UNDP/GEF Kura II project

The economic benefits of green technologies for water use

A report for the KURA II project

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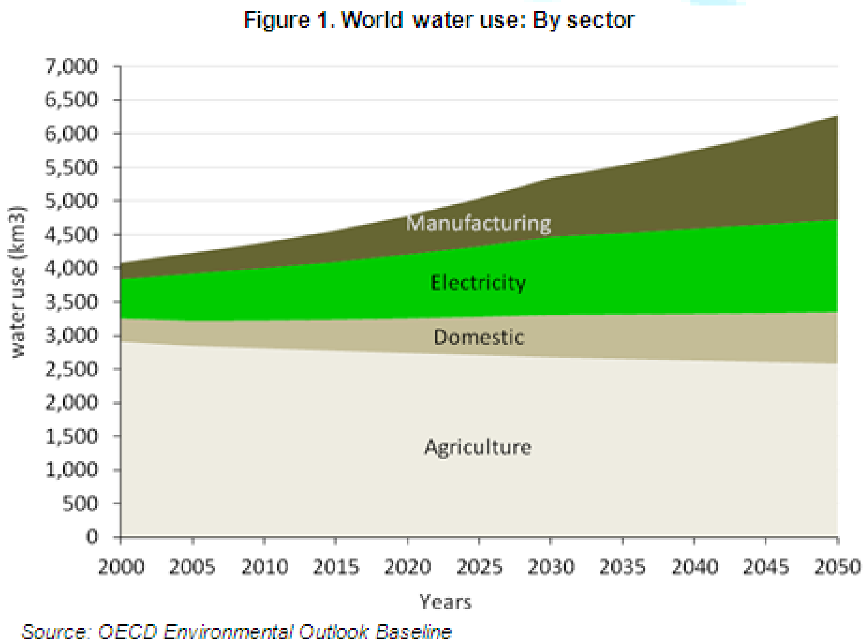
List of Acronyms

AE	field Application Efficiency
AMI	Advanced Metering Infrastructure
AMR	Automated Meter reading
AUSD	Australian Dollar
BAT	Best Available Technologies
BCR	Benefit-Cost Ratio
CAPEX	Capital Expenditure
CE	conveyance efficiency
CHP	Combined Heat and Power
EPA	US Environment Protection Agency
ESA	Ecosystem Services Approach
FAO	Food and Agriculture Organisation
GNRC	Georgian National Energy and Water Supply Regulatory Commission
GWP	Georgian Water and Power Ltd
HP	Hydro-power
IEA	International Energy Agency
MAR	Managed Aquifer Recharge
MWT	Magnetised Water Treatment
NBS	Nature-based Solutions
NPV	Net Present Value
O&M	Operation and Maintenance
PI	Precise Irrigation
PIS	Pressurised Irrigation Systems
PWS	Public Water Supply
RO	Reverse Osmosis
SME	small and medium sized enterprise
TDS	Total Dissolved Solids
TOR	Terms of Reference
UF	Ultra-filtration
UNEP	United Nation Development Programme
UNIDO	United Nation Industrial Development Organisation
UNWSCG	United Water Supply Company of Georgia
USD	US dollar
WFD	Water Framework Directive
WHO	World Health Organisation
WWT	Waste Water Treatment

1. Introduction

Globally the consumption of water is projected to increase (see Figure 1) by 2050, mainly due to population growth, economic development and changing consumption patterns. . Industrial and domestic demand for water will continue to grow, whilst the outlook for agricultural demand is uncertain: FAO estimated a 5.5% increase in water withdrawals for irrigation from 2008 to 2050 but OECD forecasted a slightly decrease in agricultural water demand from 2000 to 2050, due to uptake of water efficiency irrigation technologies (WWAP, 2018). Potentials for implementing water efficiency measures have not been exploited completely and will have a direct impact on total water use.

Figure 1 – Projected Growth of annual water consumption by sector

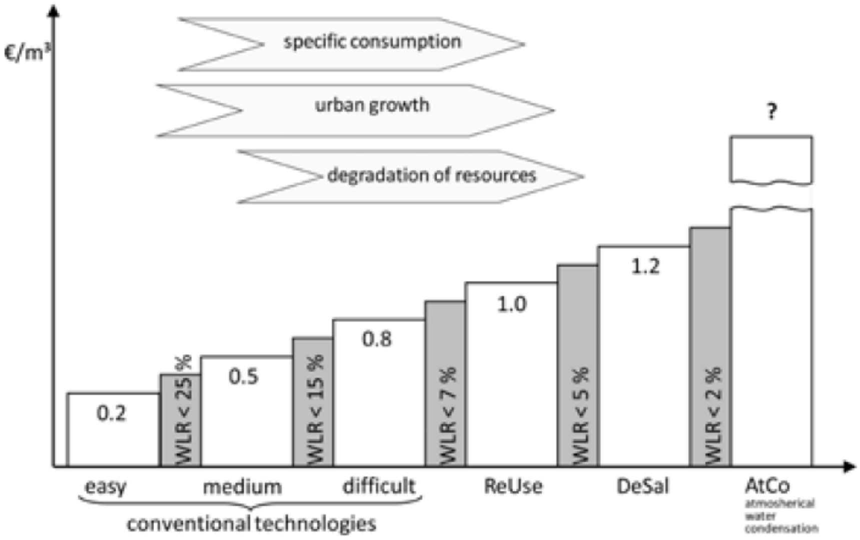


Source: OECD, 2016

UNEP (2011) estimates that without efficiency gains, global demand for water will exceed supplies by 40 %. Whilst increase in exploitable water resources will partly address of this gap, a major role will be played by water policy reforms, and investment in new infrastructure and technology. In order to understand the economic viability of such investments, a thorough understanding of associated costs and benefits is necessary. In particular, benefits' estimation should consider the impacts of the application of green technologies to society as a whole, thus including also external effects (either positive or negative).

As part of the Kura II project this report aims to review the economic benefits of green technology for water use, by considering international best practices and national experiences in the Kura river basin. This report has been prepared by considering technologies that ensure water reuse and recycling and the adoption of Best Available Technologies (BAT) in water use. We assess economic benefits according to water use. For productive uses, these are intended as the increase of net outcome per unit of water used or saving in production costs. For public water supply, improved water use efficiency is nowadays a complement to investments in long-term water supplies and infrastructure. In many cases, successful water consumption reduction strategies have made it possible to postpone investments in new water assets or more expensive technologies, such as desalination. Therefore, benefit of adoption of green technologies goes beyond O&M savings, but comprises also avoided capital expenditure. As noted by UN-Water (2011), the higher water production costs are the more competitive water efficiency measures become. Water recycling technologies are more competitive in water-scarce locations. Innovative technologies will be needed where water reduction targets cannot be achieved through conventional technologies. As sketched in Figure 2, technological choices are determined by production costs and water reduction targets. Economic benefits also include positive external effects entailed by green technologies uptake.

Figure 2 – Hierarchy of water production costs



Source: UN-Water (2011), fig. 2, p. 15.

In the case of water management, the economic benefits of water efficiency measures or the economic impacts of water quality improvements can be monetised by considering the market values of a given commodity, e.g. the selling price of a crop produced with water, or by assessing societal preferences.

As such, no absolute value for the benefit of a given technology exists, as this will vary according to local market conditions and society's preferences. The theoretical challenge of assigning a value to a unit of volume of water has long been debated in economics literature. Whilst this task is beyond this assignment, in this report we tried to report monetary values derived in grey and peer-reviewed literature, to give an order of magnitude of the benefits that investing in green technology can give. In absence of a monetary estimate, a physical indication of the positive impact of such investment, e.g. in terms of increased crop yield, or a qualitative description, is provided.

This report has been compiled by using secondary sources. Methodological approaches and results of the reviewed grey and peer-reviewed literature differ. Consequently, the type of information provided is not necessarily uniform or comparable, but the findings of previous studies support the economic case for investing in green technologies. This study is not intended to provide unit value estimates that can be immediately transferred to the Kura river basin, but to derive some relevant policy implications.

First, a definition of green technology for water use is provided. Technologies have been considered for public water supply, agriculture, industry and the electricity generation sectors and international experiences have been recalled, with particular reference to countries with climatic conditions similar to those present in the Kura river basin. For each of the techniques considered, barriers and enabling conditions for uptake have been reviewed. In the concluding part of the paper a discussion of transferability of international experiences in the Kura river basin is provided and final considerations drawn.

2. Definition of green technologies

A very general definition of green technology considers technology whose use is intended to mitigate or reverse the effects of human activity on the environment. A more specific definition is given by the *Financial Times*, which refers to green technology as the use of technology that makes products and processes more environmentally friendly, helps to reduce adverse effects on the environment as well as improving productivity, efficiency and operational performance[1]. In the case of water use, we will then consider all technologies that will make it possible to:

- Recycle and reuse water, thus diminishing the water used per unit of output
- Abate pollution after water is used
- Reduce other environmental impacts

Examples of green technologies applied to the water sector include: harvesting of rainwater; high-efficiency ultraviolet disinfection systems; reuse of grey water in productive or energy uses, reuse and recycling of waste water. It should be noted that technologies can be adopted both on the supply side and on the demand side. The following table describes the technologies that will be considered in this report, for each sector.

[1] http://lexicon.ft.com/Term?term=green-technology

Table 1 – Technologies analysed in this report

Sector	Policy objective	Technologies
PWS	Reduce Water use Reduce water losses Treat water Water supply regulation	Water efficiency retrofitting Smart monitoring Nanotechnology in filtration Decentralised wastewater processes (including constructed wetlands)
Irrigation	Reduce water use Reuse water Reduce impacts	Pressurised Irrigation Systems Precision irrigation systems Smart Water Meters Laser levelling Magnetised water Aquaponics Reuse of wastewater Soil and water conservation practices
Electricity generation and industry	Reduce water use Reuse water	Improve cooling tower efficiency. Reuse of wastewater
Hydroelectricity generation	Reduce environmental impacts	Mitigation measures

3. Public Water Supply

Water efficiency retrofitting

Water efficiency in buildings can be improved through building design, water efficient plumbing fixtures and fittings and the efficient use of water by water users. Examples of water efficient fittings include (Waterwise, 2008):

- Tap and showers retrofits, either through flow regulators or tap insert devices.
- Changing toilet cisterns to install dual flash capabilities. New toilets consume around 3 litres, compared with 9+ used by toilets installed before 1989.
- Substituting old washing machines and dishwashers with new more water efficient ones, which consume a third and a fifth of water, respectively, compared to old models.
- Water butts for collecting rainwater and trigger hose guns, for use in watering gardens.

In many cases retrofitting actions pay back in 1-3 years, depending on the water bills savings and the cost of interventions. White goods (i.e. washing machines and dishwashers) have longer payback periods. In this respect, Fidar et al. (2016) note that for these goods "there is not a sensible economic justification for accelerated replacement of a reliably working machine with a new model unless it is used very often and water and energy charges are very high" (p. 527), as their payback period is longer than their lifespan.

Water retrofitting concerns both residential and non-residential buildings, such as hotels, hospitals, etc. In this respect, water retrofitting programmes might take the form of assistance to small and medium sized businesses (SMEs) with new products and services. For many SMEs retrofitting is seen as a way of cutting O&M costs, related to water usage in business activities. For example, anecdotic evidence (Barnard et al., 2014) shows that up to a quarter of water used can be saved by hotels by implementing water efficiency retrofitting, and that would in turn entail a 10-30% saving in water bills.

Evidence from regional and national assessments supports the implementation of conservation programs. US EPA (2002) reviews water efficiency programmes in 17 cities and found that they were all successful in substantially reducing water demand and savings up to USD 260 million.

A national assessment carried out in New Zealand (Beacon, 2009) estimates that all retrofitting measure show a positive benefit-cost ratio, BCR (some measures have a BCR close to 20:1). Water retrofitting programmes have also been implemented in the USA since mid-90s (Green, 2001), with positive BCRs (varying in the range 4-20: 1). In the case of New York City, the unit cost of replacing 1.5 million toilet cisterns was lower than supply augmentation. A&N et al. (2006) defined a method to estimate the avoided cost to water utilities from water efficiency. Investment in water and treatment facilities can be deferred or downsized due to reduction in water demand entailed by water efficiency measures. Economic benefits of conservation strategies (i.e. high efficiency toilets, washing machines and gardening irrigation) have then be assessed in California[2] in terms of total avoided costs for utilities (short- and long-term cost) and they range from 561 to 920 USD/AF per year (where 1 Acre Feet = 1,233.48 m^3). All measures show a BCR greater than one, except water efficient washing machines.

A study from Cooley and Phurisamban (2016) also confirmed that efficiency measures are less expensive than most new water-supply options and are therefore the most cost-effective way to meet current and future water needs. They found that many measures have negative costs (because the reduction in maintenance costs outweighs the investment cost) and are therefore win-win options even in absence of water scarcity.

