Water reuse and reclamation: a contribution to energy efficiency in the water cycle

C. Schaum, D. Lensch and P. Cornel

ABSTRACT

Water and energy are two of the most important resources of the 21st century. Water is required to supply energy and, at the same time, energy is required to supply water. In urban water management, the key factor is warm water heating. Depending on the quality of the raw water, the provision of drinking water requires the application of different process technologies; the more complex the methods, the higher the energy demand. As in metropolitan areas, in particular, water consumption exceeds local availability, water pipelines are necessary with respective energy demand. The reuse of water can contribute significantly to conserve water and energy resources. Usually, the water to be reclaimed is supplied locally, making long-distance transport dispensable. By adjusting the process technology to the intended function (fit for purpose), it is possible to minimize the energy demand as well. Water use implies the input of energy (heat, chemically bound energy in form of organic matter) as well as nutrients (nitrogen, phosphorus, etc.). In the context of implementing water reuse technologies, they can also be reclaimed.

Key words | energy, resource recovery, water, water reuse

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INTRODUCTION: RESOURCES WATER AND ENERGY

Worldwide, the energy–water nexus is intensely discussed in the fields of research and development, its importance to be seen in the fact that the motto of the World Water Day 2014 is 'water and energy' (UN 2014a). Population growth, urbanization and climate change as well as the increase in living standards have very similar impacts on the availability of and the access to water as well as energy (Table 1). The UN (2013) estimates that the population will reach 10.9 billion in 2100 assuming medium fertility; least developed countries present the highest growth rates, the population increasing threefold from 2013 to 2100. These rising countries, in particular, have no or only insufficient access to water and energy (UN 2012).

Besides population growth, climate change exacerbates the globally unequal distribution: with water stress as a function of availability, consumption and water quality are likely to change on a local scale due to flooding (risk of contamination respectively decreasing water quality) on the one hand and droughts (decreasing availability) on the other hand (Arnell 2004). Energy availability as well is influenced by climate change, though indirectly; the challenge of minimizing greenhouse gas (GHG) emissions forces the population to energy savings; furthermore, due to climate change driven policies energy prices increase, for example. Other facts to be considered are the finiteness of fossil energy resources and the controversial discussion on nuclear energy.

Beijing, London, Los Angeles, Mexico City, Singapore, Tehran and Tokyo, cities of different development status and different locality, all have in common that the local drinking water demand by far exceeds the locally available resources. Drinking water supply can only be assured with large efforts, and quite often, with severe impacts on the environment. Excessive exploitation of existing water resources, lowering of the groundwater level, energy-intensive and costly transport of water over many hundreds of miles and energy-intensive desalination of seawater are only a few of the consequences of the current water

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Table 1 | Comparison of the resources water and energy

	Water	Energy
Access	Worldwide, about 0.8 billion people have no access to clean drinking water; about 2.5 billion people have no access to sanitary facilities. One of the objectives of the Millennium Development Goals, passed in 2000, is to halve the number of people without access to safe drinking water and basic sanitary facilities (reference year 1990; UN 2012)	About 1.5 billion people in developing countries lack access to electricity and about 3 billion people rely on solid fuels for cooking (UNDP 2009). In emerging and developing economies, in particular, there is a growing demand for energy (electricity, heat, cooling), primarily in the area of mobility. The results are negative environmental impacts, for example, smog
Population growth and increasing living standards	The UN (2013) estimates that the population will reach 10.9 billion in 2100. Population growth and increasing living standards imply higher water and energy consumption in private households, industry and food production	
Urbanization/regional availability	With increasing urbanization, the distances between the place of origin and the place of consumption of water and energy (electricity) grow, involving the construction/operation of short-distance respectively long-distance networks/pipelines	
Food/biomass production	Due to population growth, there is an increasing demand for food and thus an increasing water demand in agriculture. At the same time, meat consumption increases, thus further increasing the water demand (Hoekstra & Chapagain 2008)	There is a growing competition between the production of food and the production of biomass for energy generation (biogas biofuel). Biomass production also requires water (Gerbens-Leenes *et al*. 2009)
Climate change	There are regions confronted with increasing droughts. At the same time, the number of floods increases. Both phenomena have an impact on the availability of water and thus on the water stress index (Jiménez & Asano 2008)	The consumption of fossil energy resources causes the increase of anthropogenic GHG emissions, resulting in worldwide climate changes. At the same time, nuclear energy is controversially discussed (permanent nuclear waste storage, hazardous incidents, as in Japan 2011)
Quality/finiteness/storage	Via the global water cycle, water is virtually infinite. Freshwater in utilizable quality, however, is often scarce where it is needed. Transport and water treatment require energy. Often, local storage is feasible to a very limited extent	Useable electric energy has no natural source. Fossil energy sources are limited; their use leads to an increase in GHG concentrations in the atmosphere. Presently, the degree of alternative energy utilization (solar, wind, water, use of energy contained in wastewater) is insufficient. Large-scale storage of electricity is not yet economic

supply of the megacities' population. Already at this point, one can imagine the close interrelationship between water supply and energy availability.

