processing
- Machinery cooling
- Steam generation

Uranium enrichment
- Milling
- Conversion
- Enrichment
- Fabrication

Coal processing
- Wet washing

Thermal electricity generation

Thermal electricity generation
- Thermoelectric cooling
- Steam for turbines
- Cleaning concentrating solar power

Product
- Diesel, gasoline, heating oil
- Gas
- Electricity
- Coal

Delivery
- Pipes, ships, trucks
- Pipes, ships
- Grid
- Ships, rail, trucks

End-use

Transport
- Ships
- Trains
- Cars/trucks

Heat
- Domestic
- Industrial process

Light

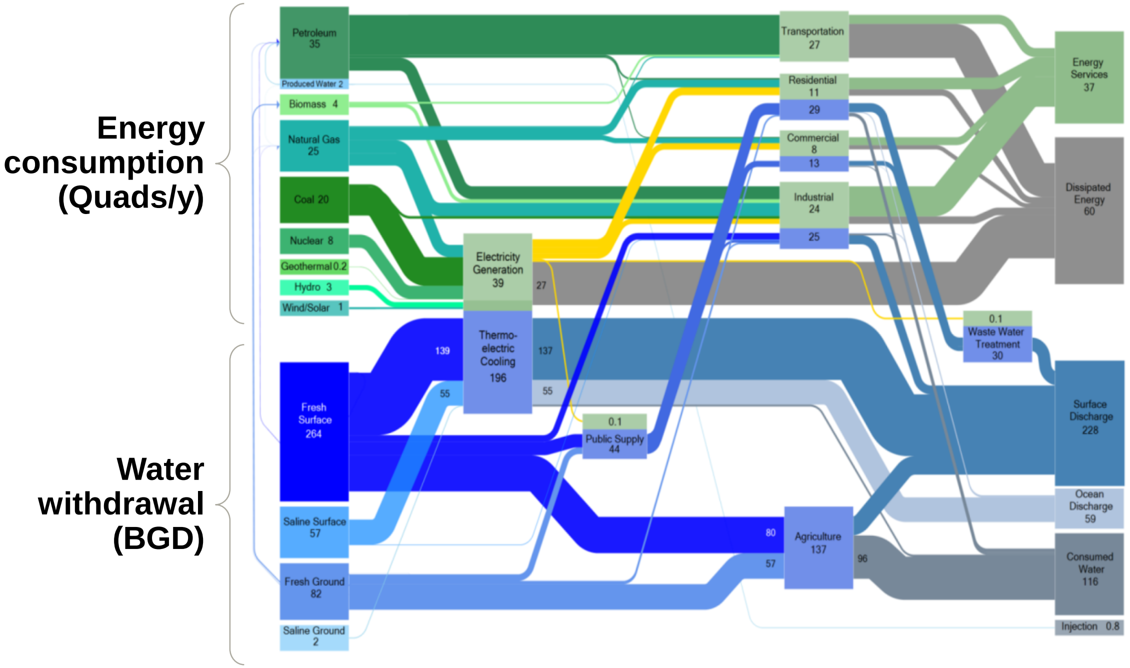
Electrical appliances

1. Frac'ing: Hydraulic fracturing;
2. Diagram adapted from BP 2013 excluding biofuels, hydropower, geothermal, wind and solar photovoltaic (see Meldrum and BP 2013 and reference therein for details on these);
3. In extraction & production, significant volume of formation water is produced.

Source: Williams and Simmons, BP (2013), "Water in the energy industry. An introduction." www.bp.com/energysustainabilitychallenge ; Meldrum et al. (2013), "Life cycle water use for electricity generation: a review and harmonization of literature estimates"; EIA (2006), "Natural Gas Processing The Crucial Link Between Natural Gas Production and Its Transportation to Market"

Water and energy flows are complex and interconnected: U.S. example

U.S. estimated energy consumption[1] (top) and Water withdrawal[2] (bottom) flows Quads/year for energy flows [green] and Millions m³/Day (Mm³D) & Billions Gallon/day (BGD) for water flows [blue]



U.S. thermoelectric cooling withdraws the largest volume of water, and the petroleum sector (including frac'ing) represents a small fraction of U.S. water consumption

1,234 Mm³D (326 BGD) of freshwater are withdrawn:

- 526 Mm³D (139 BGD) for thermoelectric cooling (43%);
- 519 Mm³D (137) BGD for agriculture (42%).

439 Mm³D (116 BGD) of freshwater are consumed:

- 363 Mm³D (96 BGD) for agriculture (83%);
- 76 Mm³D (20 BGD) for residential, commercial and industrial combined (17%). Industrial includes consumption in the petroleum sector:
  - 4.5 Mm³D (1.2 BGD) for water flooding and enhanced oil recovery (1%);
  - 0.8 Mm³D (0.2 BGD) for hydraulic fracturing in oil and natural gas (0.2%).

How to read this graph
Energy and water sources are on the left and sinks are on the right.

Note: Picture credits: U.S. Department Of Energy (2014); Frac'ing: Hydraulic fracturing; these water and energy flows are U.S.-specific and do not mirror other countries' flows; Quad: 055 × 10^{18} joules.

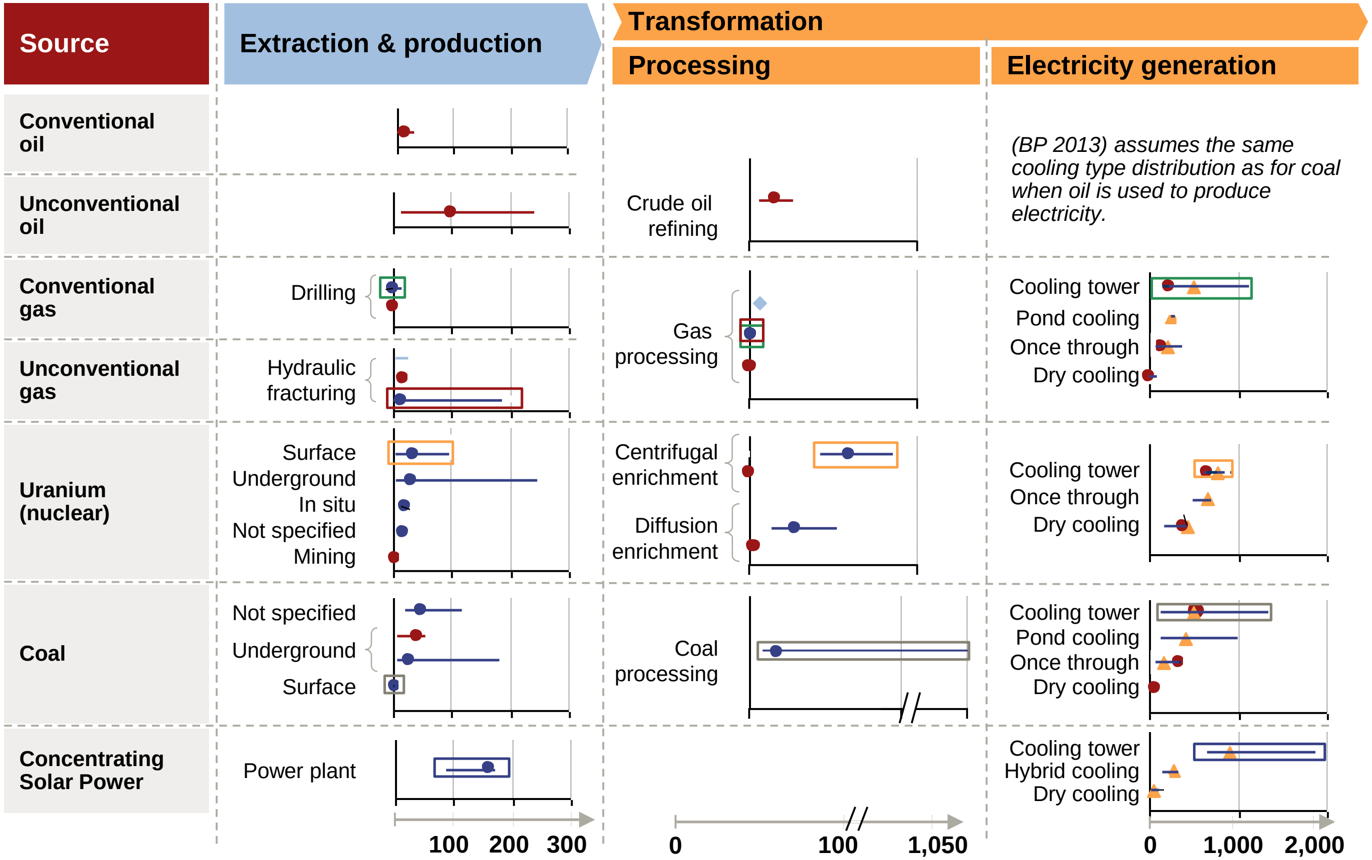
1. Note that energy consumption by the agriculture sector is not included in this Sankey diagram.
2. Water withdrawal values come from 2005 USGS data. Useful tools are under development e.g. https://www.foreseer.group.cam.ac.uk/foreseer-tool/ .