Smart monitoring and smart water grid

Aging infrastructure entails high water losses, up to 50% of distributed water (UNESCO, 2009). Leakage location is hindered by the vastness of the distribution network and the hidden nature of water pipes, which make it possible to repair leakage only when mains' breaks become apparent through visible water losses. Prevent water losses is important to avoid wasting water, but also to avoid other impacts to society, such as public services disruptions or damages to road infrastructure that occur when a pipe leaks.

Smart monitoring creates an opportunity to detect water losses of the network and run the water grid more efficiently. There are two main monitoring methods (Martyusheva, 2014):

- Automated Meter Reading (AMR), which obtains water meter readings through radio-transmitted signals. The collected information includes the serial number of the meter and the volume of water consumed. The meter can detect if the water is being used continuously, which will indicate a presence of the leak in the system. Moreover, by giving customers more information on their water use habits it can help them to reduce consumption.
- Advanced Metering Infrastructure (AMI), can be used to detect electric, gas, and water networks. These are integrated system of smart meters, communications networks, and data management systems. With an AMI system, the whole distribution network can be

[2] https://sustainablecities.usc.edu/files/2015/01/Chapter-7-Water-Conservation-Cost-Effectiveness-12-19-p.pdf

continuously monitored by hourly interval reads. The main advantages of the system are that it minimises repairing costs, by detecting even small leaks that can be repaired before they produce more substantial damages to the distribution network, and it optimises asset management, by identifying the pipes that are in most need of repair. That way, it extends the life of capital assets and in the long term reduces CAPEX.

Besides water conservation and asset management optimisation, a smart water grid, i.e. a water distribution network with sensors and devices that continuously and remotely monitor the water distribution system, can also be equipped with water quality monitoring sensors that can create alerts when potential problems arise in terms of changes in water quality. A computer-controlled system helps to monitor and control processes, by acquiring information from remote devices (e.g. pumps, valves, transmitters, etc.), and turns devices on or off, display real time operational data, provide equipment-wide to system-wide views of operation, trend data, and alarms.

The benefits of adopting smart monitoring technologies in terms of financial savings to water operators have been quantified by Sensus (2012), see Figure 3. Reducing water losses also reduced electricity costs considerably (no unit costs estimates for savings in electricity costs are available).

Figure 3 – Financial benefits of smart monitoring technologies adoption

Category	Savings as Percentage of Baseline Cost	
Leakage and Pressure Management	2.3 - 4.6	(3.5%)
Strategic Capital Expenditure Prioritization	3.5 - 5.2	(12.5%)
Water Quality Monitoring	0.3 - 0.6	(0.4%)
Network Operations and Maintenance	1.0 - 2.1	(1.6%)
Total Smart Water Savings Opportunity	**7.1 - 12.5**	**(7.4%)**

Source: Sensus (2012)

Smart metering makes it possible to better integrate improved data sets into water planning processes and could potentially improve customer engagement by providing real time information on water use. Moreover, the improved information on water consumption patterns makes it possible to implement billing based on accurate readings; and design more flexible water tariffs, which can be used as a water demand management tool. It also identifies excessive customer use and service pipe leakage. One other reason for introducing smart metering has been to improve the information regarding time of use and end-use together with to reduce labour costs for meter reading (Boyle et al., 2013; EA, 2008).

These benefits should be considered along the cost to update current infrastructure. Smart water technology requires a high upfront cost (even 6-7 times more expensive than a traditional meter), which will have a return on investment spread over several years. In the US, only about 20 percent of water utilities have adopted this new technology[3]. The lack of funding is one of the main limiting factors for smart monitoring adoption. According to the results of a survey of US water utilities US conducted by Sensus (2012) other limiting factors are the lack of awareness and political will.

Several projects worldwide have implemented Smart Water Grids into their water distribution systems, with positive results, often in connection with smart metering programmes in the energy sector, which have been introduced more widely (Boyle et al., 2013). It is estimated that in 2009 around 18% of the total number of intelligent metering projects across water and energy worldwide (Sydney Water, 2009). First applications have been limited to small-scale pilot projects, but some examples of large roll-out exists, such as that of London (through Thames Water) and New York. A detailed review of smart metering implementation in Australia and worldwide is given by Boyle et al. (2013).

Decentralised treatment systems

The introduction of green technologies is not limited to water distribution and use. Besides considering technologies that reduce impacts to the natural environment, we refer also to technologies that might increase available water sources at low cost and reduce treatment costs.

Technological innovation and advances in research have brought to light effective decentralised wastewater treatment processes, such as:

- Activated sludge digesters, which remove nutrients (that can be used as fertilisers), whilst driving down the energy required for treatment by up to half.
- Constructed wetlands with slow rate infiltration

Both technologies are characterised by lower costs than centralised systems (Nogueira et al., n.d.), but activated sludge has much higher energy requirements because of the aeration equipment. Technological advances make it possible to safely remove pollutants, but higher investment costs (compared to, e.g., groundwater abstraction) are a limiting factor (EPA, 1998). For these reasons, decentralised wastewater treatment systems are more and more considered as a viable alternative to traditional, centralised wastewater treatment plants. Almost half of the population of the US is treated through decentralised systems (Nelson, 2005). The main advantages of decentralised systems are the avoided effluent transport costs and the potential for on-site reuse. They are considered viable alternatives to centralised waste water treatment (WWT) systems in rural and remote areas, from a technical, economical or environmental point of view (Libralato et al., 2012; Chirisa et al., 2017). The following table summarises the key characteristics of the two systems.

[3] https://www.bna.com/high-cost-smart-n73014451587/

Table 2 – Key features of centralised and decentralised WWT systems

Parameter	Centralised system	Decentralised system
Collecting system	Large diameters, long distances	Small diameters, short distances
Requirements space	Large area in one place	Small areas in many places
Operation and maintenance	Full time technical staff requirements	Less demanding, can be monitored remotely
Uniformity of water	Many types of water	More uniform water
Dilution grade	Less control over the storm water, more dilution	More control over the storm water, more concentrate
Risk	Risk on a larger scale	Risk distributed
Water transfer	Increase the needs for water transfer	Water is used and reused in the same area
Social control	Social control is lost	More social control
Ease of expansion	High costs, more complexity to implementation	Low cost, less complexity to implementation
Potential to reuse	All water is concentrated in one point	Water can be reused locally

Source: Chirisa et al., 2017

JRC (2014) classifies reclamation technologies according to the energy and space they need (see Figure 4): intensive technologies require more energy and less space, and consist in accelerated artificial processes. For example, nanotechnologies in form of ultra-filtration (UF) or reverse osmosis (RO) can be used to treat low water quality and make it suitable for consequent uses. Rather, extensive technologies rely on natural processes and require a greater amount of land, but reduce energy requirements. They still require operation and maintenance.

Figure 4 – Intensive and extensive reclamation technologies

Intensive technologies	Extensive technologies
Physical-chemical systems (coagulation-flocculation, sand filters)	Waste stabilisation ponds (maturation ponds, stabilisation reservoirs,...)
Membrane technologies (ultrafiltration, reverse osmosis, membrane bioreactor, ...)	Constructed wetlands (vertical-flow, horizontal-flow,..)
Rotating biological contactors	Infiltration-percolation systems
Disinfection technologies (ultraviolet radiation, chlorine dioxide, ozone, peracetic acid, ...)	

Source: JRC, 2014

Technological advances make it possible to reduce investment cost. One example is the prototype for filtration using composite nanoparticles, developed by the Indian Institute of Technology Madras[4], that remove microbes, bacteria and other contaminants. It costs just US$2.50/year and it is deemed commercially viable[5]. This technology could represent an alternative in disperse settlements in remote areas, where the provision of centralised potable water treatment can be not possible, for economic or technical reasons.

The reduction of energy requirements for WWT plants is also an area where technological advances can help reducing environmental impacts. It is estimated that EU-27 consume circa 15,021 GWh/year

[4] http://www.dstuns.iitm.ac.in/pradeep-research-group.php

[5] https://www.theguardian.com/sustainable-business/new-water-technologies-save-planet

to treat their wastewater[6]. Conventional WWT is energy intensive as it relies on biological processes. Physical and chemical processes have been explored as a less-energy-intensive option. A new process piloted by Gikas (2017) is carbon neutral and able to produce 0.172 kWh/m^3 of wastewater.

Worldwide here are many examples of constructed wetlands in wastewater reclamation and reuse schemes (Bixio et al., 2004). The environmental and economic benefits of constructed wetlands have been extensively assessed by adopting the Ecosystem Service Approach (ESA, see Table 3), which produced a vast literature over the past decade.

Table 3 – Constructed wetland functions and related services provided

Wetland Function	Services provided
Hydrology/Water Quality	Supply of Reusable Water Increase of Surface Water Quality Groundwater Recharge
Fish and Wildlife Habitat	Food and Fibre Production Protection of fisheries/Aquaculture Educational/cultural activities Biodiversity conservation
Recreation and aesthetics	Recreational Activities
Landscape Enhancement	Land Development

Source: Adapted from Ghermandi (n.d.)

To quote just a few studies, Dunne et al. (2015) found that benefits of constructed wetland ecosystem services, in terms of nitrogen removal, worth more than double the costs. Ghermandi et al. (2009) conducted a meta-analysis of the values of ecosystem services provided by 186 wetlands and found that the benefit associated with the good and services provided by constructed wetlands increase with the anthropogenic pressures. The studies reviewed suggest a high variability of unit value for constructed wetlands, reflecting diversity in terms of size, location, beneficiaries, etc. Estimates are in the range of 100-39,100 USD/ha.

Adopting nature-based solutions in wastewater treatment processes also bring several co-benefits WWAP (2018), namely enhancing biodiversity, reducing soil degradation, habitat improvement, carbon sequestration, soil stabilization, groundwater recharge and flood mitigation (p. 59). Other socio-economic benefits include reducing health risk.

4. Agriculture

In arid and semi-arid countries the selection of irrigation methods is influenced by physical factors and socio-economic conditions. It is acknowledged (Pandya, 2018) that in order to meet future water demands agricultural production should increase worldwide by 60% and this objective could be achieved by improving the use of resources (mainly water and land). However, the increase in water productivity can be achieved only to a limited extent by a combination of water saving engineering

[6] http://www.enerwater.eu/enerwater-project-waste-water-treatment-plants/

solutions (including modernisation of irrigation systems) and soil management. Ali and Talukder (2008) argue that economic factors (i.e. profitability) play a key role in enhancing water productivity. Water conservation in agriculture is essential to prevent salinity and land degradation, which also affect water productivity.

The adoption of green technologies might not be sufficient to guarantee adequate river flow or reverse depletion of groundwater. As shown by Fishman et al. (2015) the conservation benefits of water use efficiency can be lost due to the expansion of irrigated land. They underline that conservation strategies are important to ensure sustainable water management.

The main innovative irrigation techniques to improve irrigation efficiency are: drip and sprinkler irrigation, precise irrigation (sensors), magnetised irrigation, hydroponics and smart meters. These will be described in the following paragraphs, with an indication of their benefits and implications for farmers' income. For completeness, also soil and water conservation practices will be considered.

In analysing the different irrigation techniques, we will refer to the concept of irrigation efficiency, defined by FAO as the percentage of irrigation water which is not lost during transportation (i.e. conveyance efficiency, CE) or application (i.e. field application efficiency, AE).

Whilst CE depends mainly on the length of the canals, the soil type and maintenance of the canals (see Table 4), AE is affected by irrigation practices and farmers' conservation behaviour. In the remainder of this section we will focus therefore on AE.

Table 4 – Conveyance efficiency for adequately maintained canals (%)

Length	Earthen Canals (soil type)			Lined Canals
	Sand	Loam	Clay	
Long (> 2000m)	60	70	80	95
Medium (200-2000m)	70	75	85	95
Short (< 200m)	80	85	90	95

Source: FAO

Pressurised Irrigation Systems (Drip and Sprinkler irrigation)

Worldwide, gravity irrigation systems are adopted on 86% of total irrigated area, while sprinkler-irrigation covers 11%, and the micro-irrigated areas are only 3% (Madramootoo, 2015).

Pressurised Irrigation Systems (PIS) are more efficient than surface irrigation (see Table 5). These have a conveyance efficiency of 100% and an application efficiency of 75–90%. Sprinkler irrigation saves less water than drip irrigation, since it supplies water over the entire field. Subsurface drip is more efficient than surface drip irrigation (Morad Hassanli et al., 2009).

Drip irrigation is most suitable for row crops (vegetables and soft fruit), tree and wine crops and adaptable for most soils (FAO, NA). Given the high capital costs of installing a drip system only high-value crops are normally considered for this technology.

Sprinkle irrigation is suited for most row, field and tree crops and adapted to shallow sandy soils of uneven topography where levelling is not practicable, and to the regions where both labour and water are scarce (Yadvinder-Singh et al., 2014). Compared to basin irrigation it improves water productivity (i.e. yields per water applied) in wheat, maize, sorghum, sugarcane, and cotton.