LINKAGE OF WATER AND ENERGY

Water in the cycle of urban water management

Figure 1 shows the water cycle in the area of urban water management, including the options of water reuse/reclamation. Depending on the type of water resource (groundwater, surface water, seawater/brackish water) water is extracted, treated, and distributed. Thereby, the treatment intensity varies, depending on the intended utilization (agriculture, industry/cooling water, private households).

Water withdrawal covers the total amount of water extracted from the water body (groundwater, surface water, seawater) for utilization. Depending on the type of water utilization, one has to differentiate between net loss or consumptive water use and discharge or non-consumptive water use.

- Water consumption (net loss, consumptive water use): water which is directly 'consumed', for example, via evaporation (cooling water), transpired by plants, incorporated into products or crops, consumed by people or livestock, or otherwise removed from the immediate water environment (Vickers 2001).

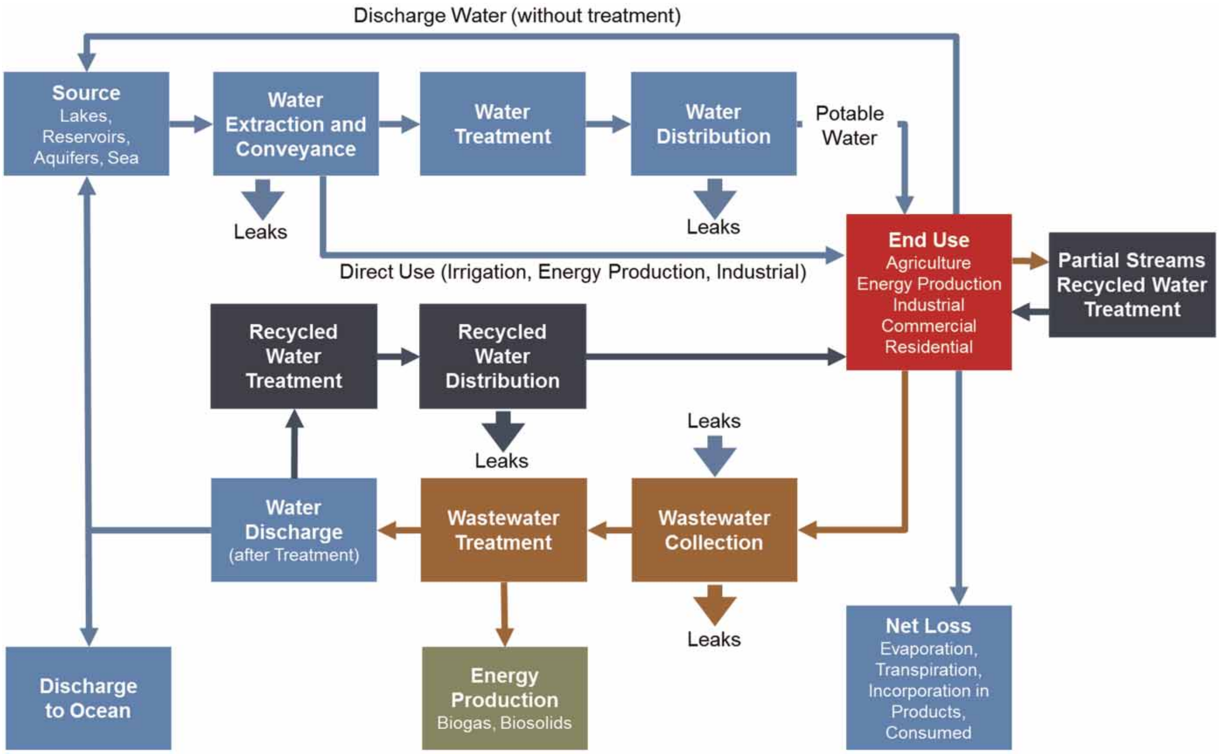

Figure 1 | Water in the cycle of urban water management (CEC 2005; WitW 2013, modified).

