Recommendations for Non-Potable Water Reuse

Implementation of projects for the reuse of treated wastewater

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Abstract

From 2023, new minimum standards for the reuse of treated wastewater will apply in the EU. Internationally, water reuse has already been a relevant issue for some time. Rising water demand worldwide, also as a result of global climate change, is increasing the scarcity of freshwater resources in some areas. Reclaimed water is increasingly considered as a valuable substitute for natural water resources. Even before the new EU regulation came into force, DWA has published an extensive report covering a variety of aspects to be considered within the scope of non-potable water reuse. This article provides an overview of that DWA Topics issue "Non-Potable Water Reuse – Development, Technologies and International Framework Conditions for Agricultural, Urban and Industrial Uses"[*].

1 Introduction

In June 2020, EU Regulation 2020/741 on minimum requirements for water reuse [1] came into force. After a three-year transitional period, it sets binding standards for all EU Member States with regard to water quality and risk management, among other things. This regulation standardises the requirements for water reuse, which is already widespread especially in southern Europe, across the EU and sets out framework conditions for future applications.

But internationally, water reuse has already long been an issue. Along with the world population growth, the need for increased food and energy production, both with significant associated "water footprints," also rises [2]. Scarcity of locally available water supplies, competition for water with agriculture and energy, climate change impacts, rising energy prices, environmental restoration, and economics will require communities to reuse far more water. Thus, water reclamation and water reuse will play an important role in future water management.

Types of Water Reuse

Unplanned reuse of municipal wastewater – untreated or treated – has been practiced for many centuries with the objective of diverting human waste outside of urban settlements [3], but also by farmers in many arid and semiarid regions to irrigate their fields. Planned water reuse is defined as the benefi-

Figure 1: Water reuse for drip irrigation of public green spaces in Bahrain (source: p2m berlin)

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[*] DWA Topics issue "Non-Potable Water Reuse" (2019) was prepared by the following members of the DWA Working Group BIZ-11.4 "Water Reuse": Prof. Dr. Peter Cornel (Darmstadt), Prof. Dr. Jörg E. Drewes (Garching), Edgar Firmenich (Frankfurt a. M.), Dr. Tim Fuhrmann (Essen), Dr. Stefan Gramel (Frankfurt a. M.), Prof. Dr. Jens Haberkamp (Münster), Andreas Hartmann (Braunschweig), Dr. Wolfgang Jendrischewski (Köln), Volker Karl (Bad Nauheim), Prof. Dr. Steffen Krause (Neubiberg), Dr. Josef Lahnsteiner (Vienna), Dr. Manfred Lübken (Bochum), Dr. Ingmar Obermann (Eschborn), Dr. Florian Schmidtlein (Essen), Jochen Sinn (Darmstadt), Prof. Dr. Dörte Ziegler (Koblenz); the following guests have contributed: Dr. Tamara Avellán (Dresden), Dr. Serena Caucci (Dresden), Emily Fokin (Münster), Alexander Grieb (Frankfurt a. M.), Roland Knitschky (Hennef), Veronika Zhiteneva (Garching).

cial use of treated wastewater and can either serve non-potable or potable applications. Non-potable water reuse comprises agricultural and urban landscape irrigation (Figure 1), as well as water use for cleaning purposes (e. g., street cleaning, car washing), for fire-fighting, recreational applications (e. g., golf courses), environmental protection measures (e. g., stream flow augmentation), intrabuilding applications (such as toilet-flushing), and groundwater recharge (also as a barrier against seawater intrusion) [4].

Need for safe application of water reuse

Multiple planned non-potable reuse projects for agricultural and landscape irrigation, but also potable reuse applications, have demonstrated that the use of reclaimed water for such applications can be practiced in a safe manner. The total volume of municipal wastewater produced per day worldwide is estimated to be about 684 million m^3. However, only about 30 million m^3 (~4.4 %) receive tertiary or advanced treatment. The largest application of water reuse globally is for agricultural irrigation [5].

Water reuse practices have to be safe for users, groundwater, surface water, and soil. Thus, it is critical that the provided effluent quality is suitable for the desired use (fit for purpose) and assures safe practices. In order to ensure proper risk management, appropriate technological and administrative measures are also necessary, taking into account the individual case-specific circumstances. Their long-term financing and social acceptance must be ensured at an early stage.

The German DWA Topics issue on Water Reuse

To address such issues, the DWA Topics issue "Non-Potable Water Reuse – Development, Technologies and International Framework Conditions for Agricultural, Urban and Industrial Uses" [6] provides recommendations on the selection of suitable treatment processes, as well as the consideration of planning, regulatory, socio-cultural, ecological, agricultural, and economic aspects that need to be taken into account in connection with water reuse. The report is intended to provide general guidance for water utilities, consulting engineers and regulatory agencies in planning and expanding non-potable water reuse.