Table 5 – Indicative values of field application efficiency (%)

Irrigation methods	Field application efficiency
Surface irrigation (border, furrow, basin)	60
Sprinkler irrigation	75
Hand and Wheel Moved	60-85
Sprinkler Pivot	75-95
Drip irrigation	90
Micro-drip	70-95
Low-energy precision	75-98

Source: FAO (NA) and Madramootoo (2015)

Drip irrigation systems can reduce irrigation requirements from 20 to 70% compared with surface irrigation. Besides saving water, other economic benefits of PIS are increased crop yields. For example, in the case of horticultural products, productivity is enhanced by 20-40% (Yadvinder-Singh et al., 2014). Studies conducted in Morocco demonstrated that drip irrigation gave 28% higher wheat yield and 24% higher water productivity compared to surface irrigation (Kharrou et al., 2011). Waheda and Ali (2013) analysed effects on yield and water productivity of maize in Egypt of different irrigation systems. Grain yield of maize under drip irrigation was circa a third higher compared to sprinkler irrigation system.

Kuşçu et al., (2009) conducted an economic analysis of drip irrigation systems in Turkey, and found that this technology was profitable for pepper, tomato, eggplant and green bean. The benefit per hectare (in terms of net returns to farmers) are summarised in Table 6.

Table 6 – Net returns of drip irrigated vegetable crops under different levels of irrigation

Irrigation	Total cost (us$ ha^{-1})				Net return (us$ ha^{-1})			
levels	Tomato	Pepper	Green bean	Eggplant	Tomato	Pepper	Green bean	Eggplant
20	1630	1483	495	1024	834	757	715	1433
40	1685	1548	556	1065	2072	2844	2167	2922
60	2255	1685	585	1120	3927	4891	2495	5225
80	2514	1748	610	1218	6770	7356	3515	7125
100	2605	1810	634	1273	6960	7614	3436	6071

Source: Kuşçu et al., (2009)

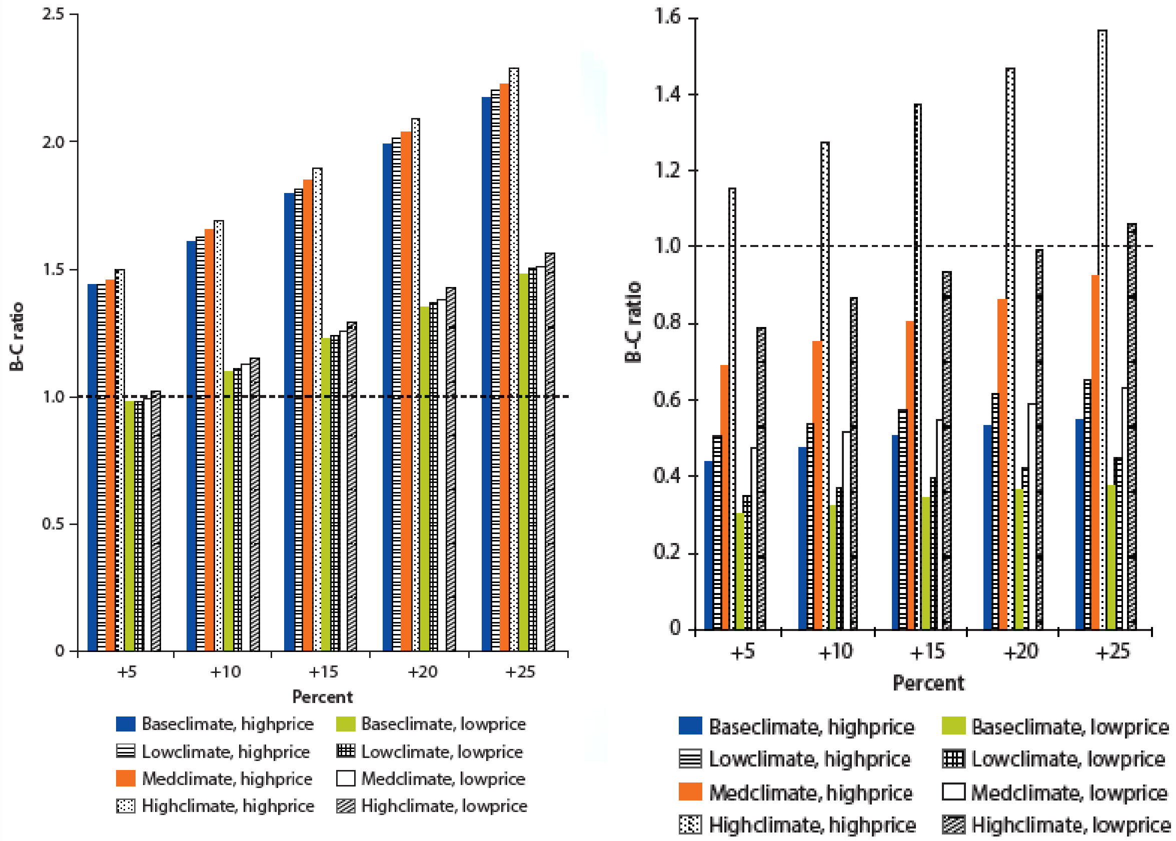
In a similar study, Imtiyaz et al. (2000) reported that rape was the most profitable crop, followed by cabbage, broccoli, and carrot. The results of both studies revealed that increasing irrigation (at 100% evaporation replenishment) did not increase the marketable yield of crops but reduced the irrigation production efficiency significantly. Therefore, the right irrigation schedule should be chosen to maximise the economic benefits of water savings irrigation techniques.

Adoption of PIS entails other O&M savings as well: by providing water to match crop requirements, drip irrigation reduces fertilizer and nutrient losses and soil evaporation (Kulkarni, 2005). Drip and spray irrigation also reduce soil erosion with respect to surface irrigation. Another advantage of drip irrigation is that it improves disease control due to better root oxygenation and minimum foliar wetting.

The economic viability of PIS depends upon a wide range of factors. Investments in PIS are cost beneficial for high value crops. Narayanmoorthy (2009) studied PIS irrigation in India for banana, grapes and sugarcane and found that investments result in a positive NPV and a BCR of around 2 for all crops considered (implying that net benefits are circa twice the total costs of PIS). Kuşçu et al., (2009)'s analysis shows that BCR of PIS investment is 5.8, for eggplant and green been, and 4.2 and 2.67 for pepper and tomato, respectively.

The World Bank conducted a series of study on adaptation options in agriculture for Georgia and Azerbaijan, and considered, among others, investments in efficient irrigation technologies under different climate change scenarios. Results show that increasing water efficiency is cost-beneficial for all climate change scenarios considered, and the BCR increases with the increase of efficiency target, in Azerbaijan, whilst in Georgia investment is viable only in the high climate scenario (see Figure 5).

Figure 5 – BCR of investment for improving water efficiency in agriculture – Azerbaijan (left) and Georgia (right)



Source: World Bank, 2014a and 2014b

Precision Irrigation

Water efficient technologies described in the previous paragraph can be combined with precise irrigation systems to further increase water efficiency. Traditional irrigation techniques, including PIS, apply irrigation water in a uniform manner, without considering soil and atmospheric conditions. As a consequence some parts of the field are over-irrigated while others do not receive enough water.

Precision Irrigation (PI) is defined as the "variable application of irrigation based on predefined maps or sensor feedback", involving the "accurate determination, quantification of crop water needs and the precise application of the optimal water volume at the required time" (Adeyemi et al., 2017: 353). The advantages associated with PI include increased crop yields, improved crop quality, improved water use efficiency/savings, reduction of energy costs and reduction of adverse environmental impacts (Shah and Das, 2012).

Many technological methods can be utilised. Advances in IT technologies make it possible to collect, and process information on soil moisture (through sensors placed close to the plant roots) and climatic conditions (via satellite), to support irrigation decisions. The sensors can monitor soil moisture and temperature to determine the optimum time to water crops. In their latest development PI systems are integrated with IOS/Android (Işık et al., 2017). This makes it possible to control the system by smart phones, thus increasing its usability. A robust design of monitoring tools including a proper combination of soil, weather and plant sensors is vital for the proper operation of PI systems. By avoiding overwatering plants and reducing water losses to evaporation, PI helps to conserve water.

The high cost of a PI system installation can be a barrier to their uptake. Despite these higher costs, El Nahri et al. (2011) compared traditional agriculture yields, with those obtained through PI and fertiliser application for an area cultivated with maize in Egypt, and reported that profitability of farming in the study area increased by almost 30%, due to the increase of crop yields.

McGuckin (1992) assessed the value of information given by the installation of moisture sensors, and found that this depends on the technical efficiency of the farmer, and ranges from USD58.23 per hectare for an efficient farmer to USD40.29 for an inefficient producer.

A study by Almas et al. (2003) concluded that feasibility of PI depends on field variability, crop value, economies of scale, and useful life of the equipment. They estimated that investment cost is in the range 35-70 USD/acre (useful life of the equipment is 5 years). This represents a financially viable option only for higher value and more water-sensitive crops.

Smart Water Meters

Besides public water supply, smart water meters can be applied to irrigation systems too, both at local or regional level. Smart irrigation metering is not limited to measuring water consumption. For example, in California smart electricity meters near water pumps collect electricity usage data to detect water losses in drip irrigation systems: their software identifies anomalies such as leaks[7] and then alert farmers with an SMS.

As an example of regional smart water meters, one thousand smart water and electricity meters were installed in Iran (in the arid regions of Arsangan and Sarvestan), 830 of which are powered cut in peak hours. The water savings amounted at 60 thousand m^3/day (Jahromi et al., 2014). In Esfaraien 90% of water wells' electro-pump are power cut in non-irrigation seasons for three months or more, reducing the groundwater level drop from 75 cm to 28 cm and water withdrawal from 30 million m^3 to 10 million m^3, equivalent to a monetary saving of 2 million USD/year (Vaseteh and Nazarboland, 2010).

[7] http://explorer.sustainia.me/solutions/smart-water-leak-detection-for-agriculture-2

Magnetised water

In the last decade magnetised water has been studied as a way to improve plant growth and increase crop yield (Maheshwari and Grewal, 2009). Irrigation with magnetized irrigation water produces higher soil moisture compared with the non-magnetized irrigation water, but cannot be considered as a water efficient irrigation technique, as it does not have significant effects on total water used (Maheshwari and Grewal, 2009). Rather, it makes it possible to use low quality (i.e. recycled or saline) water for agriculture (Surendran et al., 2016).

There are several examples of pot and field experiments conducted worldwide to test this irrigation technique. The effects of magnetic treatment vary with plant type and the type of irrigation water used (Maheshwari and Grewal, 2009). A preliminary study for Egypt (Hozayn et al., 2011) concluded that irrigation with magnetised water increased both quantity and quality of crop production, by 31.33%, 24.92% and 38.46% for wheat, lentil and check pea, respectively. Surendran et al. (2016) found that magnetic treatment increased yields for brinjal by 25.8 and 17.0% over control, for normal and saline water, respectively. Results of glasshouse experiments conducted by Maheshwari and Grewal (2009) show that yield increased by 12-23% for celery and 6-7.8% for snow peas, depending on the quality of water used.

A review of existing studies is carried out by Teixeira da Silva and Dobránszki (2014), which shows that for most crops magnetised water show positive effects on crop yields. However, they warn that the economic consequences of using magnetised water should receive careful consideration.

Application of magnetised water has also beneficial effects on soils (Ali et al., 2014), in terms of "removal of excess soluble salts, lowering pH values of soil layers, and dissolving slightly soluble components such as phosphates carbonates and sulfates" (p. 699). They also point out that it increases fertilisers' efficiency, as it enhances the extraction and uptake of P, K, N and Fe by plants.

Magnetised water has low operating costs, but its application is dependent upon the efficient integration of magnets into irrigation components and requires designing suitable pumps, compatible with technical and field requirements of magnetic water systems (Ali et al., 2014).

Installation of magnetised water treatment costed circa 115 USD/ha in Egypt, and reported very short payback periods for wheat (in the range of 0.138-0.6 season)[8], implying that its cost is repaid by the revenues generated in the same season when it is installed.

Laser levelling

Unevenness of the soil surface has a significant impact on the germination, stand and yield of crops. Traditional methods of levelling land are cumbersome and time consuming. A laser land leveller is a machine equipped with a laser-operated drag bucket and is much more effective at ensuring a flat, even surface. If intervention is carried out properly, re-levelling the whole field should not be necessary for at least eight to ten years. Evidence suggests that laser levelling reduces irrigation time and saves water by around 25-30%[9].