- Water use (discharge, non-consumptive water use): water, which, after utilization, is returned either directly (cooling water) – 'discharge water without treatment' – or after being treated (wastewater treatment plant, WWTP) – 'discharge after treatment' – to the immediate water environment. In this context, the resulting water quality (contamination as well as temperature) has to be regarded.

Besides discharge into water bodies, reuse is possible, either from the effluent of the WWTP or directly from a partial stream (Figure 1). Depending on the respective treatment water quality, water reuse is feasible in many scopes of application: agricultural irrigation, non-potable intra-urban uses (toilet flushing, landscape irrigation like in parks, golf courses, greenbelts, residential areas, cemeteries, freeway medians, school yards, fire protection and air conditioning), industrial recycling and reuse (cooling water, boiler feed and process water), recreational/environmental uses (lakes and ponds, streamflow augmentation, fisheries and snowmaking), groundwater recharge (groundwater replenishment, salt water intrusion control and subsidence control), and potable reuse (blending in water supply reservoirs, blending in groundwater, direct pipe to pipe water supply) (Asano 2007).

Looking at this overall concept, the following questions arise:

1. What is the specific water consumption?
2. What is the energy consumption for water supply (depending on the type of resource and the required quality)?
3. What can water reuse contribute with regard to the resources water as well as energy?
4. Is it feasible to reclaim the resources energy and nutrients contained in wastewater?

Water withdrawal: type and quantity

The type of water use is reflected by the geographic/climatic location as well as the degree of development of the respective country. Water availability is thereby identified via the water intensity use index, also called water stress index.

The index describes the relation between the mean annual water withdrawal and the total renewable fresh water resource (Jiménez & Asano 2008). When interpreting the water stress index, one has to distinguish the different kinds of water utilization, especially with respect to water consumption (net loss) and water use (discharge) (Cornel & Meda 2008).

In Figure 2, the specific water withdrawal is depicted for selected countries. In semi-arid regions, such as Southern Europe (Spain, Greece, Malta, and Cyprus), Israel and parts of Australia and the USA, water is mainly used as irrigation water. In contrast, in Central Europe (Germany, Belgium, France), as an example of a warm/temperate rainy climate, water utilization shifts towards industry; agricultural irrigation plays a secondary role. These relationships may be transferred worldwide, also with regard to a shift between industry and agriculture in high- and low-income countries (Jiménez & Asano 2008; World Energy Council 2010; UN 2014b). In all countries, water use for cooling, particularly in the generation of electricity, is of great importance. Where it is not possible to use seawater, fresh surface water/groundwater has to be supplied. Besides the different types of water utilization, there are distinct differences in the specific water withdrawal, especially in comparison with the USA and Australia, mostly due to differing user behavior.

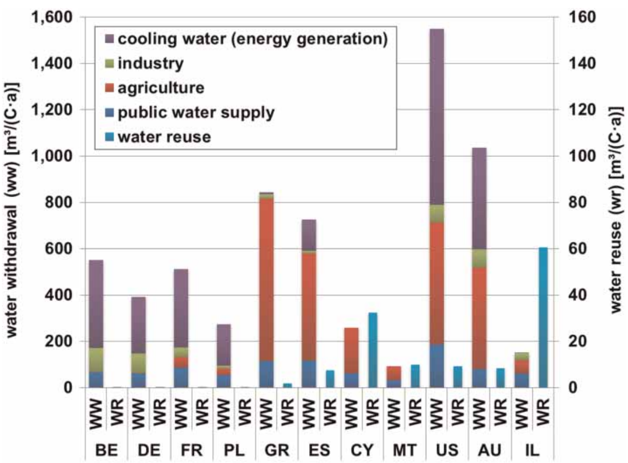

Figure 2 | Specific water withdrawal (WW) and utilization per capita (C) and year (a) for different applications in exemplar countries (Belgium (BE), Germany (DE), France (FR), Poland (PL), Greece (GR), Spain (ES), Cyprus (CY), Malta (MT), United States (US), Australia (AU), Israel (IL)) and water reuse (WR) of treated wastewater; data: Jiménez & Asano (2008), USGS (2009), Eurostat (2013, 2014a), CBoSt (2013a), ABoSt (2013b).

Climatic conditions, as well as water scarcity (water stress index), are the most important driving forces of water reuse. Figure 2 shows water reuse applications of treated wastewater, according to an investigation by Jiménez & Asano (2008). Despite potential data uncertainties, one can clearly see that in countries such as Israel, Cyprus and Spain water reuse contributes to water withdrawal. In Central Europe, in contrast, water reuse of treated wastewater is negligible. However, water reuse in industry is not included here. Water recycling and reuse in industry in developed countries is an established and well-developed practice. The use factor for water including cooling water – which is defined as the quotient of utilized to provided water – varies between 1.3 in the textile industry and up to 21.5 in the vehicle industry (Cornel & Meda 2008). The paper industry is a good example of successful implementation of water reuse. Here, the specific wastewater discharge of approximately 45 L/kg paper in 1974 was reduced to approximately 10 L/kg paper in 2008 (Bierbaum 2013).