Source: U.S. Department Of Energy (2014), "The Water Energy Nexus: Challenges and Opportunities"; Kenny et al. U.S. Geological Survey (USGS) (2009) "Estimated Use of Water in the United States in 2005" Circular 1344

Different stages of energy systems consume highly variable quantities of water

Comparison OF water consumption ranges for different life cycle stages

m3/TJ (the three columns are on different scales)



Source: BP

— Variability range

● Estimates

Source: Meldrum et al.

— Variability range

● Median

▲ Average for each cooling technology of medians for different plant configurations (e.g. IGCC[1] vs PC[2] coal plant)

■ Base cases for life cycle comparison (slide 69)

Other sources

— ◆ Clark et al. (2013) and Nicot et al. (2014)

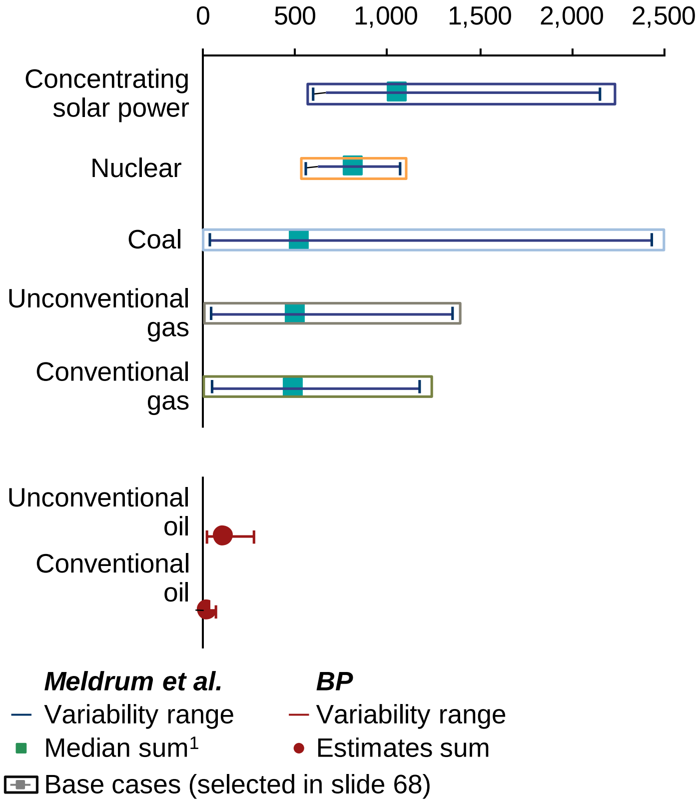
- Water withdrawal is roughly equivalent to consumption in extraction & production. Thus only consumption is considered here. However, withdrawal values in thermal electric cooling can be up to 50x higher than consumption values.
- Water consumption in thermoelectric cooling also varies significantly by plant configuration
- (see Meldrum et al. 2013)

Note: Fuel transport was not included; 1. IGCC: integrated gasification combined cycle; 2. PC: pulverized coal.
Source: Williams and Simmons, BP (2013), "Water in the energy industry. An introduction." www.bp.com/energysustainabilitychallenge; Meldrum et al. (2013), "Life cycle water use for electricity generation: a review and harmonization of literature estimates"; Clark et al. (2013), "Life Cycle Water Consumption for Shale Gas and Conventional Natural Gas"; Nicot et al. (2014), "Source and Fate of Hydraulic Fracturing Water in the Barnett Shale: A Historical Perspective"

On average, conventional and unconventional gas consume less water per unit of energy than concentrating solar power, nuclear and coal

Comparison of Life cycle water-consumption Medians & variability ranges

m³/TJ



- **The life cycle water consumption** of an energy system equals **the sum** of the consumption at each stage of the chosen energy-production pathway. In each pathway, several scenarios exist, based on possible combinations of potential:
  - **Technologies/processes** at the extraction & production, and processing stages;
  - **Cooling technologies** (and plant configuration[1]) at the thermal electricity-generation stage.
- **The comparison[1] ranks scenarios drawn from** two sources: the base cases in Figure 4 in **Meldrum** et al. 2013 (for concentrating solar power, nuclear, coal, and natural gas); and estimates for oil given in the **BP** 2013 summary table. The scenarios are summarized below in decreasing median order:
  - *Concentrating solar power*: power plant + cooling tower;
  - *Nuclear*: surface mining + centrifugal enrichment processing + cooling tower;
  - *Coal*: surface mining + processing + cooling tower;
  - *Unconventional gas*: hydraulic fracturing + processing + cooling tower;
  - *Conventional gas*: drilling + processing + cooling tower;
  - *Conventional and unconventional oil*: extraction & production + refining.
  - For each scenario **the sum of the minimum, median[1], and maximum water consumption reported** during the three stages (see slide 68) **provide the life cycle median and variability range per unit of energy produced**.
- The ranking indicates that **conventional and unconventional gas' median water consumptive intensity2 are on average smaller than for concentrating solar power, nuclear, and coal.** Water consumption in oil production is lower because it does not involve thermoelectric cooling when used directly for transport/heating.

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1. Variability in plant configuration is not displayed in this slide or in slide 68. The median value considered for cooling technology (e.g. cooling towers) is an average of the water-consumption medians for different plant configurations (e.g. pulverized coal, integrated gasification combined cycle). See Meldrum et al. (2013) for detailed data comparison (including other renewables showing the very low wind & low solar PV consumption) and performance parameter value sensitivity analysis that can alter the ranking of water consumption across energy systems (e.g. coal vs nuclear); 2. Ratio of volume of water consumed per unit of energy produced (BP term for median life cycle water consumption per unit of energy).

Source: Williams and Simmons, BP (2013), "Water in the energy industry. An introduction." www.bp.com/energysustainabilitychallenge ; Meldrum et al. (2013), "Life cycle water use for electricity generation: a review and harmonization of literature estimates"

High-temperature freshwater, a scarcity of freshwater or an excess of it frequently impose constraints on energy production

Impact of freshwater conditions on energy systems

Constraints Energy System		High water temperature[1]	Freshwater scarcity	Excess of freshwater
Thermal electricity generation (nuclear, coal, gas, CSP[2])		Cooling efficiency is reduced, forcing the plant to withdraw more water, or to reduce/shut down production.	System is unable to work in nominal conditions, forcing the plant/ process to reduce its operating capacity or shut down.	Flooding threatens existing equipment and would prevent the plant from working under nominal conditions
Oil	**Refining**			
	E&P[3]	n.a.[4]		n.a.[4]
Hydropower		n.a.[4]		n.a.[4]
Solar (photovoltaic)		n.a.[4]		n.a.[4]

- ***High water temperature***
  There are 3 main thermal constraints on cooling systems in thermoelectric generation, which can be different according to country regulations, and time of the year:
  ① **Inflow temperature** (T_{in}); *e.g.* France, Fessenheim (Rhine), $T_{in} \leq 30°C$; Germany, Philipsburg (Rhine), $T_{in} \leq 28°C$
  ② **Outflow temperature** (T_{out}); *e.g.* Switzerland, Beznau, $T_{out} \leq 33°C$
  ③ **Temperature increase** between inflow and outflow (Δ°T);
  e.g. France, Fessenheim (Rhine), Δ°T≤ 7°C [01/12-28/02]; Δ°T≤ 4°C [01/06-31/08]; Δ°T≤ 6.5°C [rest of year].
- ***Water scarcity***
  A minimum water flow downstream of the power plant is required, **constraining water consumption and thus electricity generation** (*e.g*. in France, legislation requires the water flow downstream to be a certain fraction of the minimum annual flow of the river). The plant must therefore either reduce production to meet the required standards or drain water stocked upstream in reservoir dams.

---

1. Freezing can also be an issue when ice reduces/blocks water intake; 2 CSP: Concentrating solar power; 3 E&P: Extraction & production;
4. n.a.: Not applicable.

Source: IHS (2013), "Water Stress and the Risks to Electricity Generation in Europe"; EDF (2014), "Centrales nucléaires et environnement - prélèvements d'eau et rejets"

Over the past 10 years, numerous events have demonstrated the critical impact water constraints have on energy production

Timeline of water-related impacts on electricity generation

2003:
Heat wave
- Spain shut down reactors
- France and Germany allowed some thermal discharge to exceed standards
  - France, EDF forced to stop production from 4-5 **nuclear** reactors, costing 300€ M in imported electricity

2008:
Drought caused Tennessee valley to lose 1/3 of **nuclear** capacity, in order to meet thermal discharge requirements

2009:
France lost 1/3 of **nuclear** capacity, to stay within thermal discharge limits

2010:
The Hope Creek **nuclear** generating plant in New Jersey had to reduce power because the temperature of the intake cooling water was too high

2012:
As a result of drought, companies using hydraulic fracturing to extract **oil and gas** faced higher water costs and even the prospect of being denied access to water for 6 weeks or more, in several states, including Kansas, Texas, Pennsylvania, and North Dakota

2012:
Water levels at the Oyster Creek **nuclear** plant water rose 2m above the normal level, threatening to submerge the pump motor (at a height of 2.1m above the normal level) and affecting the water-intake structure, which pumps cooling water through the plant

2003

2014

2006:
A multi-year drought halved power production at the North Platte Project **hydropower** plants

2008:
In China, dozens of planned **coal-to-liquids** (CTL) projects were abandoned due to concerns over water scarcity

2010:
The construction of Hualapai Valley Solar's 340 MW **concentrating solar power** plant stalled over water-availability concerns. It is now being developed, but will have to purchase effluent water or use dry-cooling if this is insufficient.