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[8] http://magneticeast.com/downloads/presentations/agriculture.pdf

[9] http://dswcpunjab.gov.in/contents/data_folder/Laser_Level.htm

A study funded by Thomson Reuter Foundation[10] found that wheat yield increased by 7-9% in laser levelled fields and energy saved amount to about 755 Kwh/ha in India. The same study estimated that benefits (due to higher yields and money saved on water and energy) amount to USD 143.5 per hectare a year from growing rice and wheat. In this case study, affordability was ensured by pooling resources, as small-holder farmers either rent the equipment or form a cooperative to share the costs (circa USD 10 for a day's work). Central government in many case subsidised part of the cost borne by farmers' groups or cooperatives. Discrimination against women and gender inequalities acted as a barrier for a complete uptake, as women farmers are less likely to adopt new technology due to socio-cultural barriers: they lack access to information and have to rely on men to negotiate prices.

Abdullaev et al. (2007) reported that a three year experiment of laser levelling of cotton fields in small private plot in Tajikistan reduced run-off by 24% and entailed water savings in the range of 333 – 1,509 M^3/ha. As a result, farmers' net income increased by 22% and gross margins were 92% higher than the control fields. Major barriers for uptake were the absence of initial capital of farmers and scattered land location.

Larson et al. (2016) discussed the main determinants for adoption of laser levellers in agriculture.

Aquaponics

Aquaponics is an environmental friendly technology used to grow horticultural products at small scale in arid countries. It is a recirculating system, which combines the practice of fish farming (aquaculture) and the cultivation of plants in water without soil (hydroponics). Water is therefore used to host fish and growing crops: organic waste of the fish fertilizes the water used to irrigate the plants, and the plants purify the water for the fish. Hence aquaponics makes it possible to produce more food with the same resource.

Aquaponics is suitable for a number of fish such as tilapia, carp, barramundi, bass, jade perch, golden perch, silver perch and a huge range of horticultural products such as tomatoes, cucumbers, lettuce and green leafy vegetables, high priced herbs and others (FAO, NAa). According to the FAO[11], integrated farms in some cases can reduce water consumption by 90% compared to traditional agriculture.

The few available studies on the economics of aquaponics regard mainly experiences in Austrialia and the USA (where aquaponics represent 2% of all aquaculture farms, Egle, 2015), and focus on the economic viability of aquaponics farms, instead of the wider economic benefits of this technology with respect traditional farming. A recent analysis by Quagrainie et al. (2018) showed that although aquaponics systems require higher investment and operating cost they have lower production costs for vegetables compared with the hydroponics system. In their study, aquaponics is profitable only for organic production though.

From an economic point of view, the integration of the fish and plant production system produces economic cost savings over either system alone. Shared cost savings come from spreading out

[10] http://news.trust.org//item/20150525123449-gmlon/
[11] http://www.fao.org/fao-stories/article/en/c/1111580/

operating costs and capital costs over the two systems (Goddek et al., 2015). Engle (2015) summarises the main economic indicators for aquaponics farms, and shows that production costs are covered by market prices (see Table 7) and that farms are profitable businesses (Table 8).

Table 7 – Estimated production costs for aquaponics farms, with relevant market prices

	Literature source				
	Baker (2010)	Bailey et al. (1998)	Rakocy & Bailey (1998)		Tokunaga et al. (2015)
Location	Hawaii	Virgin Islands	Virgin Islands		Hawaii
Plant type	lettuce	lettuce	lettuce	basil	lettuce
Production cost	$1.50/lb	$11.14–$12.40/case[a]	$6.15/case	$0.75/lb	not calculated
Market price	not reported	$20/case	$20/case	$10.20/lb	$2.15/lb
Fish type	tilapia	tilapia	tilapia	tilapia	tilapia
Production cost	$4.99/lb	$3.17–$3.78/lb	$1.46/lb	$2.50/lb	not calculated
Market price	not reported	$2.50/lb	$1.46/lb	$2.50/lb	$5.00/lb

[a]A case of lettuce typically contains 24 heads of lettuce.

Source: Egle (2015)

Table 8 – Estimated investment costs, profitability and returns of investment of aquaponics

Literature source	Location	Total investment cost ($)	Profitability		
			Annual net returns ($)	Internal rate of return	Modified internal rate of return
Bailey et al. (1998)	Virgin Islands				
Large scale		$1,030,536	$278,038	22%	n.a.
Small scale		$285,134	$30,761	11%	n.a.
Chaves et al.	Scotland	$58,760	$16,701	27%	n.a.
Holliman et al. (2008)	Alabama				
Catfish		$70,640	-$11,579	n.a.	n.a.
Tilapia		$70,640	$4,222	n.a.	n.a.
Rupasinghe and Kennedy (2010)	Australia	n.a.	n.a.	0%–57%	n.a.
Tokunaga et al. (2015)	Hawaii	$217,078	n.a.	n.a.	7.36%

Source: Egle (2015)

Aquaponics is a labour-intensive technology and while it can create job opportunities, it also shows high labour costs. Moreover, it has also high energy costs. The results of the financial analysis conducted by Adler et al. (2000) also confirmed that aquaponics is profitable, with a return of 12.5% over a 20 years lifespan. The payback period was 7.5 years. Total fixed costs amounted at almost 245 thousand USD and variable costs were almost 290 thousand USD. NPV of the investment was positive for all interest rates considered. The costs for one commercial aquaponics system analysed by Heidemann et al. (2015) are lower though, in the region of 67 thousand USD for variable costs and 40.5 thousand USD for capital costs. Revenues were estimated at circa 115 thousand USD, with net profits from the second year of almost 48 thousand USD. Aquaponics is therefore an economically viable option for potential producers in the US.

The main environmental benefits of aquaponics are linked to nutrient reuse and water recycling. Moreover, it makes it possible to treat the wastewater of traditional aquaculture with no additional costs. Rizal et al. (2018) acknowledge that other important benefits, such as resource scarcity, climate change mitigation, are often neglected, along other social aspects. They then conducted a qualitative analysis of these aspects. They conclude that ex-ante and ex-post benefit assessment methods have yet to be developed.

Besides the financial burden, another major barrier to uptake of this technology is the skill and knowledge necessary to run a combined system. As stated by Rizal et al. (2018), "aquaponics is a technology-intensive, capital-intensive and knowledge-intensive method of food production" (p. 2). Therefore, training and assistance to prospective aquaponics farmers are essential for the uptake of this technology. Moreover, whilst aquaponics can contribute potentially to food security, its costs could exclude the poor and its dependency on electricity and water might limits its use in remote areas (Riza et al., 2018).

Use of non-conventional water sources: the case of wastewater

In a water scarcity situation the use of non-conventional water sources become an option to ensure irrigation. Besides harvesting rainwater, the use of wastewater (either treated or untreated) is an option. Between 5 and 20 million hectares are irrigated with raw and diluted wastewater worldwide (Drechsel and Evans, 2010). Wastewater is rich in suspended solids and dissolved nutrients, making it more suitable for agriculture than freshwater.

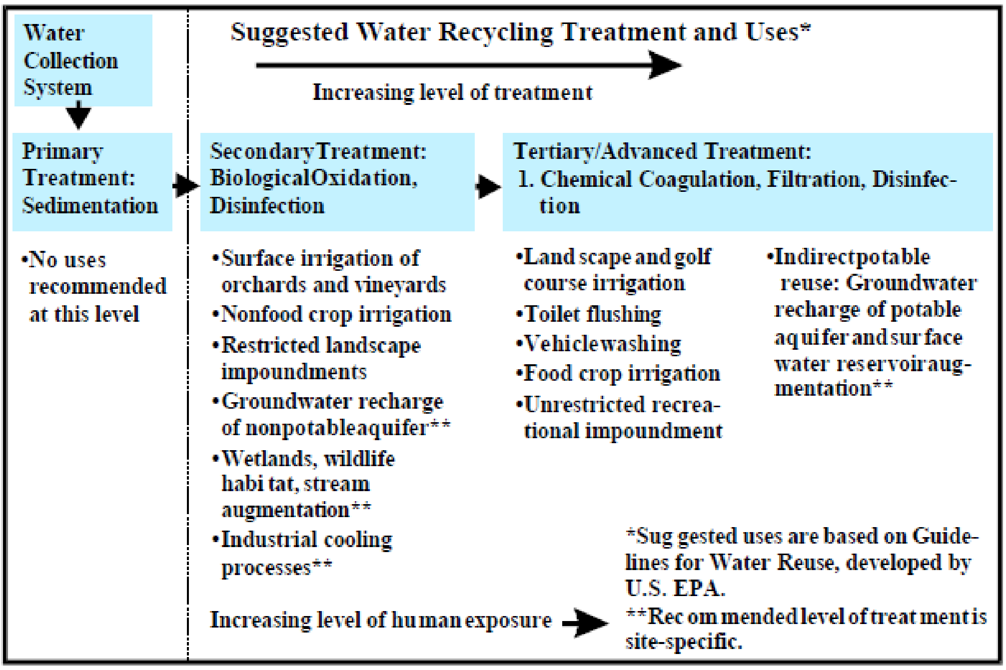
Treated wastewater reuse is increasingly used, especially in areas with limited water sources to increase the amount of water available for agricultural uses (Kfouri et al., 2009). In Europe, only 2.4% of the treated urban wastewater effluents, that is less than 0.5% of annual EU freshwater withdrawals[12], but potentially 6 billion cubic meters could be reused, according to the EU Commission's estimates. In particular, Cyprus and Malta already reuse more than 90% and 60% of their wastewater, respectively. Conversely, in other arid regions like North African countries the spread of water reuse is surprisingly uneven and slow (Kfouri et al., 2009).

The main factors boosting the development of water reuse schemes are over-abstraction from freshwaters, nutrient pollution of receiving waters, and the greenhouses gas production associated with alternative water harvesting options (Hamilton et al., 2006).

The degree of "reusability" of wastewater depends on the level of treatment, as highlighted in Figure 6. In order to minimise health risks, additional treatment is necessary, and can be performed as an additional process at wastewater treatment plant, or through an ad-hoc process. It is estimated that the treated effluents of a small town of 100,000 inhabitants can be used to cultivate up di 100 hectares of land (van Lier and Huibers, 2010). As discussed above, technologies can be applied at centralised level, at the wastewater treatment plant, or decentralised level, close to the wastewater source in smaller or remote communities.

[12] http://ec.europa.eu/environment/water/reuse.htm

Figure 6 – Level of wastewater treatment and related uses



Source: EPA (1998)

Wastewater reuse accrues several benefits to society (see

Table 9). First, it provides a constant and reliable source of water, and therefore can therefore avoid investment in other resource development options in areas characterised by water scarcity (Kfouri et al., 2009; Anderson, 2003). Other environmental benefits of water reuse are related to improvement in water quality: as water abstractions are reduced due to water reuse, the quality of surface water improves (Anderson, 2003). Moreover, wastewater reuse can be combined with recreational uses, e.g. by watering public parks: freshwater is saved as the parks do not need to be irrigated and the quality of soil is maintained. Moreover, carbon sequestration is improved, for the increase in vegetation. As noted by De la Cueva Bueno et al. (2017), whilst the UF and RO deliver water of adequate quality for agricultural uses, these remove all organic content from wastewater and therefore require the addition of fertilisers.

A major barrier to wastewater reuse is constituted by health and environmental concerns, for micro-pollutants present in treated wastewater can contaminate the food produced. In this respect, technological development offers positive perspectives. For example, Battilani et al. (2010) designed a decentralised compact pressurised membrane bio-booster, and complemented with gravel filter and were able to remove E.coli and heavy metal to comply with WHO standards.

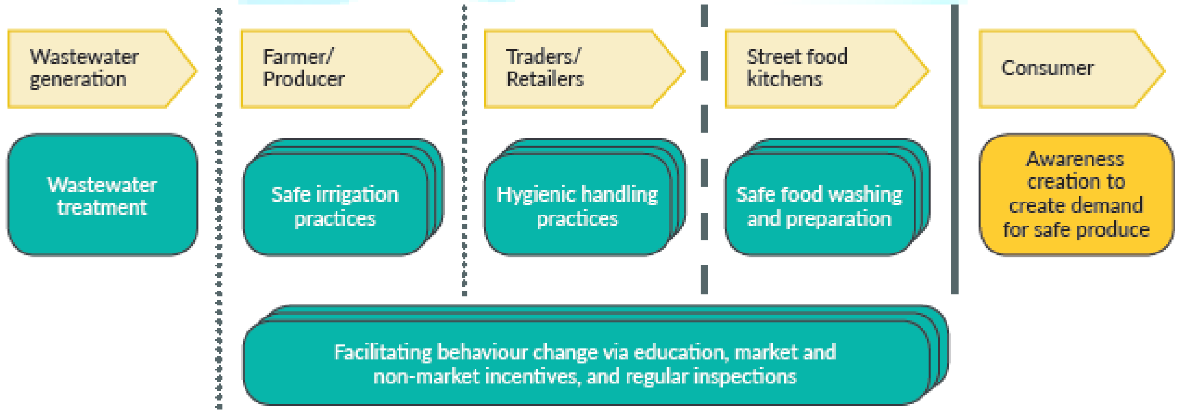
Table 9 – Benefits of water reuse

Sector	Benefits
Agriculture	Reduced diversion costs Security and reliability of supply Increased farm production Savings in fertilisers application Increase in properties value due to reduced salinity
Urban Water Supply	Savings in capital costs of diversion structures and drought storage Savings in O&M costs and including pumping energy and treatment chemicals Lower treatment costs for downstream users
Industry	Value added from reused wastewater
Environment	Savings in wastewater diversion Reduction in pollutant discharges Better downstream water quality Improve recreational value of waterways Creation or enhancement of wetlands and riparian habitats Aquifer recharge

Source: Adapted from Kfouri et al. (2009), Anderson (2003) and EPA (1998)

The use of wastewater for irrigation can have adverse effects on farmers, through the direct contact with contaminated water, public health, through the consumption of food produced, and to the environment, which get pollutants from effluents (Hussain et al., 2001).To further reduce risk, irrigation infrastructure should be properly designed, and preventive actions can be adopted along the food-chain, as illustrated in Figure 7.