Energy consumption: type and quantity and significance of urban water management

In Figure 3, the specific energy consumption is depicted, subdivided into the areas of transport, agriculture, industry, services, and residential, for different countries. Compared with data in Figure 2, one can observe analogies to water

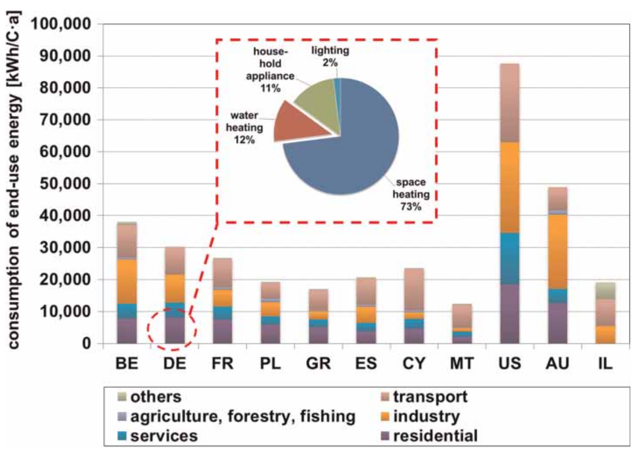

Figure 3 | Specific end-use energy consumption per capita (C) and year (a) for different areas and countries (see Figure 2 for abbreviations) (Israel: 'others' includes residential), data: Eurostat (2013, 2014a), AGEB (2013), ABoSt (2013a), CBoSt (2013b), EIA (2014).

withdrawal. Regarding the specific energy consumption, again there is a significantly higher consumption in the USA and Australia. The low industrial water consumption in Southern Europe (Greece, Spain, Cyprus, and Malta) – as can be seen in Figure 2 – is directly reflected by lower energy consumption.

In addition, Figure 3 shows the type of energy consumption in the area of private households, with Germany as an example. Here approximately 12% of the energy demand is required for warm water heating. Due to different climatic conditions, in Australia the percentage of warm water generation is 25% (space heating/air conditioning: 45%; cooking, appliance, lighting: 30%) (Kenway *et al*. 2008).

Figure 4 shows an initial overview of the energy consumption in urban water management using the example of Germany. Thermal energy required for warm water generation is approximately 20 times higher than the consumption of electricity for water supply and disposal. Even where drinking water is provided via desalination of seawater with resulting doubled power consumption, the basic difference from thermal energy persists. Thereby, the difference in quality of the energy forms electricity and heat has to be taken into account.

Energy consumption for water plays an important role in private households (12–25% of the total energy demand, depending on the geographical location). In municipalities, water supply and disposal are key factors, too, as they are the main consumers of electricity in communes/cities, together with street lighting. In California, for example, approximately 50% of the total municipal energy consumption is taken up by water supply and wastewater treatment (Wilkinson 2000). However, regarding the overall energy consumption (including traffic), the energy consumption for public urban water management, including warm water generation in private households, is very low, in Germany for example <5%. Even though there is a shift in absolute numbers as a function of the specific energy and water consumption, one can identify a similar relationship for high- and middle-income countries worldwide (e.g. USDoE 2006; Kenway *et al*. 2008; Yeshi *et al*. 2013).

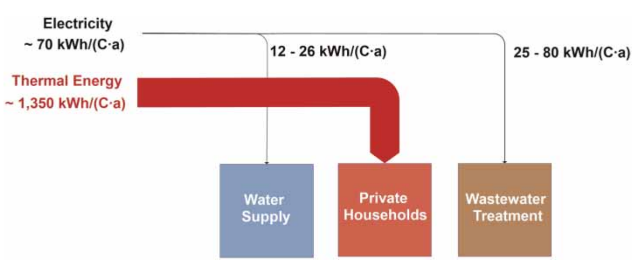

Figure 4 | Specific energy consumption per capita (C) and year (a) in the area of urban water management, using the example of Germany; drinking water from groundwater/surface water, wastewater treatment via activated sludge process; specific water consumption approximately 120 L/(C·d) (Meda *et al*. 2012b).