2011:
Drought limited **hydro** generation, leading to increases in coal demand and higher prices, as well as strict energy efficiency measures and electricity rationing

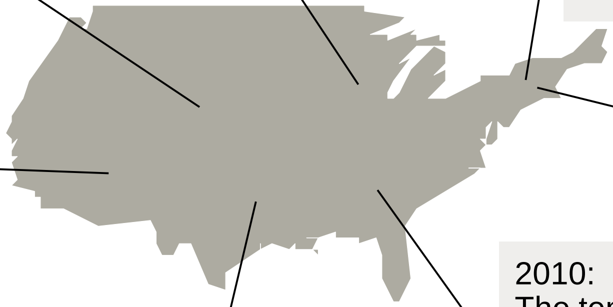
2012:
In India, a delayed monsoon resulted in higher electricity demand for irrigation and reduced **hydro** generation, resulting in two days of blackouts

⬜ High water temperature 🟦 Freshwater scarcity 🟧 Freshwater excess

Source: IEA (2012), "World energy outlook 2012"; Union of concerned scientists (2011), "The energy-water collision, power and water risk"; U.S. Department of Energy (2013), "U.S. Energy Sector Vulnerabilities to Climate Change and Extreme Weather"; Robert Krier - InsideClimate News (2012), "Extreme Heat, Drought Show Vulnerability of Nuclear Power Plants"

Spotlight on the U.S.: high-water temperature and water scarcity result in electricity-production decline/shut-down

Examples of water-related impacts on electricity Generation



2007 & 2008:
Extended droughts resulted in the 1,650 MW Laramie River **coal** power station running out of cooling water and forced it to import water from the High Plains Aquifer and the Wheatland Irrigation District, which would ordinarily have used this water for irrigation.

2013:
Reports show that development plans for **solar photovoltaic (PV) and concentrating solar power (CSP)** projects in the southwestern U.S. faced water-related issues. Water required for actual solar projects exceeds local availability across 10 watersheds (California & New Mexico).

2006:
Due to high water temperature, four **nuclear** plants were forced to reduce output even though the county was experiencing high electricity demand at that time. *E.g.* Prairie Island plant reduced output by 50%.

2012:
Low river levels restrict barge transportation of **coal** and **petroleum** products.

2012:
- Connecticut **nuclear** power station shut down one reactor because the temperature of the intake cooling water was too high
- The EPA granted the Braidwood reactor permission to discharge water at ~1°C higher than the normal level because of exceptionally hot lake-water temperature

2012:
The Vermont Yankee **nuclear** plant reduced production by 17% because of low river level and high water temperature.

2010:
The temperature of the Tennessee River rose above 32°C, forcing once-through cooling facilities, such as Browns Ferry **nuclear** plant, to reduce output for up to 2 months, to meet legal temperature limits

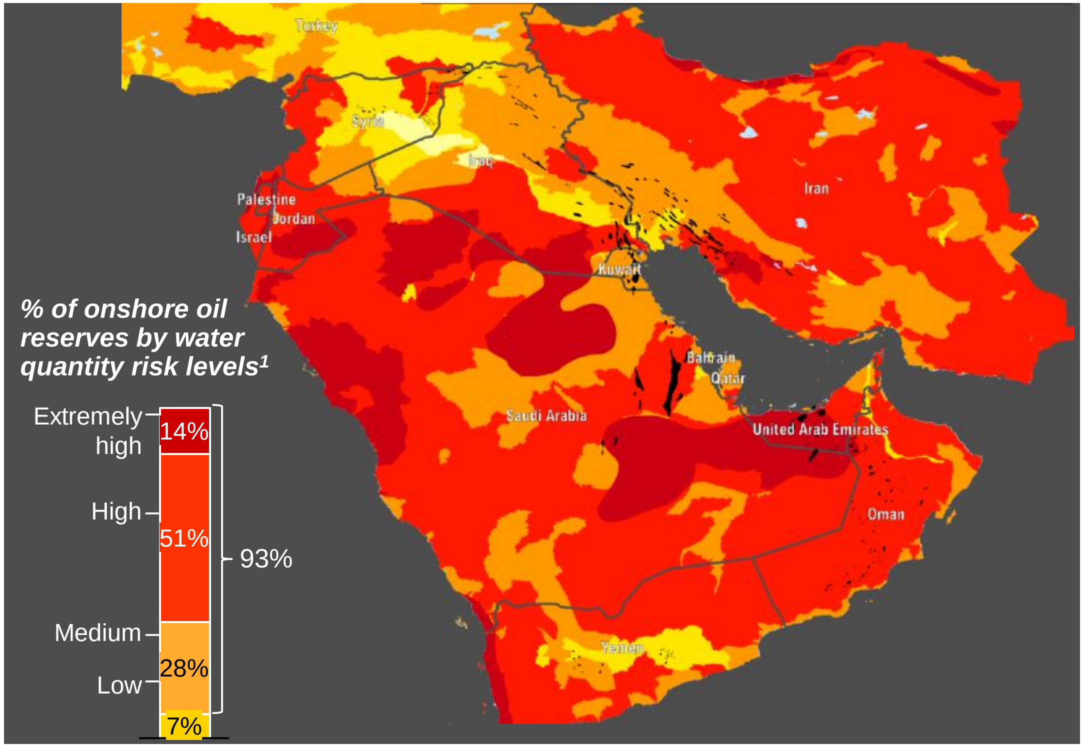
⬜ High water temperature 🟦 Freshwater scarcity

Note: Electricity demand increases significantly during heat wave and drought, at the same time as baseload power (coal and nuclear, both using large amounts of water for cooling purposes) is at risk of being curtailed or interrupted to comply with regulations governing the temperature of discharge water.
Source: Union of concerned scientists (2011), “The energy-water collision, power and water risk”; U.S. Department of Energy (2013), “U.S. Energy Sector Vulnerabilities to Climate Change and Extreme Weather”; Wald, The New York Times (2012), “So, how hot was it?”; Klise et al. (2013), “Water use and supply concerns for utility scale solar projects in the Southwestern United States”

Spotlight on oil: water scarcity in the Middle East may constrain future energy development

Onshore oil reserves overlap with Overall water quantity risk Levels[1]

% of onshore oil reserves by water quantity risk levels[1], and geographic location



● Geographic location of onshore oilfields

- **~93% of onshore oil reserves** are located in **medium-to-extremely high-risk areas by overall freshwater quantity, presenting** a range of challenges:
  - The Middle East's **inadequate water infrastructure** is already **constraining asset development** (*e.g.* lack of water-injection capacity in southern Iraq's biggest field is an obstacle to capacity growth), causing **project delays and giving rise to additional costs. This is occurring** for several reasons, including competition for water from other sectors (*i.e.* agriculture);
  - Because of rising oil-consumption by **desalination plants,** national oil companies face the risk of losing valuable oil exports;
  - Water-intensive enhanced oil recovery and shale-gas exploration (Saudi Arabia) will face **longer-term challenges**.
- Upstream, energy companies are already **recycling** produced water when possible[2]. Governments are working on **improving infrastructure, conserving resources and developing more efficient desalination technologies[3]**

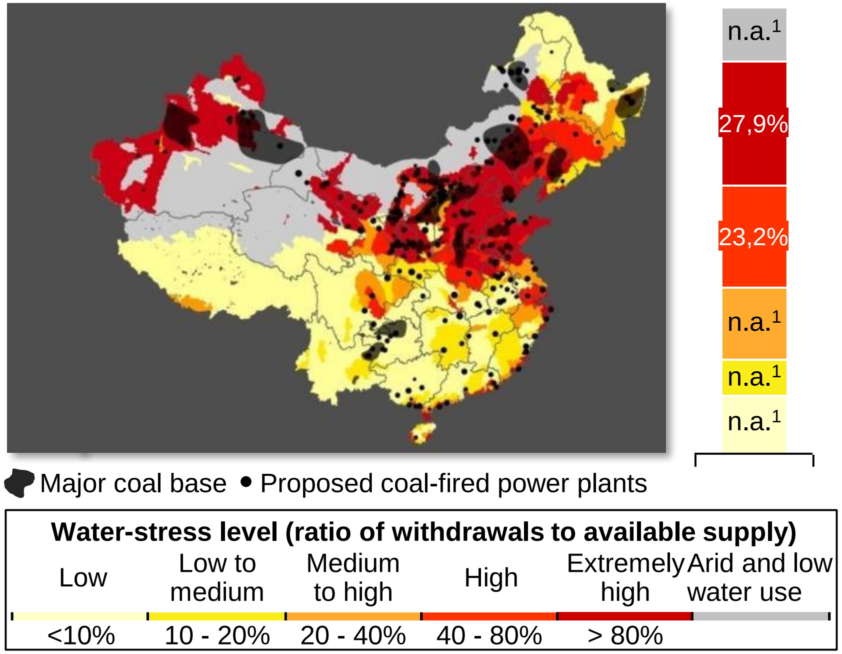
Note: Picture credits: Wood MacKenzie (2013); Total 2012 Onshore Oil Reserves: 294 Bn bbls.