Figure 7 – Reducing consumption related-risks along the food chain when reusing wastewater irrigation



Source: WWAP, 2017 (Fig. 7.1a, p. 17)

The economic benefits of reuse wastewater have been assessed in several studies. Garcia and Pargament (2015) analysed the economic impacts of a wastewater reuse plan that would provide irrigators instead of deriving freshwater from the Yarqon river, in Israel, and found that the project has a NPV of 4.83 million USD/year. Specifically, the project costs amount at 0.16 USD/m^3, whilst the market value for reclaimed wastewater is between 0.24-0.31 USD/m^3. The most important economic benefit is the replacement value of desalinated water, whose production costs vary between 0.99 and 1.26 USD/m^3.

Molino-Senante et al. (2011) consider 13 water-reuse projects for environmental purposes and found that internal benefits only would not justify the project from an economic point of view, but the consideration of external costs makes the project beneficial from a societal perspective. Weldesilassie et al. (2009) estimated the benefit of improving the wastewater quality for farmers who use untreated wastewater in the area surrounding Addis Ababa in Ethiopia: their results reveal that on average farmers are willing to pay 0.37% of their income on improvement programmes, or between 4.5-4.85 USD/ha.

Reuse of treated wastewater in agriculture and aquaculture entails more benefits than risks, even if effluents are untreated. Simmons et al. (2010) studied the long term effects of using untreated wastewater for irrigation in the Faisalabad district in Pakistan, and found that using wastewater instead of freshwater increased wheat and straw yields by 19.5% and 18.6%, respectively.

Maton et al. (2010) assessed the benefits of using treated wastewater used to irrigate vegetables in Crete. They found that the benefits range from 0.02 €/m^3 to 2 €/m^3, depending on the level of water scarcity.

The effects of use of RO in terms of soil salinity and crop yield are well documented by the literature. Silber et al. (2015) compared the crop yields of banana by using two different approaches to managing irrigation water salinity: salt leaching from the field (“conventional” management) and water desalination before field application (“alternative” management), They found that treatment before water application reduced water requirements by half, improves crop quality and reduces salt load in the groundwater and increased crop yield.

Reuse of reclaimed water is normally subsidised in Europe. For example, in Spain farmers pays 0.12 €/m^3 for applying water, when the full supply cost is 0.40 €/m^3 (BIO, 2015). However, the alternative supply source would be desalinated water, which has a production cost of 1 €/m^3. In this case, the societal benefit of using reclaimed instead of desalinated water is the difference between the production costs of the two technologies, i.e. 0.60 €/m^3.

FAO (2010) reported the results of two case studies or wastewater reuse in Spain, which imply the upgrade of existing WWTP to tertiary level and the reuse in agriculture and recreational uses, and found that both cases are cost-beneficial, with BRCs of 2.85 and 5.35.

Soil and water conservation practices

Soil conservation practices are not *strictu sensu* technologies, but they are here recalled as they help to save water and conserve soil characteristics, and can be adopted in conjunction with the technologies analysed in previous paragraphs. The importance of using Nature-Based Solutions (NBS) has been emphasised in the United Nation World Water Development Report 2018 (WWAP, 2018), for two reasons: first, they give benefits that are equivalent or similar to conventional grey (built) water infrastructure; secondly, in many circumstances they improve the performance of grey infrastructure. The main benefits of Conservation Agriculture (CA) with respect to the traditional one are: improved soil structure and stability; increased drainage and water-holding capacity; reduced risk of rainfall runoff; reduced pollution of surface waters with pesticides of up to 100% and fertilizers up to 70%; lower CO2 emissions (Stagnari et al. (2009) quoted in WWAP, 2018).

The main soil conservation practices can be grouped into two categories (Shock et al., 2013; WWDR, 2018):

1. According to land use:
- Manuring and composting, by using organic manures and composts to improve water infiltration and percolation;
- Vegetative strips, to decrease erosion;
- Agroforestry, where trees are grown with traditional crops and pastures.;
- Conservation tillage, in the form of minimum tillage, trip till or no tillage at all. Several studies quoted in Hatfield et al. (2001) show that tillage increased soil water evaporation compared with untilled areas. When crop residue from the previous harvest is retained on the soil surface, water losses are reduced and soil moisture enhanced by 34 to 50% (Sauer et al. (1996). As a consequence, crop yield also increases (Norwood, 1999).

2. According to water use:
- Avoid over-irrigation and schedule irrigation based on soil water content: this can is a consequence of using sensor technologies described above
- Apply deficit irrigation. Some plants, such as almonds, grapes and alfalfa, can grow under water shortages, as they can extract water from a greater depth. For some plants, yield and quality are positively related to some water deficit during part of the growing season. For other crops, such as potatoes and onions, water stress negatively affects crop yield.

Another water conservation strategy is managed aquifer recharge (MAR), where treated (or partially treated wastewater) recharge aquifers through infiltration into ponds, trenches, lagoons or injection wells (Dillon et al., 2012). The soil and unsaturated zones of the aquifer help to remove pollutants, and therefore groundwater can be reused. This can be considered a form of indirect reuse of low quality water in agriculture, when the recharged aquifer is then used for watering crops.

In Europe the majority of MAR applications are based on induced bank filtration and surface spreading methods and are utilizing surface water from lakes or rivers. Only a few examples exist where reclaimed water is used to augment drinking water supply.

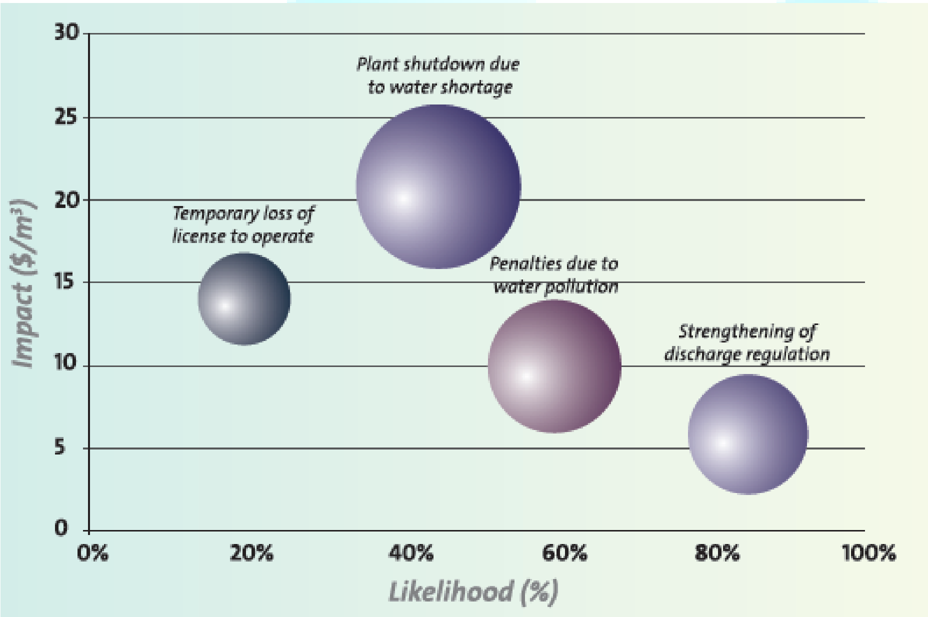
For example, the entire quantity of treated wastewater produced in Paphos, the fourth largest city located in southwest Cyprus, is used for Ezousa aquifer recharge and then which is subsequently pumped for irrigation through diversion in an irrigation channel (Qadir and Sato, 2016). No MAR practices are registered in the Kura river basin.

Maliva (2018) notes that despite the acknowledged benefits of MAR in terms of water resources management, its limited application is due to the fact that policy makers lack evidence on the economic feasibility of such projects. Benefits from MAR are related to the increase water stored on the ground and the potential, consequent beneficial uses (Khan et al., 2008). Other benefits are the "reduced groundwater pumping costs, and avoidance of the need to replace or deepen production wells, restoration or maintenance of environmental (e.g., spring) flows, avoidance of land subsidence, and prevention of saline-water intrusion" (Maliva, 2018). In a study artificial storage and recovery in Murrumbidgee Region of New South Wales (Australia), Khan et al. (2008) found that estimated benefit of MAR through infiltration basins in terms of security of supply during drought years is three to seven times the cost (their cost estimates are in the range 62 to 174 AUSD/Ml). Donovan et al. (2002) considered the MAR of aquifer in Las Vegas Valley and assessed only the private benefits (in terms of avoided costs) for having a more accessible groundwater source. Specifically, they estimated the energy savings of MAR in 5 USD/year per abstraction (circa 0.4 centUSD/m^3) and the avoided costs of deepening the well would be 2.2 centUSD/m^3. Net benefits per individual well are circa 700 USD/year. Finally, the study from Damigos et al. (2017) show that non-use component of MAR practices is significant.

5. Industry

In Europe and North America industry is the second largest user of freshwater (UNIDO, 2007). OECD (2012) forecast that from 2000 to 2050 global water demand for manufacturing industries will increase by 400%. Water scarcity can have very serious effects on some major industrial sectors (UNESCO, 2016). Veolia (2014) identify the main operational risks for industrial premises related to water shortages and estimate that this would cost more than 15 USD/m^3, with a likelihood of more than 40% (see Figure 8).

Figure 8 – Effect of water scarcity on industrial operations



Source: Veolia quoted in EpE(2018)

Water can be used in industrial production processes for different purposes and in different sectors, as illustrated in Table 10.

Table 10 – Water use in industrial sectors

Purpose	Industrial Sector	Notes

Energy production	Hydropower generation	it serves other purposes, like agriculture, flood control, and water storage
Cooling water	Thermal Power generation	Largest single industrial water users
Process water	Various	Steam is used for power generation or chemical reaction
Water for products	Food, pharmaceutical and beverage	Water is embedded in the final products.
Water for washing	Mechanical and Textile	Washing and removing waste of productive processes

Source: Adapted from UNIDO (2007)

The potential water savings from efficiency measures are highlighted in Table 11. These figures are in line with results of WRAP (2005), which estimates that these entail a decrease between 20-50% of water consumed.