Application of water for energy generation

Supplying energy requires water (Figure 5). Thereby, water is required for providing primary energy (i.e. extraction, refining, and transport) on the one hand, and the generation of electricity (cooling water) on the other hand. When water is used as cooling water, water loss by evaporation has to be considered: approximately 3% of the total water input (Olsson 2012).

In the field of biomass production, the difference in biomass utilization (gas, ethanol or diesel) has to be taken into account as well as the application of irrigation water for crop production. Thereby, irrigation is a function of climatic and agricultural (plant species) boundary conditions (Gerbens-Leenes *et al*. 2008, 2009; McMahon & Price 2011). Table 2 shows an overview of the different types of specific water consumption required for the provision of energy. One can clearly see that in the field of biomass production, water loss is approximately 100 to 1,000 times higher than water loss for fossil or nuclear energy.

The importance of adequate water supply can clearly be seen in the fact that there are increasing numbers of so-called energy–water collisions. In summer, power stations have to reduce their capacity as a result of too warm water bodies or water scarcity, to be seen for example in the USA or in Germany. Not least, the reactor catastrophe in Fukushima, Japan shows what can happen in case of a breakdown of cooling systems, even though in this case the cause of the accident itself was a natural catastrophe.

Besides the use of water in energy generating processes, there is also a direct use of water for energy production. Water utilization, via geodetic height or tidal range, is strongly dependent on geographical boundary conditions (e.g. McMahon & Price 2011; Olsson 2012).

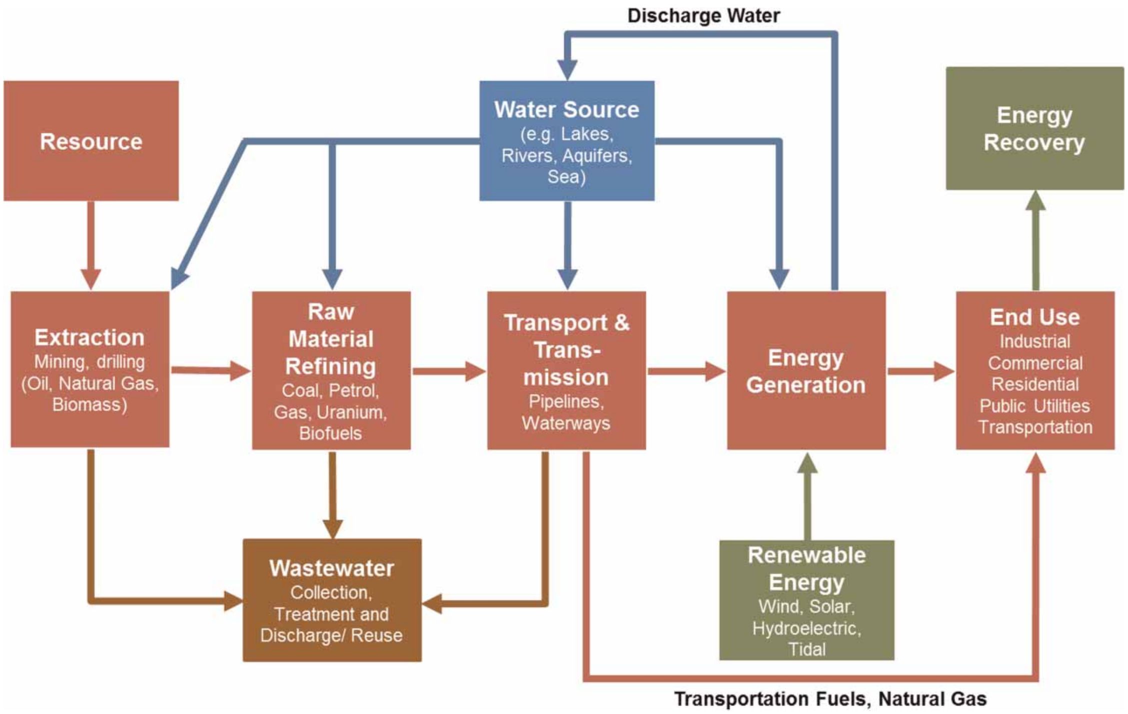

Figure 5 | Water for energy generation (WitW 2013, modified); *note:* water inputs and outputs may be in different water bodies.