1. Overall Water Quantity Risk is a weighted average of six risk indicators: baseline water stress, inter-annual variability, seasonal variability, flood occurrence, drought severity, upstream storage;
2. Oil and gas companies produce a large quantity of saline formation water during the exploration and production of a field. Mature depleted fields require either water or gas injection to maintain production (enhanced oil/gas recovery);
3. Saudi Arabia is building the first large-scale solar seawater reverse osmosis plant.

Source: Wood MacKenzie (2013), "Troubled waters ahead"

Spotlight on coal: water-supply risks may constrain China's energy development. Its focus on long-distance water-transport is perceived as too narrow a solution

China's proposed coal Plan overlap with and split by water-stress levels (2012) Map (left), % of proposed generation capacity by water-stress levels (right)



- **Over half of total proposed coal-power generation capacity would be located in high-to-extremely-high water-stress regions, as of July 2012[2].**
- China is hoping to develop shale gas, which may be constrained by the availability of water in water-scarce regions.

China's Major response focuses on increasing supply

- One of the **main proposals for reducing water stress** in China is to **divert water from the wet south to the more arid north[3]**, over a distance of more than 1,000 km, and **at a cost of $79.4bn**. The environmental and technical challenges associated with this diversion project are considerable. Water pumped as of October 2013 was so polluted that treatment accounted for ~1/3 of the overall project cost[4].
- **Alternative** and/or complementary **responses** to this water-supply risk exist. Seawater **desalination** could have supplied the same volume of water at a lower cost. Only 40% of industrial water use is **recycled**, compared with 80% in Europe. **Higher water prices** (prices in most cities are 1/10th of European prices) could reduce wasteful water consumption.

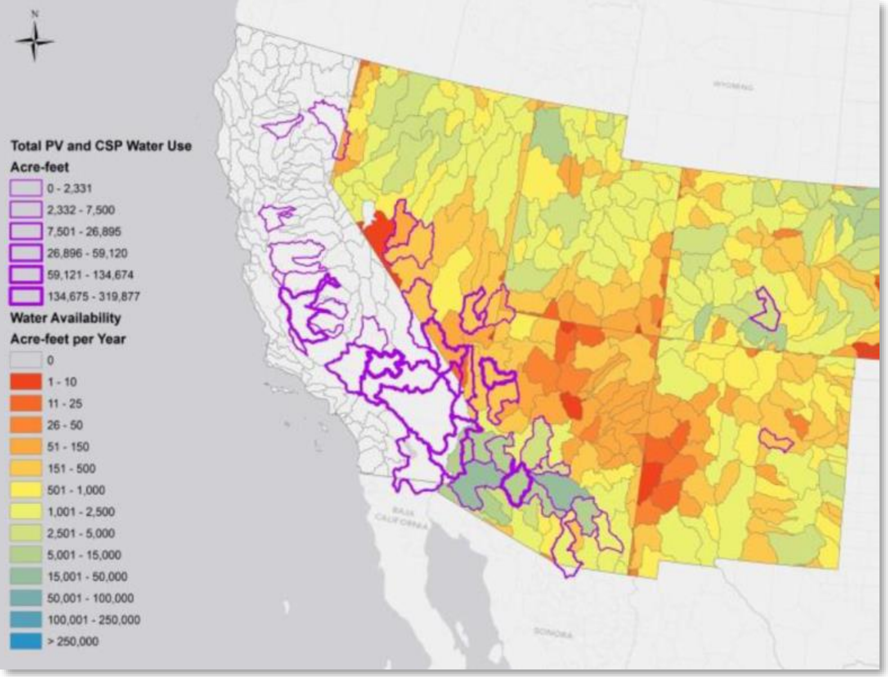
Note: Picture credits: WRI (online); 1. n.a.: not available; 2. When 58% of existing coal mining production and coal-fired power generation are already located in high/extremely high water-stress regions; 3. The south-north water-diversion project, linking the Yangzi and Yellow rivers, is expected to dispatch 45 km^3 of water. The project's first channel, due to open soon, would pump 14.8 km^3 of water through 1,160 km. 4. The Economist (2013).

Source: World Resource Institute (online); The Economist (12-18 Oct. 2013), "Desperate measures", "All dried up"

Spotlight: concentrating solar power and photovoltaic development plans may be constrained by a lack of water in Southwestern U.S.

Projected water use[1] of current solar PLANs[2] & with appropriated-water[3] availability

Acre-foot (usage) and acre-foot per year (availability)



- **California and New Mexico limited appropriated water[2] supplies could impede their solar development plans.**
  - Concentrating solar power requires water mainly for cooling but also for power-plant construction and cleaning. Photovoltaic also requires water for panel manufacturing (e.g. silicon processing) and cleaning, although consumption is lower than in CSP (10 to 100 times less[3]);
  - Among all the U.S. watersheds with projected solar developments, 9 **in California** and 1 **in New Mexico** were identified as potentially problematic **due to the limited availability of water.**
- **Water demand must be balanced between solar developments and other rapidly growing water-use sectors.** Alternative solutions include:
  - **Use of treated brackish** or **wastewater,** rather than freshwater, which would increase the average water cost by 4-35 times;
  - **Water imports** or a **shift** to less water-intensive **technologies,** such as **dry-cooling**. Dry-cooling cuts water usage (*e.g.* 92% in recent case study[4]), but also reduces efficiency (*e.g.* from 3.1%[5] up to 7%[6]).

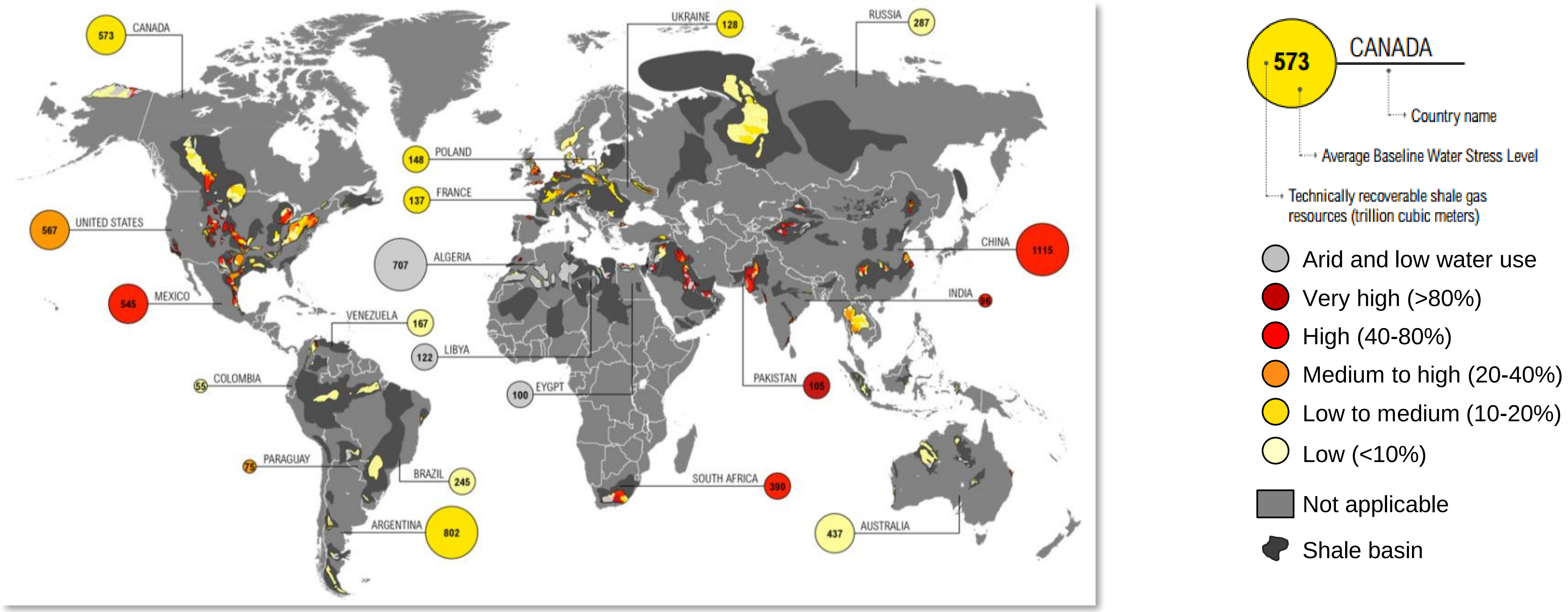
Note: Picture credits: Klise et al. (2013);

1. Water use for project construction and 25-year projected operation & maintenance;
2. Solar development plans include those currently operating, under construction and (for a large majority) under planning;
3. The map shows the availability of ‘appropriated-water’, defined as water potentially available for new development by abandonment and transfer of the water right from its prior use. Such transfers have traditionally involved sales of water rights from irrigated farmland to urban uses. It is opposed to ‘unappropriated water’ for which a permit or water right is needed from the state. ‘Unappropriated’ water is typically more difficult and costly to tap than ‘appropriated water’;
4. Meldrum (2013);
5. Liqreina and Qoaider (2014);
6. A.T. Kearney Energy Transition Institute (2013).