Table 11 – Potential for water savings in industry

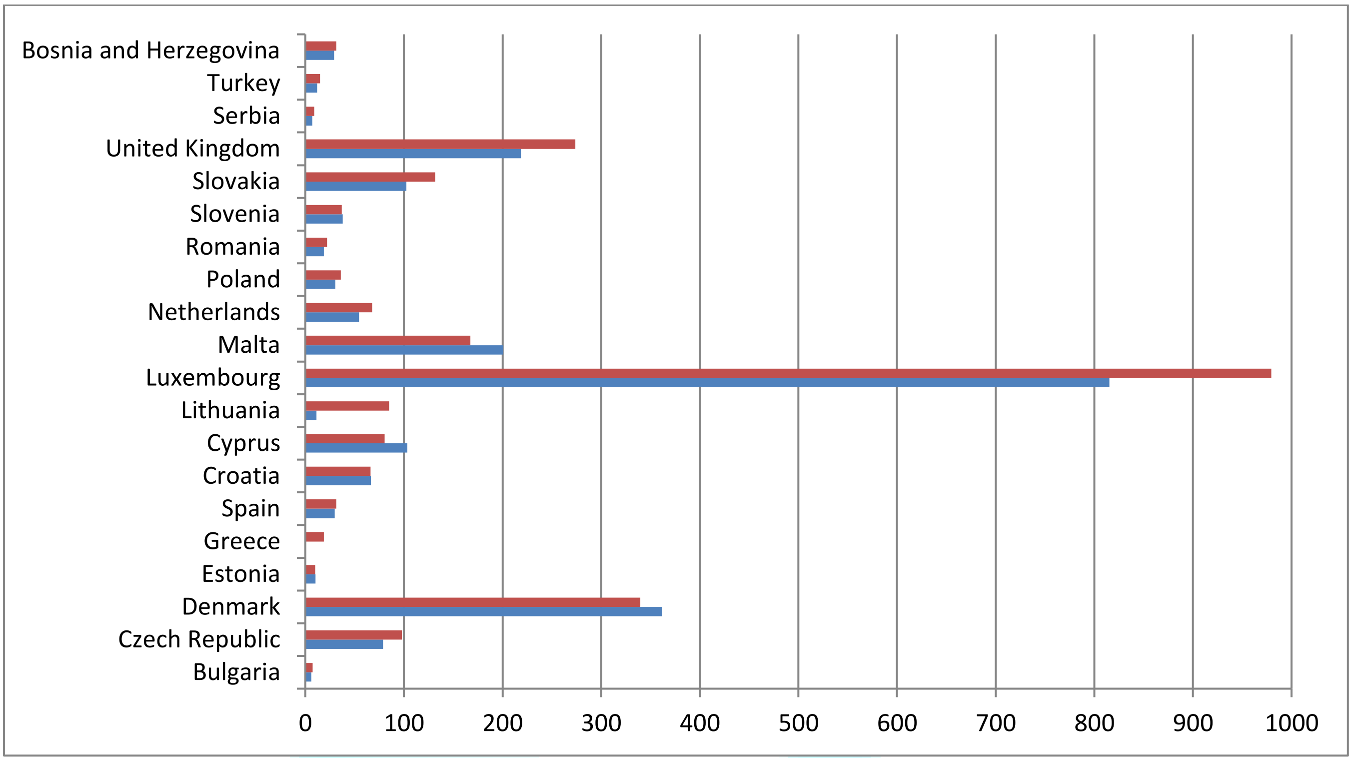
Efficiency measures	Potential savings (%)
Closed loop reuse	~ 90%
Closed loop recycling with treatment	~ 60%
Automatic shut-off valves	~ 15%
Counter-current rinsing	~ 40%
High-pressure, low-volume upgrades	~ 20%
Reuse of wash water	~ 50%

Source: Afed, n.d.[13], p. 39, table 3.1

By increasing water use efficiency in industrial processes, more output is produced per m^3 of water used. In order to compare productive processes, water productivity, i.e. the output produced per cubic meter of freshwater, is used. This is the "ratio of value of the amount of water withdrawal (in m^3 or in m^3 per capita) to the value of output from the industrial activities using this water" (UNIDO, 2007: 14). Data on industrial water productivity are published by Eurostat, for European countries, and the World Bank, for selected countries worldwide. Figure 9 shows the industrial productivity for several European countries: Luxemburg and Denmark have the highest ratios, with around 1,000 and 340 €/m^3, respectively. Bulgaria and Serbia show the lowest industrial water productivity, with 7.3 and 7.4 €/m^3, respectively. All countries considered improved this indicator over the period 2004-14, except Denmark, Cyprus and Malta (which already used industrial water in a very efficient manner).

[13] http://www.afedonline.org/water%20efficiency%20manual/PDF/4Chapter%203_Industry.pdf

Figure 9 – Industrial water productivity (2010 €/m³), 2004 and 2014.



Source: Own elaborations on Eurostat data[14]

This indicator captures only part of the private benefit deriving from water efficiency measures. At firm level, water efficiency improvements produce advantages in terms of saving costs for electric power, gas, chemicals, and wastewater disposal (EPA, 2000), but also some drawbacks, as reduction in water use produces an increase in the concentration of pollutants in effluents. At societal level, efficient water use entails major environmental, public health, and economic benefits by helping to protect drinking water resources and improve water quality, and ultimately by maintaining aquatic ecosystems.

There are no data available for the Kura river basin.

Installation of water saving devices

Table 12 summarises the main options that can be implemented at firm level to increase water efficiency. Whilst some measures consist of improved production sequencing or introducing more water conscious routines in operations, in many cases major process changes or equipment replacement are necessary. Available options will depend on the productive processes and on water quality requirements.

Information on costs and benefits of water saving strategies for the industrial sector are scarce, due to confidentiality reasons (Dworak et al., 2006). This study compiled a dataset of water saving experiences across Europe, with an indication of estimated costs and benefits. Most measures have a

[14] http://ec.europa.eu/eurostat/web/products-datasets/-/t2020_rd210

payback period of less than 2 years, with the exception of installing close-circuit in manufacturing (which has a longer payback period). Some experiences of implementation of water saving measures and related financial benefits for different industrial sectors are also reported in the UNIDO website[15].

Table 12 – List of water saving measures for industry

Type of measure	Notes	Interventions
General Management Practices	Require a management commitment	- Develop a mission statement and a plan. - Educate and involve employees in water efficiency efforts. - Inform your chemical suppliers or service contractors (cooling tower, laundry, dishwasher, landscaping) that water efficiency is a priority.
Equipment changes	Substantial savings on water, sewer and energy bills	- Install high-efficiency toilets, or retrofit water-saving devices on existing ones. - Install faucet aerators and showerheads. - Install high-pressure, low-volume nozzles on spray washers. - Install in-line strainers on all spray headers; inspect nozzles regularly for clogging. - Replace high-volume hoses with high-pressure, low-volume cleaning systems. - As equipment wears out, replace with water-saving models. - Equip hoses with spring loaded shutoff nozzles
Operating and Maintenance Procedures	Generally low investment costs. Behavioural change necessary	Detect and repair all leaks. Identify discharges that may be re-used and implement re-use practices. Examples include: —final rinses from tank cleaning, keg washers, fermenters —bottle and can soak and rinse water —cooler flush water, filter backwash —pasteurizer and sterilizer water —final rinses in wash cycles —boiler makeup —refrigeration equipment defrost —floor and gutter wash
Landscape irrigation	During drought conditions outdoor watering restrictions may be imposed	- Detect and repair all leaks in irrigation systems. - Use properly treated wastewater for irrigation where available. - Water the lawn or garden during the coolest part of the day (early morning is best). Do not water on windy days. - Water trees and shrubs, according to water needs. - Install efficient water irrigation systems, and set sprinklers to water the lawn or garden only – not the street or sidewalk. - Minimize or eliminate fertilising, which promotes new growth needing additional watering.
Other outdoor uses	Do not operate during droughts	- Sweep or bow paved areas instead of hosing off. - Control hose flow with an automatic shut-off nozzle. - Wash vehicles less often; use a commercial car wash that recycles water. - Do not install or use ornamental water features unless they recycle the water.

Source: Adapted from EPA (2000)

[15] https://www.unido.org/resources/publications/safeguarding-environment/water-management

A 2012 report from Alliance for Water Efficiency considered water saving potential in five industrial sites located in the Great Lakes Region in the USA (representing beer brewing, manufacturing, metal plating, plastic compounding and leather tanning) and estimated a total saving of almost 4 million USD over a 20 years period.

Water reuse

In recent years the focus of water management policies has moved from simply reducing water use, to a circular economy approach. The WBCSD developed the 5R approach (reduce, reuse, recycle, restore and recover water resources)[16] to tackle water scarcity in industrial processes with a risk-based strategy.

Reclaimed wastewater recycling in industry is especially important in industries with high water usage, e.g. the metal manufacturing, paper and plastic industries (Rebhun and Gideon, 1988). Water reuse is also relevant for mining, where water is an essential component to support a range of activities including mineral processing, dust suppression, slurry transport, and cooling. Much of the water is extracted to dewater mines or is a by-product of extraction and can be acidic and contain toxic amounts of metals or other pollutants.

Besides reducing the amount of water taken from the natural environment, the reuse of water in industrial processes has other advantages, such as cost reductions due to lower water bills and reusing by-products or sharing ancillary services. In environmental terms, reusing water also reduces polluting impact, as effluents are not directly discharged. Finally, reuse reduces thermal energy consumption and potentially processing cost. Recycled water can come either from internal (i.e. process water) or external sources (i.e. wastewater). Water can be reused directly when an industrial process does not alter the qualities of the raw water (such as cooling or heating) and therefore can be recycled, or after treatment. The water quality required for reuse, together with the industrial activity that produces wastewater, determine the level of water treatment. The polluting loads of the main industrial processes are summarised in

.

For industrial reuse, several decentralised wastewater treatment options are available, from simpler systems (such as water stabilisation ponds, constructed wetlands, and non-planted filters), to more advanced technologies that use anaerobic digestion (e.g. anaerobic baffled reactors, biogas settlers, and anaerobic digestion) or other treatments such as membrane filtration, activated carbon, advanced oxidation processes, etc. (Ranade and Bandhari, 2014).

Water can be reused either within a business itself, or among different industrial premises located in the same area (Bruni, 2012). This second process is labelled industrial symbiosis (SSWM, n.d.), which normally takes three main forms, namely exchanges of by-products or process water, sharing of treatment plants or other ancillary services. Effluents of industrial processes can be reused by other sectors, such as agriculture or other uses requiring low water quality (UNIDO, 2007).

[16] https://www.wbcsd.org/Clusters/Water/Resources/spotlight-on-reduce-reuse-and-recycle

Table 13 – Wastewater content in the main industrial processes

Industry	Typical content of effluent
Pulp and paper	• Chlorinated lignosulphonic acids, chlorinated resin acids, chlorinated phenols and chlorinated hydrocarbons – about 500 different chlorinated organic compounds identified • Coloured compounds and absorbable organic halogens (AOX) • Pollutants characterized by BOD, COD, suspended solids (SS), toxicity and colour
Iron and steel	• Cooling water containing ammonia and cyanide • Gasification products – benzene, naphthalene, anthracene, cyanide, ammonia, phenols, cresols and polycyclic aromatic hydrocarbons • Hydraulic oils, tallow and particulate solids • Acidic rinse water and waste acid (hydrochloric and sulphuric)
Mines and quarries	• Slurries of rock particles • Surfactants • Oils and hydraulic oils • Undesirable minerals, i.e. arsenic • Slimes with very fine particulates
Food industry	• High levels of BOD and SS concentrations • Variable BOD and pH depending on vegetable, fruit or meat and season • Vegetable processing – high particulates, some dissolved organics, surfactants • Meat – strong organics, antibiotics, growth hormones, pesticides and insecticides • Cooking – plant organic material, salt, flavourings, colouring material, acids, alkalis, oil and fat
Brewing	• BOD, COD, SS, nitrogen, phosphorus - variable by individual processes • pH variable due to acid and alkaline cleaning agents • High temperature
Dairy	• Dissolved sugars, proteins, fats and additive residues • BOD, COD, SS, nitrogen and phosphorus
Organic chemicals	• Pesticides, pharmaceuticals, paints and dyes, petro-chemicals, detergents, plastics, etc. • Feed-stock materials, by-products, product material in soluble or particulate form, washing and cleaning agents, solvents and added-value products such as plasticizers
Textiles	• BOD, COD, metals, suspended solids, urea, salt, sulphide, H_2O_2, NaOH • Disinfectants, biocides, insecticide residues, detergents, oils, knitting lubricants, spin finishes, spent solvents, anti-static compounds, stabilizers, surfactants, organic processing assistants, cationic materials, colour • High acidity or alkalinity • Heat, foam • Toxic materials, cleaning waste, size

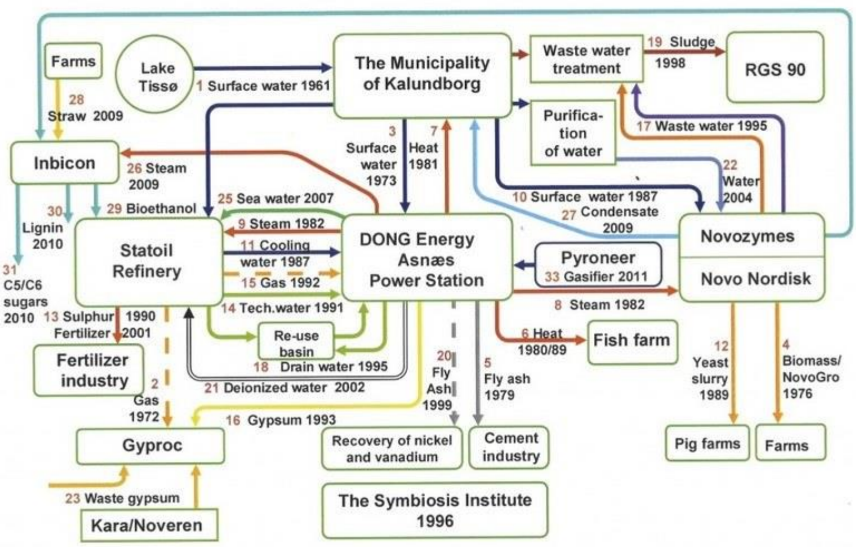
Source: WWAP, 2017 (table 6.4, p. 63)

A well-documented case of industrial symbiosis is that of Kalundborg[17], established initially between the local municipality and an energy company to supply water, and extended later to include 30 exchanges of water, energy and other by-products. Farmers participate too, as purchasers of fertiliser products and waste heat (see Figure 10). The collaboration amongst different firms resulted in mutual benefits. The main outcomes of this collaboration are[18]:

- 3 million cubic metres of water saved through recycling and reuse every year
- 150,000 tons of yeast replaces 70% of soy protein in traditional feed mix for more than 800,000 pigs.