Table 2 | Water consumption for the supply of primary energy and water withdrawal and consumption for the generation of electricity

	Supply of primary energy	Electricity generation	
	L/kWh	Withdrawal L/kWh	Losses (evaporation) L/kWh
Crude oil	4.0[a]	–	–
Nuclear	0.1–0.2[b]	95–227[a] 2–10[b]	3–7[a]
Coal	0.6[a] 0.02–0.25[b]	75–190[a] average 136[b]	2–6[a] 0.15–4.2[b]
Natural gas	0.4[a]	average 53[b]	0–4.1[b]
Biomass: biogas	–	–	165–1,400[c], 230[d]
Biomass: ethanol	212–1,508[c]	–	–
Biomass: biodiesel	1,418–2,066[c]	–	–

[a]Olsson (2012); water usage for electrical generation: water loss about 3% of total water withdrawal.
[b]McMahon & Price (2011) (also Gleick 1994; USDoE 2006).
[c]Gerbens-Leenes *et al*. (2008, 2009); sum of blue water (surface and groundwater for irrigation evaporated during growth) and green water (rainwater that evaporated during production); maximum possible electricity capacity via Carnot process assumed 59%.
[d]Example of Germany, biogas plant with corn plants (Rosenwinkel *et al*. 2012).

Application of water for supplying water and the significance of water reuse in municipalities

Water supply includes the application of energy. Thereby, to begin with, the energy demand depends on the quality of the raw water (groundwater, surface water, seawater/brackish water, WWTP effluent) and the water quality to be achieved for the intended function (agriculture, industry, and private households). The decisive factor of influence is the process technology applied for treatment (affects both drinking water preparation and wastewater treatment), for example from basic mechanical treatment up to membrane technology/reverse osmosis (Asano 2007; Cornel *et al.* 2011). With regard to the intended use, the selection of treatment processes again depends on various boundary conditions, particularly the compliance with legal requirements/limit values and meeting standards, for example for the application of irrigation technologies, as well as economic aspects (Asano 2007).

Another key factor, besides the applied treatment technology, is water conveyance/distribution. There are various examples, where local water provisions are insufficient for supplying the population/city. The results are water pipelines with respective energy consumption for water conveyance, existing in practically all metropolitan areas and megacities. For example, in Germany, the city of Stuttgart is supplied with water via pipeline from Lake Constance; in China, there is a water pipeline from the south to the northern regions; in Israel, water is supplied via the Yarkon–Negev pipeline, approximately 130 km long from northern to southern Israel where the water has to be lifted more than 350 m; in Australia, during the 2006/2007 drought, Adelaide and Sydney had to be additionally supplied via a water pipeline (Kenway *et al.* 2008). Water pipelines require additional energy depending on the distance to be covered and the difference in altitude; for example, a 100 km line with an overall increase in height of about 250 m requires approximately 2.5 kWh/m^3 of energy (Yüce *et al.* 2012; Pearce 2012).

Table 3 shows the specific electricity consumption for water and wastewater treatment. Depending on the applied treatment technology and the respective boundary conditions (raw water quality, pumping energy, etc.), the derived specific factors regarding the treated amount of water (kWh/m^3) are comparable. In worldwide comparison, there are differences in the population-specific values. Due to significant differences in the specific water consumption (e.g. water consumption in private households in Germany is approximately 120 L/(C·d), while in Australia it is approximately 194–303 L/(C·d); Kenway *et al.* 2008), the population specific energy consumption differs by a factor of 1.6–2.5.

Table 3 | Consumption of electricity and influencing factors for urban water management

	Water quality	Primary energy drivers	Electricity consumption kWh/m^3	
Extraction, conveyance and treatment	Groundwater (incl. distribution)	Pumping	0.37–1.30[a] 0.5[b] 0.27–0.45[c]	≈0.5
	Surface water	Pumping	0.5–4.0[d]	
	Brackish water	Reverse osmosis	4[e] 1.2–1.5[f] 1.5–2.5[g]	≈1.5
	Seawater	Reverse osmosis	4.0–8.0[d] 3.24[f] 5–10[g] 3.5–4.0[h] 2.5–4.0 (average 3.1)[i]	≈3.5
Wastewater collection, treatment, discharge	Wastewater	Aeration	0.5–1.0[j] 0.43–1.12[h]	≈0.75

[a]Hessenenergie (1999), groundwater extraction (deep well) and distribution, ΔH 50–150 m.
[b]Rödl (2007), water collection, treatment and distribution, benchmark of 98 water distribution companies in Bavaria, approximately 70% collection and treatment and approximately 30% distribution.
[c]Rödl (2006), water collection, treatment and distribution, benchmark of 75 water distribution companies in Baden-Württemberg, approximately 70% collection and treatment and approximately 30% distribution.
[d]Olsson (2012).
[e]Gleick (1994).
[f]GEI (2010).
[g]Asano (2007), brackish water: 1,000–2,500 mg/L TDS (total dissolved solids).
[h]Kenway *et al.* (2008).
[i]Voutchkov (2012).
[j]DWA (2013), on average 33–50 kWh/(C·a) depending on the size of the WWTP, assuming the wastewater amount to be treated at approximately 150 L/(C·d).