Source: Klise et al. (2013), “Water use and supply concerns for utility-scale solar projects in the Southwestern United States”; Liqreina and Qoaider (2014), ‘’Dry cooling of CSP plants, an economic competitive option for the desert regions of the MENA region’’; A.T. Kearney Energy Transition Institute (2013), “Concentrating Solar Power FactBook”; Meldrum et al. (2013), “Life cycle water use for electricity generation: a review and harmonization of literature estimates”

Spotlight: Shale resources are unevenly distributed around the globe, and most are not located where freshwater is abundant

Location of World’s Shale Plays, Volume of Technically Recoverable Shale Gas in the 20 Countries with the Largest Resources, and the Level of Baseline Water Stress



○ Arid and low water use

● Very high (>80%)

● High (40-80%)

● Medium to high (20-40%)

● Low to medium (10-20%)

○ Low (<10%)

▨ Not applicable

● Shale basin

- **8 of the top 20 countries** with the largest **shale-gas resources face arid** conditions **or high-to-extremely-high** baseline **water stress** where the shale resources are located; these are China, Algeria, Mexico, South Africa, Libya, Pakistan, Egypt, and India.
- Irrigated agriculture is the largest water user in 40% of shale plays[1]. **~38% of the areas where shale resources are located are arid or under high-to-extremely-high levels of water stress.**

Note: Picture credits: WRI (2014); Recent advances in frac’ing could result in 100% of freshwater being replaced with produced water;

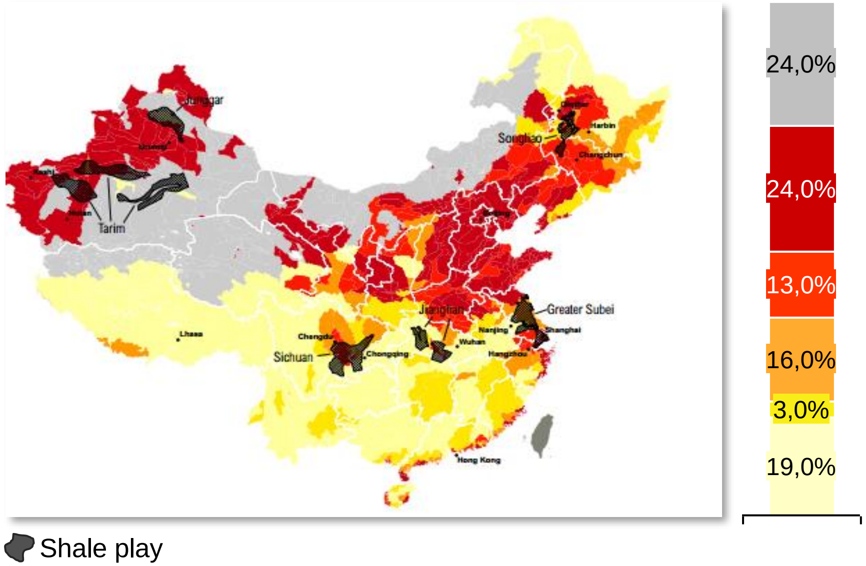
1. “Competing water demands from drilling and frac operation can rapidly escalate and result in conflicts with other water users. Farmers have raised concerns or stood up against the potential for shale development in many parts of the world, (ex. Poland, South Africa, the U.S. to name a few)” WRI (2014).

Source: WRI (2014), “Global shale gas development, Water Availability and Business Risks”

China’s shale gas is located in high-to-extremely-high water-stressed & densely populated regions, dominated by water use in agriculture

China’s shale-gas play Overlap with Water-Stress level, 2014

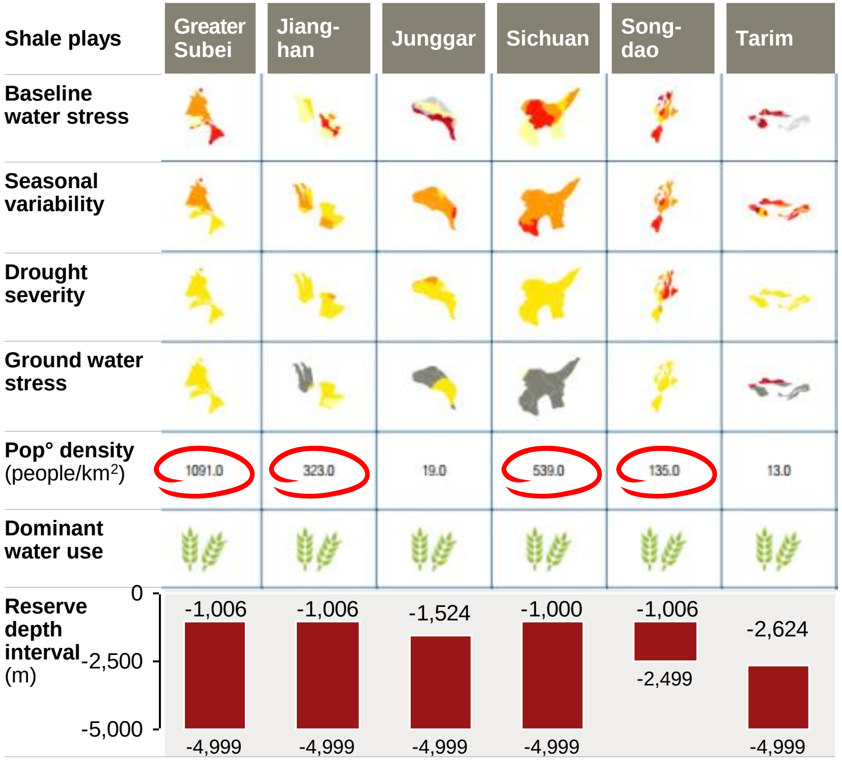
Map, and % breakdown by water-stress levels



Water-stress level (ratio of withdrawals to available supply)					
Low	Low to medium	Medium to high	High	Extremely high	Arid and low water use
<10%	10 - 20%	20 - 40%	40 - 80%	> 80%	

Over 60% of China’s shale resources are located in regions with high-to-extremely-high water stress. All shale resources across China are located in areas with high population density, except for the Tarim and the Junngar plays.

Water availability indicators for shale Plays in China



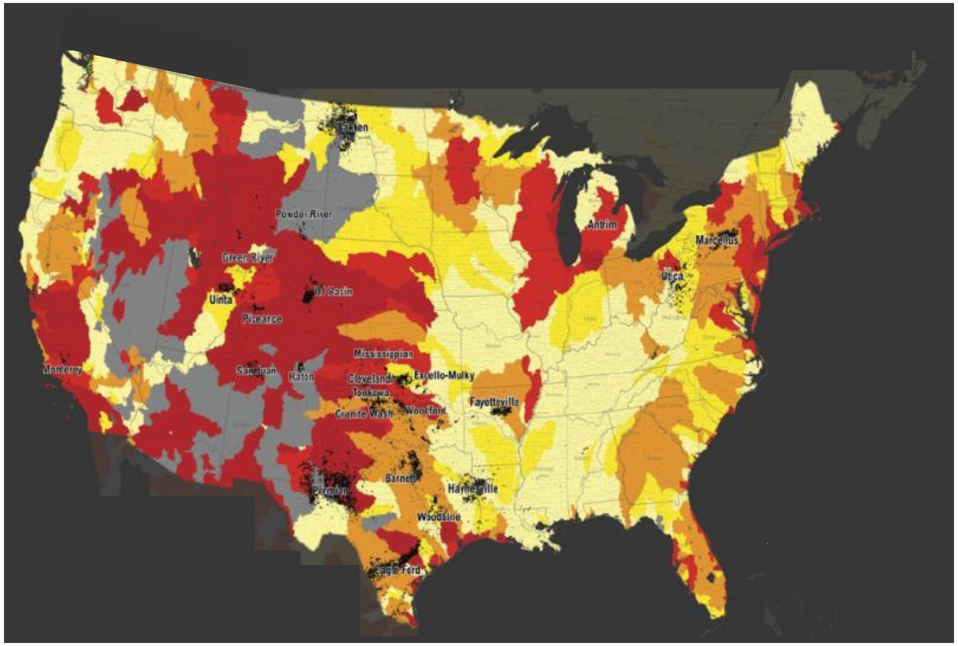
Agriculture is the dominant water user across all of China’s shale plays. Thus companies operating there will have to face intense competition with other users for what is already a very scarce resource. This could result in higher costs, reputational risks, and increased regulatory uncertainty.