[17] https://www.ellenmacarthurfoundation.org/case-studies/effective-industrial-symbiosis
[18] www.symbiosis.dk/en/

Figure 10 – Kalundborg industrial symbiosis exchanges



Source: Ellen Macarthur Foundation

The most important ancillary service from industrial water reuse is energy generation. Wastewater residues are a potential renewable feedstock that can be used to generate bioenergy (chap. 6 in Ranade and Bandhari, 2014). Wastewater treatment processes can generate bio-hydrogen, bio-electricity, algae-based biodiesel and bioplastics. Once these businesses opportunities are exploited, related net profits constitute potential benefits. As noted by the WWAP (2017: 64) the market for industrial water treatment technologies is predicted to grow by 50% by 2020.

The first obvious barrier is the initial project costs, which include both investment (that is, design and project management, equipment purchase and installation) and operation costs (including employees' training, disposal of waste and monitoring). In this respect, whilst some measures can be implemented at minimal cost, with short pay-back periods, others require substantial investments. In many cases governments' support to private firms in adopting water saving initiatives is necessary. For example, in the UK the Enhanced Capital Allowance (ECA) scheme allow businesses to write off 100% of investments in designated sustainable technologies and products against tax in the first year of investment (WRAP, 2005). The private benefits from installation of water saving devices consist on reductions of electricity bill, due to decrease of pumping, water heating and cooling.

No studies were found that assessed the benefits of industrial water reuse in monetary terms.

6. Energy generation

Energy uses about 8% of all freshwater withdrawn worldwide and as much as 40% of freshwater withdrawn in some developed countries (IRP, 2012). Energy demand is projected to increase by one-third from 2010 to 2035, and water demand will increase at twice the rate of energy demand (IEA, 2012).

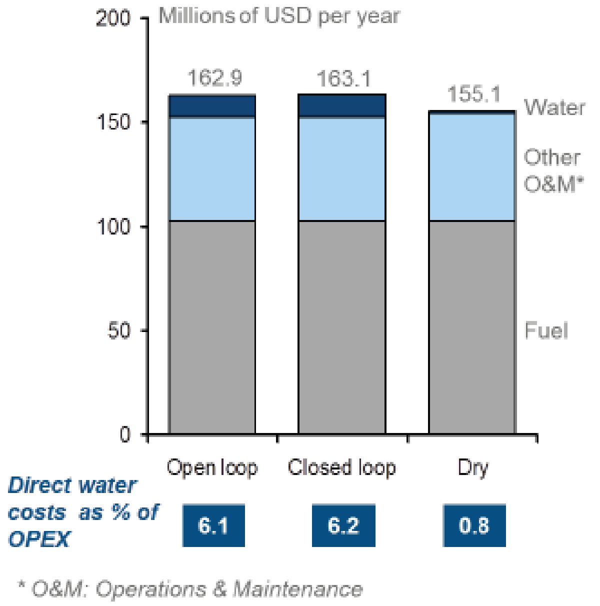
Efficient water management for energy companies is therefore of paramount importance to ensure that effects of energy demand increase on water resources are minimised.

Improve cooling tower efficiency

Water reuse in energy production is a common practice, in terms of process water for cooling. A cooling tower is design to conserve water by recycling it through the condenser. However, some water that is lost from the cooling tower by evaporation and this must be replaced with freshwater. Efficiency of cooling towers is measured in Cycles of Concentrations, COC, i.e. how often freshwater is used. Most cooling towers operate within a COC range of 3 to 10, where three cycles is generally considered as minimum efficiency and 10 is considered good efficiency (EDF, 2013). Cooling tower efficiency can be enhanced by the addition of certain water treatment chemicals to increase the solubility of calcium salts, mitigate corrosion, minimize fouling and control the growth of microbiological organisms like algae, bacteria, etc.

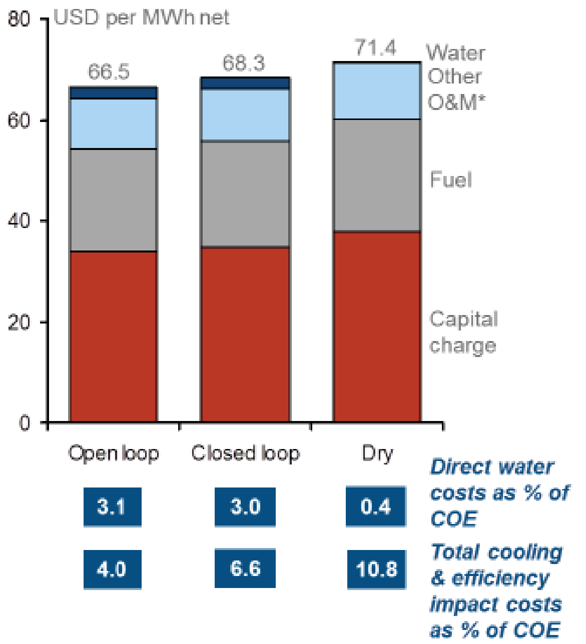
Kablouti (2015) argues that, although circa 90 % of global power generation is currently water intensive, the switch to from closed loop to dry cooling seems unlikely in the short- to medium-term in most regions, given the current water price levels. Dry systems show lower total O&M costs compared to less water efficient technologies (Figure 11), but the higher investment and fuel costs do not make this technology attractive to private investors, as the cost of producing electricity is higher in dry cooling systems compared to alternative technologies (see Figure 12). He noted that dry cooling systems are more developed in the USA and China, where regulatory pressures and increasing water scarcity have played a positive role for the uptake of this technology.

Figure 11 – Yearly OPEX by cooling technology



Source: Kablouti, 2015

Figure 12 – Breakdown of Cost of Electricity generation, by cooling technology



Source: Kablouti, 2015

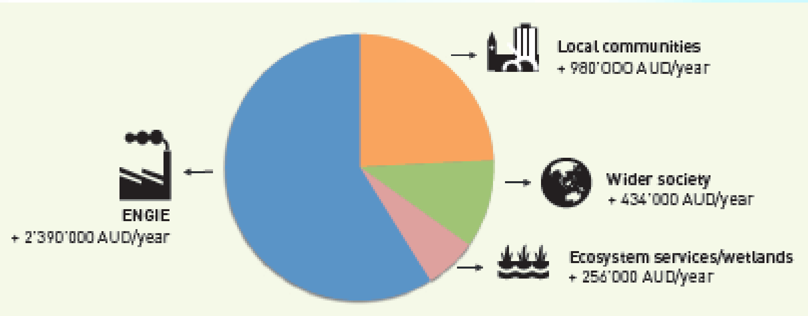
It should be noted that the move towards more water efficient technologies does not *per se* guarantee that water consumption in the energy sector will decrease. A recent study by IRENA and WRI (2018) concluded that in India the transition from once-through to recirculating cooling systems will drastically reduce withdrawal but will increase total absolute water consumption (despite an improvement in water intensity, from 2.09 m^3/MWh in 2014 to 1.57-1.92 m^3/MWh in 2030). Similar conclusions are drawn for China by Lin and Chen (2018), and for the USA by NETL Water-Energy Program[19].

Heat reuse in power plants

Cogeneration (or Combined Heat and Power, CHP) plants integrate energy and heat production. They are more efficient than traditional power plants, as the heat produced during generation is used and water required for cooling processes is reduced.

One example for which economic benefits of water reuse have been monetised is the Kwinana Cogeneration plant, in Austrialia. The plant is primarily fuelled by the natural gas and supplies both steam and electrical power. Waste heat from the gas turbine exhausts is used to drive a steam turbine, further enhancing the efficiency of the plant. The overall water saving from this water recycling project reaches nearly 4,000 m^3/day. The unit benefits are estimated in 3.27 AUD/m^3 (estimated by considering all stakeholders). Overall benefits are depicted in Figure 13.

Figure 13 – Total benefits of the water efficient project in the ENGIE cogeneration plant



Source: EpE (2018), page 77

Moreover, increasing water efficiency in cooling towers might entail environmental impacts that should be tackled in an integrated manner. In the USA a pilot project considered restoring wetlands for water cooling. Instead of using freshwater other water sources like brackish water, wastewater treated effluents or mine water can be used. In once-through systems wetlands can be used as a thermal sink to cool water before discharge into the river. In circulating cooling systems, wetlands functions as buffers to improve water quality. The project considered closed loop re-circulating cooling water system that resulted in increased levels of carbonates, sulphates, phosphates, calcium, and sodium and resulted in a reduction of pH from 9 to 7 and a significant reduction in conductivity and total dissolved solids (TDS). The study conclusion was that “constructed wetland can mitigate the demand on traditional surface water and ground water resources from power production” (AES et al., 2013: 89).

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Mitigation measures for hydropower generation

Hydropower is a clean, renewable energy source contributes directly to global low-carbon energy goals, and therefore to climate change mitigation. HP plants also provide flood mitigation, improve water security through water storage for irrigation and other purposes, and contribute to stable downstream flow regimes. Construction and operation of HP plants also entail environmental impacts. The complex interactions between dam construction and the affected ecosystems have been studied since the early '80s, to improve the understanding of how rivers ecology is affected by engineering works. Goodwin et al. (2006) classify environmental impacts according to where they occur:

- Downstream: besides morphological alterations (such as reduction in channel bed slope, encroachment of riparian vegetation, decreases in the channel's conveyance capacity, changes in channel pattern or style, and degradation of the river bed) other effects include the loss of biodiversity due to the lack of major flood events, and the worsening in water quality for the increase of fine organic material.
- Upstream: the main impacts are sedimentation and the drowning of natural migratory barriers
- Basin-wide there is an alteration of the nutrient balance, and a worsening of the overall ecosystem resilience to external disturbances, i.e. droughts, fire, etc.
- Coastal areas: the regulated flow regime alters the timing of freshwater outflow to estuaries or coastal wetlands, and in periods of water stress, such as droughts, the fish population can be severely impacted.

Whilst these impacts have been frequently overlooked in the first phase of hydropower (HP) development, the increase awareness of the potential harmful effects of dam construction have boosted efforts to mitigate these impacts. In Europe the implementation of WFD has prompted a research and policy debate on the necessary mitigation measures (at national, river-basin or EU level) to reach the good ecological potential in European rivers. Mitigation measures have been identified for each of the relevant impacts, as described in Table 14.

Run-of-the-river facilities, usually operating with constant water flows and generating electric base load, have different effects than storage plants. The main external effects of these HP plants are the reduced connectivity. As a result, aquatic life and recreational activities can be affected, whilst flows are not altered.

Moreover, at international level, the IEA developed a technology roadmap for hydropower (2012), where environmental impacts were acknowledged and possible mitigation measures identified. IRENA (2015) quote environmental impacts as one of the main barriers for HP development. Recently, the Mekong River Commission published recommendations on how to tackle environmental impacts. They employ a "mitigation hierarchy" approach, where 1. Impacts should avoided in planning; 2. If it is not possible to avoid these impacts, these should be mitigated; 3. If impacts cannot be mitigated, they should be compensated (MRC, 2018). Wang (2012) made the case for adopting the benefit sharing approach for HP projects instead.

The main benefits of implementing mitigation measures are obviously the avoided effects listed above. Several studies are available that assessed those impacts in economic terms.

Mattmann et al. (2016) conducted a meta-analysis of 29 valuation studies (only two considered middle-income countries) and found that public aversion towards deteriorations in landscape, vegetation and wildlife caused by hydropower is strong and there is a limited WTP to mitigate these effects. The authors see it as a major barrier for HP development and concluded that "HP plants will have to be planned in areas where they have as little impact as possible on the surrounding landscape, vegetation and wildlife" (p. 74).

A study from the MRC (2018) found that the importance of trade-off between the energy, water and food. The proposed HP development is expected to create economic benefits for USD 160 billion, on the one hand, but also to entail negative impacts on other sectors, mainly fisheries (which will suffer an economic loss of USD 25-30 billion). Other negative impacts related to HP development are documented for ecosystem services (Yang and Chen, 2014), and food security (Sparkes, 2013).