The data in Table 3 show a significant correlation between the quality of the raw water and the energy consumption; thereby, the applied processes aim at drinking water quality. This also applies to water reuse, where the aspects of conveyance and treatment intensity, in particular, have to be taken into account and show savings potential: that is, by using water resources close to the point of origin, energy for long-distance transport is minimized. In addition, water technologies to be applied should be adjusted to the respective raw water quality and the intended use. In intra-urban areas, in particular, there is mostly no differentiation in treatment qualities, that is, the highest standard (drinking water) applies. From the point of view of linking water and energy, this fact should be critically discussed in terms of 'Fit for Purpose'.

Table 4 shows an overview of the energy consumption for water reuse as a function of raw water, treatment technology, and intended use. One can see very clearly the differences, starting with the supply of irrigation water (approximately 0.3–0.4 kWh/m^3) up to the production of drinking water via a multi-barrier system (1.3–1.4 kWh/m^3).

Within the context of an Australian study, drinking water production via desalination was compared with different scenarios of water reuse (direct potable reuse: treatment of WWTP effluents with – inter alia – ultrafiltration, reverse osmosis, disinfection and discharge, direct storage and conveyance to drinking water production facilities; non-potable reuse: treatment via precipitation/flocculation, ultrafiltration and disinfection and feeding into a process water network). Figure 6 shows the results for the respective energy consumption. Compared with desalination, energy consumption can be halved via water reuse for drinking water production. The energy consumption for non-potable reuse is only about one-quarter of that for desalination. Economic evaluations show identical trends for annual costs (ATSE 2013). Yüce *et al.* (2012) and Pearce (2012) show similar results for the comparison between seawater desalination and water reuse.

One can clearly see the differences in comparison with desalination. The data, as illustrated in Tables 3 and 4, also show that water reuse offers energetic advantages compared with treatment processes for groundwater/surface water, very distinct in the area of non-potable reuse in agriculture. In case of short transport lines (pumping energy), in particular, water reuse can make an important contribution to resource conservation.

In addition to water reuse with regard to conventional, centralized sanitary concepts, water reuse from partial wastewater streams is another option, often together with the development of new/alternative sanitary concepts, for example, Bieker *et al.* (2010). Various scales can be applied for the utilization of grey water, from a one-family house to multi-storey buildings/hotels and the semi-centralized approach with up to 50,000 inhabitants. The main objective of grey water utilization is to produce service water, for example, toilet flushing or for irrigation. Based on semi-industrial scale tests, Meda *et al.* (2012) determined the energy consumption of grey water treatment (without

Table 4 | Energy consumption and influencing factors of water reuse

Raw water	Treatment[a]	Intended use	Energy consumption kWh/m^3
Raw wastewater	Floc/Filt/UV	Irrigation	0.32[b]
Raw wastewater	UASB/RBC/UV	Irrigation	0.8[c]
Effluent WWTP	Floc/Filt/UF/UV/Cl	Non-potable reuse	0.4[d]
Raw wastewater	CAS/Floc/MF/RO/UV	Indirect potable reuse, industrial purpose, etc.	1.96[b]
Effluent WWTP	Floc/MF/RO/UV		1.45[b]
Effluent WWTP	Floc/UF/RO/UV/Cl	(Indirect) potable water	1.2[d]
Effluent WWTP	OZ/Floc/DAF/Filt/OZ/AK/UF/Cl	Potable water	1.34[e]

[a]CAS: conventional activated sludge process; Floc: precipitation/flocculation; DAF: dissolved air flotation; Filt: filtration; MF: microfiltration; UF: ultrafiltration; RO: reverse osmosis; OZ: ozonization; AK: activated carbon (filter); Cl: disinfection via chlorination; UV: disinfection via UV.
[b]Yüce *et al.* (2012).
[c]Müller (2013); Müller K., personal communication, 2014.
[d]ATSE (2013).
[e]Lahnsteiner & Lempert (2007); Lahnsteiner J., personal communication, 2009.