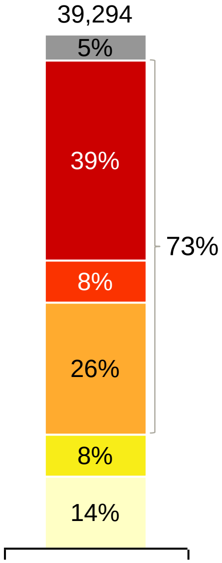
1. Note: Picture credits: WRI (2014); Recent advances in frac’ing could result in 100% of freshwater being replaced with produced water.
Source: WRI (2014), “Global shale gas development, Water Availability and Business Risks”

Spotlight: hydraulic fracturing developments in the U.S. are located in medium-to-extremely-high water-stress regions

Shale gas wells Overlap with U.S. water-stress zones[1]

Map of water-stress zones (left) and shale gas wells by water-stress level (right)





● Shale gas wells location

Water-stress level (ratio of withdrawals to available supply)

Low	Low to medium	Medium to high	High	Extremely high	Arid and low water use
<10%	10 - 20%	20 - 40%	40 - 80%	> 80%	

- **The future of the U.S.' shale-gas industry may be hindered by water constraints.** Since 2011:
  - 47% of hydraulically fractured wells were in regions with high or extremely high water stress;
  - In California and Colorado, 96% and 97% of the wells respectively, were in regions with high or extremely high water stress;
  - More than 1 well of every 2 (55%) was drilled in an area experiencing drought.
- **Potential solutions include**:
  - Recycling and reuse of produced water and drilling waste water (*e.g.* some operators in the Marcellus region are reusing almost 100% of produced water and flowback water, as it is usually cheaper to truck wastewater to the nearest permitted disposal wells, in Ohio);
  - Use of municipal wastewater (*e.g.* major operators buying effluent water from local municipalities), brackish water or seawater.
  - Recent advances in frac'ing could result in 100% of freshwater being replaced with produced water[2]

Note: Picture credits: Monika Freyman, Ceres report (2014);

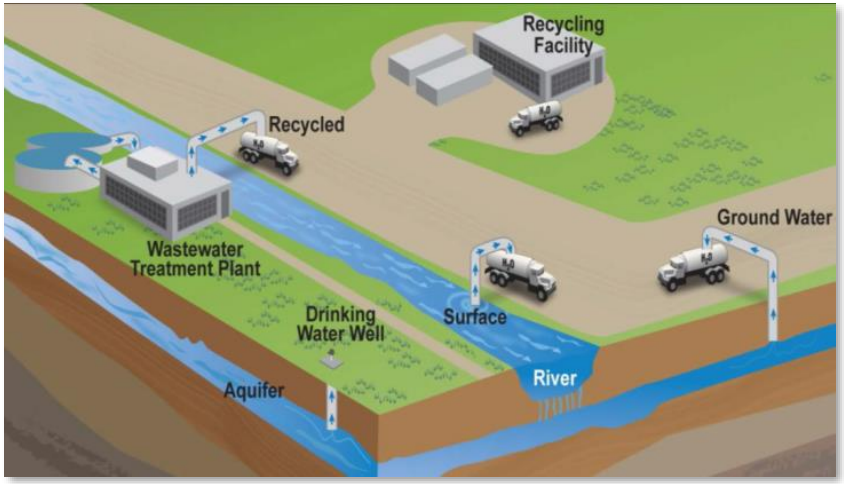
[1] This map is a snapshot which may vary in time;

[2] Statoil online.

Source: Monika Freyman, Ceres report (2014), "Hydraulic fracturing & water stress: water demand by the numbers"; Statoil online accessed in Sept. 2014 http://www.statoil.com/en/OurOperations/ExplorationProd/ShaleGas/Pages/2014_28May_Bakken_pilot.aspx

Spotlight on hydraulic fracturing: where and how is water sourced and consumed?

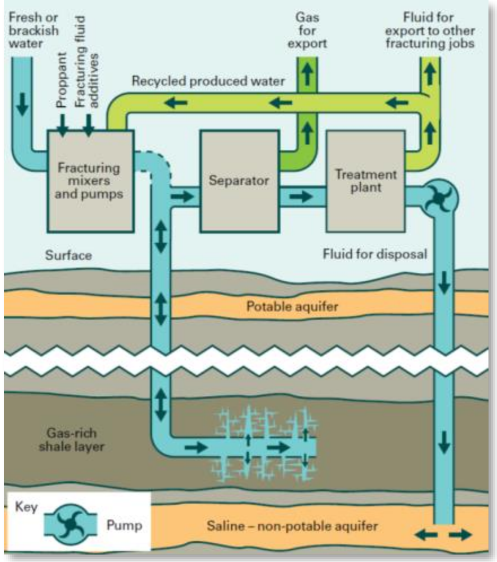
Possible sources of water supply[1]



Water for hydraulic fracturing can be drawn from a variety of sources, including:

- Surface water.
- Groundwater.
- Recycled flowback/produced water from previous frac operations.
- Other types of recycled wastewater.

Water use flow diagram



- **The reservoir is fractured hydraulically using frac fluid** (fresh or brackish water, proppant usually sand, and chemical additives <1% in volume) **injected into a horizontal well.**
- Oil and gas are then produced along the same well path.
- The flowback fluid and any produced water from the reservoir are either reused in other frac jobs or disposed of.

Note: Picture credits: EPA (2012); BP (2013); Recent advances in frac'ing could result in 100% of freshwater being replaced with produced water;
1. Water sources can also include non-potable deep-water aquifers not represented in the graphic on the left.
Source: EPA (2012), "Study of the potential impacts of hydraulic fracturing on drinking-water resources"; Williams and Simmons, BP (2013): "Water in the energy industry. An introduction." www.bp.com/energysustainabilitychallenge ; API (2010), "Water management associated with hydraulic fracturing"

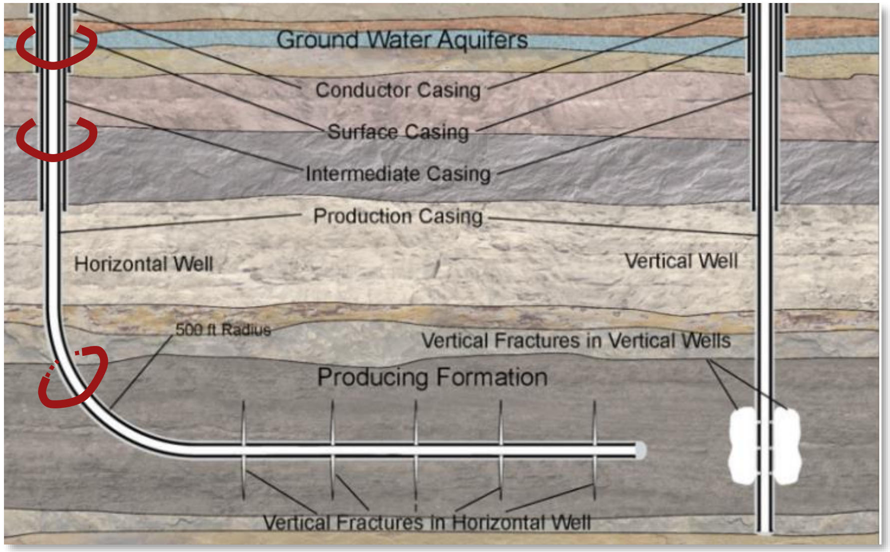
Well integrity is one of the main risks associated with shale-gas development but it is not specific to frac operations

MAIN RISKS ■ specific & □ non specific to the frac operations		MITIGATION
On-site Surface spill	• Injected and produced fluids (e.g. drilling fluids, produced water, hydrocarbons, flowback water and frac fluids) may spill during the operation, storage, treatment, transfer and disposal stages, contaminating local water/environment.	• Follow industry standards and regulations for surface casing, transport, storage tank/lined impoundments, and maintenance. • Prepare contingency plans. • Re-use or dispose of flowback fluid and produced water via injection wells.
Truck traffic	• Trucks trips required for transportation of frac and flowback fluids could impact local communities, infrastructure, and water quality.	• Use centralized water storage and pipelines to reduce truck traffic. • Optimize transport operations.
Water Consumption	• The volume of water injected/consumed in frac'ing may compete with other uses. However, per unit of energy produced, the water required for frac'ing is a small fraction of water consumed over the life cycle of other forms of energy (see slides 69 & 82).	• Leverage alternative supply or solutions for reducing freshwater consumption: • Recycling, reuse of flowback water and potentially 100% produced water. • Alternative water supply (e.g. brackish water, municipal wastewater). • Waterless hydraulic fracturing (e.g. with propane, CO_2, N_2).
Subsurface Contamination	• **Well integrity** issues may arise along the well and result in the migration of reservoir fluids across geological layers. • If well integrity fails, the chemistry of reservoir fluids may increase subsurface contamination.	• Follow well design and industry operating standards and apply appropriate cement evaluation and remediation measures. • Evaluate barriers above and below the reservoir, and apply factors in stimulation design that ensure containment of the treatment within it.
Induced seismicity	• Disposal of wastewater via an injection well may induce low-intensity induced seismicity in a predisposed geology.	• Characterize geomechanical conditions and avoid frac'ing risky geology. • Research correlations between induced seismicity & injection wells. • Reduce disposal requirements by reusing flowback and produced water.
Other Risks	• Air quality (e.g. potential emissions of methane from well operations or compressors) and land damage risks.	• Leak detection, maintenance and repair. • Capture gas flowback (e.g. reduced emissions completion).