Table 14 – Main impacts of stored HP and mitigation measures

Impact	Mitigation measures
Upstream continuity fish	Ramp Fish pass (e.g. lift, ladder etc) By-pass channel Catch, transport & release of fish Stock from hatchery
Downstream continuity fish	Fish-friendly turbines Fish screens/grids Trap, transport & release Fish pass By-pass channel
Low flow	Provide additional flow to river River morphology changes to make best use of available flow
Fish flow	Mitigation flows for fish migration
Variable flow	Passive flow variability (e.g. using natural variability via V-notch weir) Actively delivered flow variability e.g. timed release from dam
Rapidly changing flows	Install a balancing reservoir external to the river channel Relocate tailrace, including to the sea, a lake, a larger river or a separate channel alongside the original or a recreated river channel Reduce rate at which flow ramps down (including using a bypass valve) Modify river morphology e.g. by introducing structures to reduce velocity and provide shelter for fish Install balancing reservoirs in the river channel Fish stocking
Sediment alterations	Mechanical break-up of bed armouring Mechanical removal of accumulations of sediment (e.g.to reform pools) Re-introduce sediment downstream of river intake structures (e.g. through sluice gate; passively by weir design; by returning dredging downstream) or water storage reservoirs Restore lateral erosion processes in river (e.g.by removing engineering) Introduce flows sufficient to mobilise sediment Fish stocking
Ponded rivers (impoundments)	Create an artificial bypass channel to provide some flowing water habitat Reduce storage level (e.g.by raising bed or lowering dam) to increase flowing water habitat In-channel habitat improvements Lateral reconnection (e.g. tributaries, floodplain features) such as oxbows
Lake level alteration	Limit level variation by reducing abstraction or by balancing abstraction with increased inflows (e.g. by transfers from another reservoir etc) during ecologically sensitive periods

	Limit level variations in part(s) of the reservoir by creating a separate area (embayment) in which levels are maintained Manage shore/shallow habitats e.g. control erosion, plant overgrowth. Renaturalisation of lake shore or artificial habitats. Maintain connectivity between reservoir and tributaries for fish movement Create artificial floating islands with associated shore/shallow habitats Fish stocking to compensate for lost spawning/rearing habitat
Physico-chemical alteration	Flexible intake (i.e. floating intake able to take water from surface layer of reservoir) Multiple intakes at different heights that can be alternated as reservoir levels vary Manage reservoir levels so that water from surface layers provides the river flow mitigation during ecologically sensitive periods

Source: Halleraker et al., 2016, table 4, p. 30-32.

7. Barriers and determinants for adoption

Most of the necessary technologies for promoting the sustainable management of water resources are already tested and ready for application on larger scales. However, their uptake is lagging behind. Possible reasons are economic and financial constraints, which lowered the financial capacity of many countries to implement innovative water technologies, and the lack of knowledge dissemination.

As noted by UN-Water (2011), "water usage is often technologically determined and changing behaviour requires replacing the current technology being employed with an alternative technology. Capital costs can often be significant" (p. 21).

Successful transfer of technology is dependent on at least three factors: the availability of the physical technology or equipment; the skills to use the equipment; and the organizational ability and know-how to manage the operation and maintenance (Still Well, 1994).

When assessing the potential for water saving technologies in the irrigation sector, a distinction must be made between water supply and irrigation technology. This distinction is necessary as the enabling factors in the two cases differ: whilst the funding and management of scheme infrastructure is usually a government/donors concern, the irrigation technology is more likely to be funded and managed by farmers themselves, and therefore the cost of in-field equipment is a significant limiting factor. Moreover, as noted by de Lang (2004) "to promote farmer adoption, technology should be effective, easy to apply, in the desired amount, easy to operate and maintain with local resources and affordable".

It should be noted that also social-economic factors are relevant too. Baba Kpadonou et al. (2017), found that major drivers of farmers' decisions to adopt water conservation practices are the presence of children (aged 6 to 14) in the household, land holding, land tenure, awareness and training. They also found that access to alternative cash sources such as remittance and cash farming are important.

Qadir and Sato (2016) give a comprehensive review of the main obstacles for wastewater reuse. The main limiting factor is the lack of treatment for wastewater, which is discharged directly into river bodies, or used to irrigate crops, as it is rich in nutrients and do not require pumping costs, with the consequence that farmers often do not receive water for irrigation of adequate quality. Other constraints highlighted in the economic literature are (Kfouri et al., 2009; Qadir and Sato, 2016):

- Financial constraints: reused wastewater is more costly to produce than freshwater. Government's budget constraints limit the collection of wastewater in an effective manner, and the low water tariffs do not guarantee that treatment and collection facilities, when existent, are adequately maintained.
- Complete understanding of economic impacts. The business case for reusing water is not always put forward, due to lack of feasibility studies and economic analysis that clarify the true costs (i.e., including also environmental costs) of implementing reuse policies
- Lack of awareness for potential wastewater and reuse
- Regulatory environment, with lack of support to reuse policies and insufficient coordination amongst regulatory agencies
- Health issues: the lack of treatment hinders the possibility of using wastewater due to safety concerns and might lead to prohibition of using wastewater for irrigation (although this is not always applied)
- Preference for use of freshwater instead of wastewater. As a consequence, demand for reclaimed water generally is lower than it is for alternative sources of freshwater
- Lack of skills necessary to develop wastewater reuse schemes

Qadir and Sato (2016) analyse water recycling and reuse policies in Tunisia, Jordan, Israel, and Cyprus to conclude that to overcome these constraints regulation plays a key role: in these countries wastewater is now considered an economic asset, instead of an environmental burden and its reuse is an essential part of strategic planning and management of water and wastewater. In this respect, the World Health Organization has developed general guidelines and standards for wastewater use that are guide to regulating agencies to develop reclaimed wastewater use regulations and monitoring programmes (WHO, 2006). At European level the relevant piece of legislation is the Directive 91/271/EEC (1991) concerning urban wastewater treatment (Dalahmeh and Baresel, 2014) and the WFD.

The main barriers for adoption of water saving initiatives in industries, identified by the WBCSD (2017: 18) are related to water quality requirements or regulatory constraints, and limits to resources available. Water reuse can be hindered by the fact that water quality after reuse does not meet process needs, or by the risk that concentration-based effluent limits will not be met with reduced water consumption. Therefore additional investments might be necessary to ensure regulation compliance, because the more water efficient an industrial premise becomes, the more concentrated effluents are and more costly to treat. Moreover, waste and residual streams should be managed accordingly, which might be challenging. Another limiting factor is public perception of the use of alternative water sources to freshwater (especially in the food and beverage industries). Finally, financial, physical (i.e. assets) human resources to implement water saving measures might be constrained.

8. Policy implications for the Kura river basin

Water conservation in public water supply has been pursued by both national water policies in the Kura river basin in recent years. By considering total water productivity, a general improvement can be observed, see Table 15.

Table 15 – Total water productivity in the Georgia and Azerbaijan (constant 2010 USD, GDP per m³ of total freshwater withdrawal) 1997-2012

	1997	2002	2005	2008	2012
Azerbaijan	0.8	1.6	2	-	5
Georgia	-	-	5	6.2	-

Source: World Bank[20]

Whilst there are no extensive programmes for water efficiency retrofitting the existing building, metering penetration has increased and produced positive results. For example, the metering programme launched in Baku, which now covers 77% of the population, has entailed a reduction in consumed water of circa 15%, equivalent to 5 million m^3/year (Mr. Maqsud Babayev, pers. comm.).

Metering has also improved in Georgia: it varies across the country, from 72% of customers metered, for Rustavi Water, to 23% in Tbilisi (GNRC, 2017). In September 2010, metering was made compulsory (before it was voluntary) for non-household users, while metering of households has been implemented stage by stage. In Tbilisi it has been gradually implemented. Currently, GWP Ltd. has been piloting of advanced water metering system, which will give access to real-time water consumption data. Moreover, UWSCG inspect water losses through a diagnostic service that detects water losses by means of special equipment (using acoustic methods) and prioritise works accordingly (Mr. Misha Tataradze, pers. comm.).

As there is not wastewater treatment in rural and remote areas, the potential for decentralised treatment systems should be further investigated.

Both countries in the Kura river basin have put the modernisation of agricultural activities at the top of their national agricultural strategy and are massively investing in rehabilitation of aging irrigation and drainage infrastructures (through lining of irrigation canals in Azerbaijan and the application of water- efficient irrigation technologies such as drip and sprinkler irrigation). Whilst this will reduce the network losses, the consequent increase of the irrigated area needs to be counterbalanced by an increase in water productivity. The transition to more water efficient irrigation systems will require that crop productivity is enhanced as well. Currently, both countries show very low crop productivity compared to European countries with similar climates. More detailed information on agricultural water uses and productivity can be found in Paccagnan (2018). Some projects demonstrated the potentials from switching to more efficient water technologies.

In Azerbaijan an attempt was made to strengthen the promotion of sustainable farming practices in collaboration with other organizations already actively working in the country in this field. These were FAO, ADB, WB, and EU funded research projects. All shared their resources and experiences with the FAO and worked to complement each other in the promotion of CA. For example, several

[20] https://data.worldbank.org/indicator/ER.GDP.FWTL.M3.KD

projects were implemented in Azerbaijan by ICARDA. The projects aimed to introduce CA practices to strengthen the sustainability of farming mainly through improvement in soil structure and health; reduction in wind and water erosion; saving water and making cropping less vulnerable to unfavourable climatic conditions. As a result of the above mentioned projects the area under CA reached 2,421.5 ha in 2013. The results of the FAO project on CA also convinced policy makers to begin the introduction and adoption of CA in Azerbaijan. Today the country has taken measures to implement programs on resource saving technologies, as envisaged in the national agriculture development plan (Mr. Elchin Mamedov, pers. comm). Another example is the North-East Development Project financed by the World Bank successfully established water user associations (WUAs) and rehabilitated some 31,000 ha of farmland. The main outcomes of the projects were: increased water supplies and improved water-use efficiency (reduction of water losses in the range 29-50% of conveyed water); introduction of higher-value crops, increasing crop yields and expanding livestock activities. WUAs managed the rehabilitated irrigation systems and distributed water to irrigators in an equitable manner, with increases in crop, forage and livestock productivity: reported yield increases vary from 30% for crops and 60% for orchard fruits (IFAD, 2013).

In Georgia, in 2014 the introduction of water efficient irrigation technologies was part of a target programme of the Ministry of Agriculture “Plant the Future”, where central government incentivised the uptake of water efficient irrigation methods through a co-funding scheme: upon presentation of a concept plan, farmers were offered funds to cover 70 percent of plant costs and 50 percent of the cost of an irrigation system. 506 fully equipped orchards have been financed by the government, covering a total area of 3,343 hectares.

Although water reuse is not yet common practice in Georgia, there are some positive experiences that could be replicated. For example, the Georgian company Biu Biu, i.e. the largest poultry producer in the whole Southern Caucasian region, reuse poultry sludge for irrigation. In Azerbaijan, industrial water reuse is significant, as shown in Table 16. The mining industry constitute 66% of the value produced by industry, followed by manufacturing (28%) and production and distribution of electricity, gas and water (6%). No statistical information is available on industrial water reuse in Georgia.

Table 16 – Water use by industrial activities in Azerbaijan in 2016 (million m^3)

	Mining	Manufacturing industry	Production and distribution of electricity, gas and water
Abstraction from natural resources	275.2	16.6	1358.8
Fresh water consumption	277.7	46	2089.2
Volume of recycled and reused water	270.3	252.9	1797.4
Water losses during transportation	2.7	2	309.9
Discharge of sewage waters	270.6	14.7	1079.6
of which untreated waste water	21.9	2.8	84.6

Source: Azstat website

By considering the value of industrial products, available from the website of the State Statistical Committee of Azerbaijan, the industrial water productivity can be estimated for the main industrial sectors, as shown in Table 17.

Table 17 – Industrial Water Productivity in Azerbaijan

Industrial Sectors	Value Industrial Production (ml AZN)	Water abstracted (ml m^3)	Water Productivity (AZN/ m^3)	Water Productivity (USD/ m^3)
Mining industry	21192	275.2	77	45
Manufacturing industry	8899	16,6	536	316
Electricity, gas and steam production, distribution of supply	1938	1358.8	1.43	0.84

Source: Own elaborations on Azstat data

Therefore, by considering water productivity for industry sub-sectors it should be noted that the manufacturing sector has an indicator similar to most European countries. Possibilities for improving water use in other sub-sectors should be further investigated.

9. Conclusions and recommendations for future research

This report explored several technological developments that can help reduce water consumption and related environmental effects, for the major sectoral water uses, namely PWS, agriculture, industry and energy. Whilst we identified major advantages from their adoption and highlighted the key barriers that should be addressed to increase uptake, it should be noted that no one-size-fits-all solution exists, and rather location-specific measures should be identified by considering long-term and holistic (for example in terms of the water-energy-food nexus) solutions.

We also highlighted the key trade-offs among energy and water use, but further research is needed to improve the understanding the key interdependencies among water use efficiency improvement, energy consumption and land use. In this respect, a workshop was hold in July 2018 to fill this gap, which successfully identified WEF nexus hotspots in the Kura river basin. Previous research includes the nexus assessment in the Alazani/Ganykh (UNECE, 2015), which considered the main linkages between energy, water and land use, with particular attention to the impact of HPP development, the use of fuelwood for heating purposes, and the impacts of agricultural practices on water resources. Other aspects of the nexus should be further investigated, in particular economic viability of adopting more water efficient irrigation technologies for the agricultural sector and the potential for adopting nature-based solution to improve water quality and resilience to extreme events.

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