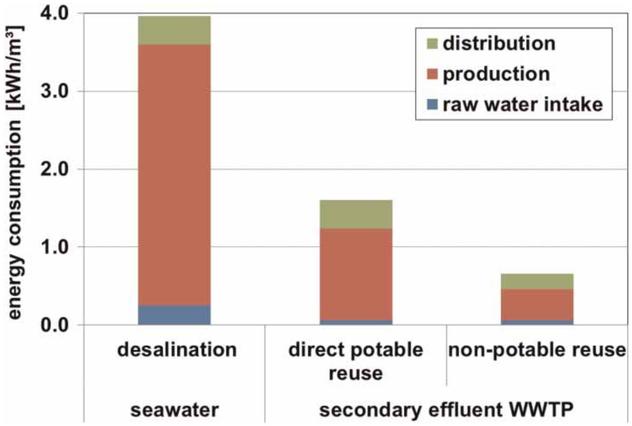

Figure 6 | Energy consumption as a function raw water and clean water quality, results from a fundamental Australian study, data: ATSE (2013).

Table 5 | Energy consumption of grey water treatment

Intended use	Treatment process	Energy consumption kWh/m³
Service water (e.g. toilet flushing)	Activated sludge process, disinfection, distribution	0.6[a]
	Membrane biological reactor, disinfection, distribution	1.2[a]
	Multistage RBC, disinfection, distribution	<1.5[b]
	Membrane biological reactor, disinfection, distribution	1.5[c]
	Treatment, disinfection, distribution	1.5–3.0[d]

[a]Bieker *et al*. (2010), semi-centralized approach for approximately 30,000–50,000 C, grey water: 40 L/(C·d).
[b]Nolde (2000), multi-storey building.
[c]Friedler & Hadari (2006), multi-storey building.
[d]fbr (2005).

disinfection and distribution) to be between 0.1 and 0.7 kWh/m^3, depending on the applied process technology. Including disinfection and distribution, the energy consumption of grey water treatment is between 0.6 and 1.5 kWh/m^3 (Table 5).

Prospects: utilization of the resources energy and nutrients contained in water

Water utilization involves energy input, especially regarding heat (e.g. water for body hygiene) and via organic matter (feces, food waste, etc.) as chemically bound energy (Cornel *et al.* 2011; Meda *et al.* 2012b). There are various procedural approaches for heat recovery from wastewater. Where heat pumps are used, the annual performance factor has to be considered (including the primary energy consumption or whether the operation is exclusively with renewable energy) (Cornel *et al.* 2011). Due to the higher heat potential of grey water, decentralized/semi-centralized approaches are of special interest. In municipal wastewater treatment, chemical energy bound in wastewater is used during sewage sludge treatment via digestion and thermal utilization (Schaum *et al.* 2010). With industrial wastewater (e.g. from food industry) with a high organic load, biogas can be produced via anaerobic wastewater treatment. Current research projects also focus on the anaerobic treatment of municipal wastewater. However, presently this is only relevant in warm climates (low chemical oxygen demand concentration, wastewater temperature, post-treatment, dissolved methane) (Cornel *et al.* 2011).

In addition to energy recovery, it is important to utilize the nutrients contained in wastewater. Besides phosphorus, an essential and at the same time limited resource (Schaum 2007; Petzet 2013), nitrogen exists in usable form. Via specific partial treatment wastewater can be applied in agriculture (utilization of water and nutrients). There are various examples of implementation worldwide (Asano 2007).

CONCLUSION

Water and energy are two of the most important resources of the 21st century. Access to these resources has developed very differently worldwide. While in developing countries access to water and energy is often non-existing, there is a high demand for water and energy in newly industrialized countries, often associated with missing sustainability in project implementation. Factors such as population growth/urbanization, food production as well as climate change will further aggravate the problem of water and energy.

Water is needed to supply energy. The focus here is on heat utilization for cooling in power stations as well as on water consumption (irrigation) in the field of biomass production. At the same time, water supply needs energy.

With regard to urban water management, warm water heating is the main factor.

Depending on the quality of the raw water, different treatment technologies are needed to provide drinking water, starting with solely conveying energy (groundwater), flocculation/filtration (surface water) up to reverse osmosis (seawater). The more intensive the treatment technology, the higher the energy consumption. As, especially in metropolitan areas, the water demand exceeds local availability, water pipelines are necessary, again increasing the energy demand.

Water reuse can contribute significantly to conserving resource water as well as energy. Mostly, the water to be used is available locally, thus making long-distance transport unnecessary. By adjusting the treatment technology to the intended use (Fit for Purpose), energy consumption can be minimized. Compared with seawater desalination plants, water reuse offers a significant energetic advantage (energy consumption lower by a factor of two); the same applies for the comparison with alternative treatment processes.

The use of water includes the input of energy (heat, chemically bound energy in the form of organic matter) and also nutrients (nitrogen, phosphorus, etc.). In the context of implementing water reuse processes these can be utilized as well.

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