Source: API (2009), "Hydraulic fracturing operations - well construction and integrity guidelines"; API (2010), "Water management associated with hydraulic fracturing"; API (2011), "Practices for Mitigating Surface Impacts associated with hydraulic fracturing"; EPA (2014), "Oil and Natural Gas Sector Hydraulically Fractured Oil Well Completions and Associated Gas during Ongoing Production"; CERES (2014), "Hydraulic fracturing and water stress; water demand by the numbers"; Flewelling et al. (2013), "hydraulic fracture height limits and fault interactions in tight oil and gas formations"; Flewelling et sharma (2013), "Constraints on upward migration of hydraulic fracturing fluid and brine"; Vengosh et al. (2014), "A critical review of the risks to water resources from unconventional shale gas development and hydraulic fracturing in the US"; National Research Council (2012), "Induced seismicity potential in energy technologies"; Council of Canadian Academies (2014), "Environmental impacts of shale gas extraction in Canada"; Schlumberger interviews; A.T. Kearney Energy Transition Institute Analysis

Well integrity can be managed appropriately through best practices

Well-integrity Management



Well integrity is the "*application of technical, operational and organizational solutions to reduce risk of uncontrolled release of formation fluids throughout the life cycle of a well*" (NORSOK D-010).

Well integrity management prevents most subsurface issues by restricting the migration of formation and frac fluids across geological formations, by ensuring efficient isolation along the well, and by constraining the propagation of fractures within the boundaries of the reservoir.

The main risks include the loss of integrity in a segment along the well (*e.g.* see red circles on the picture), which could result in unintended communication between different geological formations and/or the release of reservoir fluids. These could then migrate to shallower formations and potentially contaminate groundwater aquifers or drinking-water resources.

Mitigation measures and industry standards have been developed and applied to address well integrity risks by:

- Ensuring **zonal isolation** of the well through **proper cementing** and **well-casing best practices** (*e.g.* strict drilling regulations require the surface casing to be set below the deepest groundwater aquifer).
- **Containing the fracturing zone** within the producing formation by:
  - Properly assessing the geologic conditions[1] and characterizing the geo-mechanics of the reservoir to calibrate the frac'ing parameters[2];
  - Monitoring fracture coverage (*e.g.* through microseismic or tracer logging).

Note:Picture credits: API (2009);

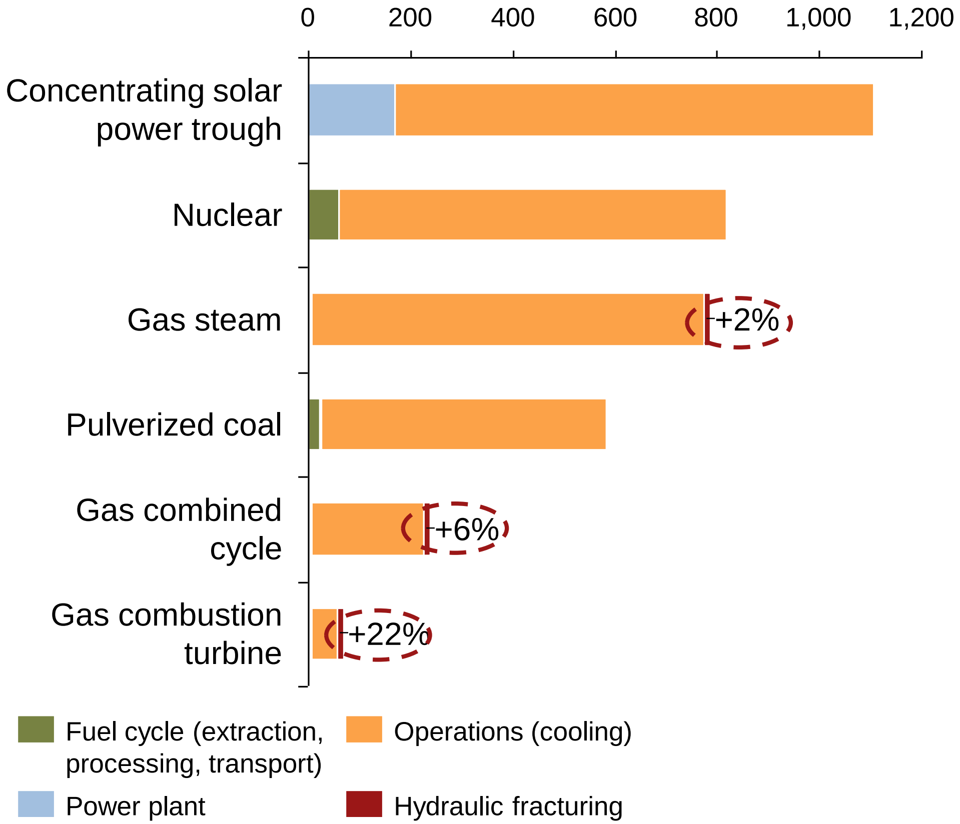
1. Including reservoir thickness, depth, proximity to potable groundwater resources, seismic activity level;
2. Vertical/lateral extent and azimuth; surface injection pressure, proppant concentration, fluid and sand/proppant rate).

Source: API (2009), "Hydraulic fracturing operations - well construction and integrity guidelines"; API (2010), "Water management associated with hydraulic fracturing"; API (2011), "Practices for Mitigating Surface Impacts associated with hydraulic fracturing"; Standard (2013), "Well integrity in drilling and well operations"; Schlumberger interviews

Hydraulic fracturing increases by 2-22% the median life cycle water consumption of conventional gas per unit of energy produced

Impact of Hydraulic fracturing on Gas median Life cycle water consumption

m^3/TJ



- **The fuel cycle** represents **only a small fraction** of total **life cycle water consumption** per unit of energy produced, which is **dominated by thermoelectric cooling.**
- **Median water consumption in hydraulic fracturing** is reported to be ~13 m^3/TJ, which **represents a 2-22% increase over the median life cycle water consumption of conventional gas**, depending on plant configuration.

How to read this graph

- The graphic compares the sum of median life cycle water-consumption estimates for each stage of the base cases for concentrating solar power, nuclear, gas and coal plant described in Figure 4 of Meldrum et al. 2013[1].
- These median values do not reflect the important variability within estimates for each stage, described in slide 68.

Note: Water withdrawal can be up to 50 times larger than water consumption. “More generally, life cycle water use estimates are a limited indicator of aggregate impact on water resources, given the critical spatial and temporal characteristics of resource demands and availability.” (Meldrum et al 2013); This analysis does not include water generated by burning CH_4; Recent advances in frac’ing could result in 100% of freshwater being replaced with produced water;

1. Gas steam values were taken from table 5 and cooling tower assumed as base case like for gas combined cycle.

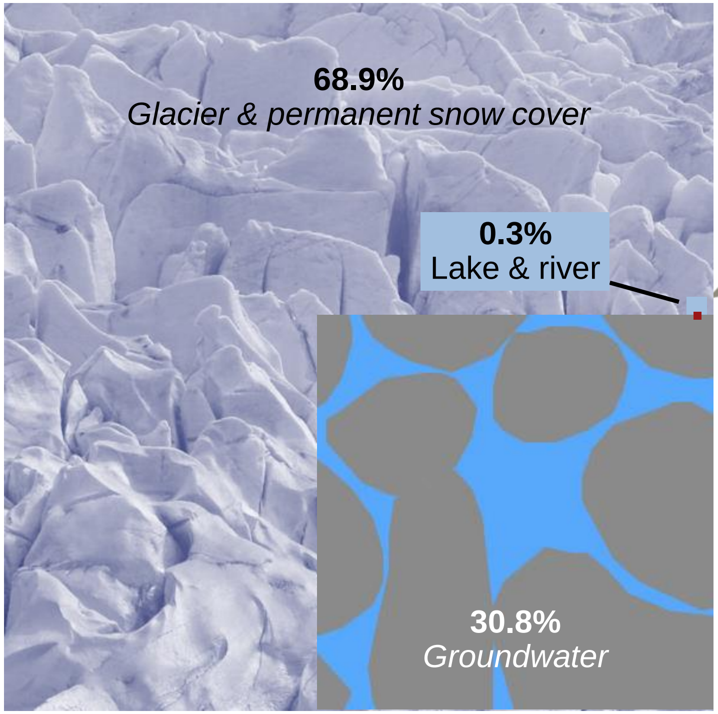
Source: Meldrum et al. (2013), “Life cycle water use for electricity generation: a review of harmonization of literature estimates”

Appendix and bibliography

"Useful" freshwater is scarce, mostly used by agriculture & supply-demand gap is expected to reach ~40% by 2030

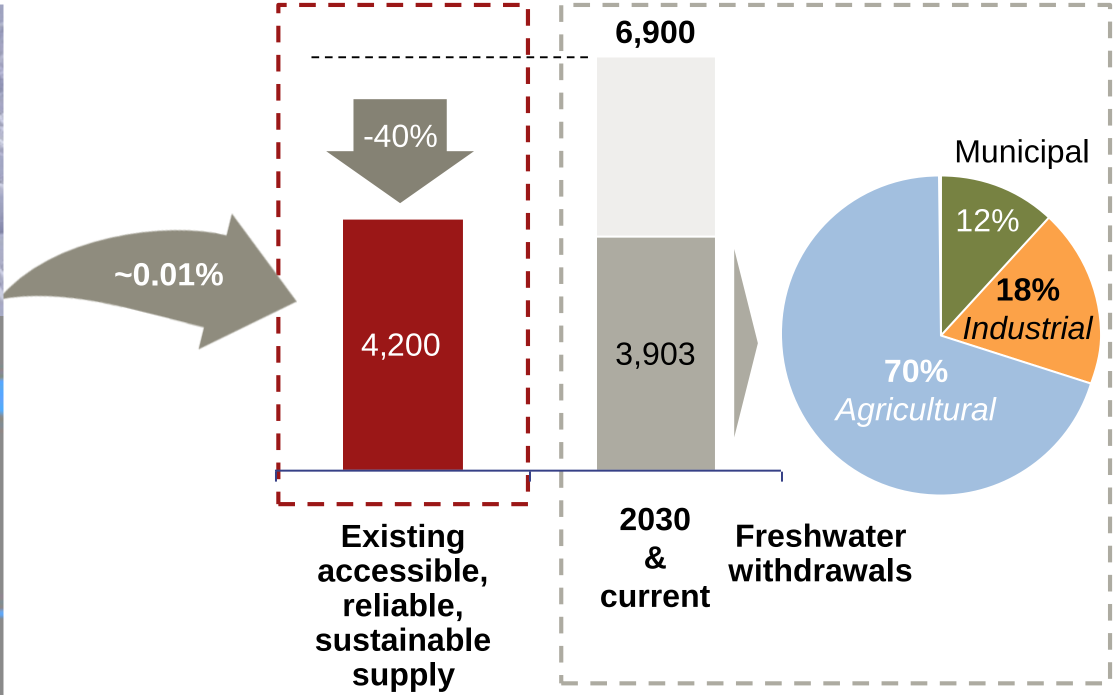
Global freshwater resources

km^3, % ~35 million km^3



Global annual freshwater balance

km^3, % (2009, 2011)



The tiny fraction of the global freshwater resources that is accessible, reliable, sustainable is almost completely withdrawn by human activity

Source: UNEP (2008), "An Overview of the State of the World's Fresh and Marine Waters"; 2030 Water Resources Group (2009), "Charting our water future"; World Bank World Development Indicators database (accessed 2014, data 2011); A.T. Kearney Energy Transition Institute analysis

Back up: Summary table of environmental impacts from shale gas

Environmental Impacts from Shale-Gas Development Seen as Priorities by Government, Industry, Academia, and NGO Experts

Development Stage	**Activities** Activities associated with the development of shale	**Burdens** Burdens that could be created by a development activity and that would have potential impacts that people care about	**Development stage** Aspects of the environment that could be affected by the shale-gas development process
Site preparation	Land clearing and infrastructure construction	Storm water flows	Surface water quality
		Habitat fragmentation	Habit disruption
Drilling	Venting of methane	Methane	Air quality
	Casing and cementing	Methane	Ground water quality
	Casing accidents	Methane	Ground water quality
	Cementing accidents	Drilling fluids/cuttings Fracturing fluids Flowback and produced water	Ground water quality
Fracturing and completion	Use of water and groundwater	Freshwater withdrawals	Surface water availability
			Ground water availability
	Storage of fracturing fluids	Fracturing fluids	Surface water quality
	Venting of methane	Methane	Air quality
Storage/ disposal of fracturing fluids and flowbacks	On-site pit/pond storage	Flowback and produced water	Surface water quality
			Groundwater quality
		Fracturing fluids	Surface water quality
	Treatment by municipal wastewater treatment plants	Flowback and produced water	Surface water quality
	Treatment by municipal wastewater treatment plants	Flowback and produced water	Surface water quality

Note: See details available in the reference cited in WRI (2014): Alan J Krupnick - Resources for the Future (2013), Managing the Risks of Shale Gas: Key Findings and Further Research (http://www.rff.org/rff/documents/RFF-Rpt-ManagingRisksofShaleGas-KeyFindings.pdf) ; Recent advances in frac'ing could result in 100% of freshwater being replaced with produced water.
Source: WRI (2014), "Global shale gas development, Water Availability and Business Risks; Schlumberger interviews

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Acronyms

AIDS: Acquired immunodeficiency syndrome
bbl – bbls: Barrel(s)
BGD: Billions gallons/day
Bn: Billion, 10^9
BOD: Biological oxygen demand
BRIICS: Bresil, Russia, India, Indonesia, China, South-Africa
CAGR: Compound annual growth rate
Capex: Capital expenditure
CO2: Carbon dioxide
CSP: Concentrating solar power
D: Demand
DS: Degree scenario
e: estimation (e.g. 2030e)
EDF: Electricité de France
ETP: Energy technology perspective of the IEA
FI: Falkenmark indicator
GDP: Gross domestic product
GWI: Global water intelligence
HIV: Human immunodeficiency virus
IEA: International Energy Agency
IGCC: Integrated gasification combined cycle
IPCC: Intergovernmental panel on climate change
km^3: Cubic kilometer, 10^9 m^3
kWh: kilowatt hour
LLC: Limited liability company
M: Million, 10^6
MED: Multi-effect distillation
MENA: Middle-East and North Africa
Mm3D: Millions m^3/day
MSF: Multi-stage flash
n.a.: Not applicable
n.a.: Not available
NOAA: National oceanic and atmospheric administration
NREL: National renewable energy laboratory
OECD: Organisation for economic co-operation and development
Opex: Operational expenditure
PC: Pulverized coal
ppm: Parts per million
PV: Photovoltaic
RAS: Returned activated sludge
RO: Reverse osmosis
ROW: Rest of the world
S: Supply
TJ: Tera joules, 10^{12} J
Tn: Trillion, 10^{12}
TSS: Total suspended solids
UNDP: United nations development programme
UNEP: United nations environment programme
USGS: United States geological survey
WAS: Waste activated sludge

Picture credits (1/2)

Slide 11: Spegazzini Glacier, Argentino Lake, Patagonia, Argentina.

Slide 12: Hydrological cycle schematic UNEP (2008), “An Overview of the State of the World’s Fresh and Marine Waters”.

Slide 13: Withdrawal: Pumping of Lake Tangipahoa in Pike County, MS, USA; Consumption: Germany's Jaenschwalde coal plant; Discharge: Effluent discharge into Humboldt Bay from Outfall 001.

Slide 23: Water stress map, UN water (2014), “The United Nations world water development report 2014: Water and Energy”.

Slide 24: % of Population without Access to an improved Drinking water source, World Resources Institute (2013), “Aqueduct Global Maps 2.0”.

Slide 25: Road tanker tieman.com.au

Slide 26: Virtual water trade flows, Dalin et al. (2012), “Evolution of the global virtual water trade network”.

Slide 27: An irrigation pivot watering a field of turnips.

Slide 40: Aerial view of the residential area of the suburb of Milton during the great Brisbane Flood of 2011, the worst flooding disaster in Australia’s History. Image includes submerged parkland and local dining area of Rosalie.

Slide 45: Ranking of risk factor causes of fatality by income group, WHO (2009), “Global Health Risks: Mortality and Burden of Disease Attributable to selected major risks”.

Slide 48: Water in the tanks waiting for draining to the river after treatment.

Slide 52: Thermal, Waterworld (online); Membrane, Konia (online); Biological/chemical, bbdr (online).

Slide 56: Activated sludge, ewisa (online).

Slide 59: A desalination plant unit within a power generation facility.

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Slide 66: Water Availability cost curve – India, 2030 Water Resources Group, (2009), “Charting our water future”.

Slide 67: Aerial view of nuclear power plant on Hutchinson Island, Florida.

Slide 69: U.S. energy consumption and water withdrawal interconnected flows, US Department Of Energy (2014), “The Water Energy Nexus: Challenges and Opportunities”.

Slide 75: Onshore oil reserves overlap with Overall water quantity risk Levels, Wood MacKenzie (2013), “Troubled waters ahead”.

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Slide 79: China’s shale-gas play Overlap with water-stress level, 2014 & Water availability indicators for shale plays in China, WRI (2014), “Global shale gas development, Water Availability and Business Risks”

Slide 80: Shale gas wells Overlap with U.S. water stress zones, Monika Freyman, Ceres report (2014), “Hydraulic fracturing & water stress: water demand by the numbers”.

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Slide 83: Well integrity Management, API (2009), “Hydraulic fracturing operations - well construction and integrity guidelines”.

Slide 85: An aerial view of the Hoover Dam holding back Lake Mead.

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