The following sections provide an overview of the report's contents, focusing especially on aspects regarding the development and implementation of water reuse projects.

2 Regulations and Risks

Conventionally treated municipal wastewater effluents include pathogenic microorganisms, antibiotics including antibiotic resistant bacteria and antibiotic resistance genes, as well as residual nutrients, dissolved solids, remaining levels of heavy metals, and a wide range of natural and synthetic trace organic chemicals. Their presence is generally concerning due to potential adverse impacts on human and environmental health, particularly from pathogens and chemicals (Figure 2). To minimise health and environmental risks, sufficient elimination of potentially harmful water constituents through efficient barriers and their monitoring is therefore an essential part of water reuse.

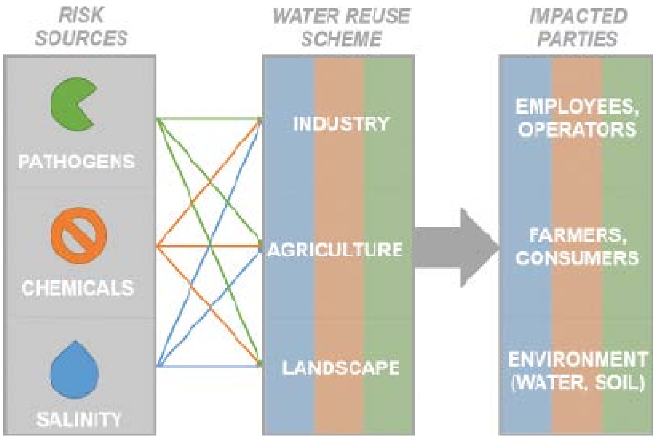


Figure 2: Risk sources and exposure in water reuse schemes

Risk Management

Risk management plays a major role in the new EU regulation. To manage risks related to water reuse, government regulations have to go beyond the definition of technical standards and requirements but must also cover additional aspects such as source control programmes (discharger control), water quality monitoring, and the responsibilities and rights of the parties involved (implementation organizations, operators, consumers), as well as a proper rate or fee structure for reclaimed water.

In many countries there is no lack of legally binding sets of rules and standards or of recommendations for minimum standards for water reuse. The problem in most areas with scarce water resources is rather, above all, an implementation deficit with a lack of compliance and insufficient monitoring by governmental and/or private regulatory institutions. Often, the capacities and resources of those institutions are not appropriate to guarantee a functioning and trustworthy regulatory system.

International Guidelines

In 1992, the Food and Agriculture Organization (FAO) published recommendations for the agricultural application of reclaimed water being based on previous WHO guidelines [7] and considering health aspects as well as requirements in terms of crops and soil [8]. Extensively revised guidelines for non-potable water reuse were published by the World Health Organization (WHO) in 2006 [9]. These represent a specific framework for the development of individual national directives and standards for the reduction of microbiological health hazards associated with water and provide information regarding monitoring procedures to assure microbiological safety. Fundamentally, the quality requirements should be adopted to the respective use of the water and consider, for example, salt and nutrient contents for agricultural water uses, in addition to those of pathogens.

The WHO approach to managing risk associated with water reuse is based on the Hazard Analysis and Critical Control Point (HACCP) system for analysis and control of hazards in any treatment train, and the Stockholm framework for preventive risk assessment. Risk management frameworks feature the same steps: identify the problem, determine the hazard in the system, quantify the hazard (exposure, dose-response), assess and characterize the risk, and manage the risk (Figure 3). Risk assessment can range from a straightforward risk matrix to an extensive quantitative microbial risk assessment.

The main guideline for addressing risk in non-potable water reuse is the Sanitation Safety Planning (SSP) Manual for Safe Use and Disposal of Wastewater, Greywater and Excreta [11]. SSP is a participative approach involving all stakeholders. Risks are followed from wastewater generation through the various reuse applications (agriculture, irrigation) to their individual end points (environmental discharge, crop production). It serves to maximize benefit of wastewater or greywater reuse while minimizing illness and contamination. Responsibility for SSP implementation is shared across numerous stakeholder agencies, depending upon the reclaimed water application purpose. Due to the broad nature of SSPs, their implementation can be difficult to coordinate, particularly in developing countries. Difficulties are encountered due to lack of or incompletely established improvement plans, supporting programmes, and management procedures. Additionally, the chances of success might be reduced by problems such as lack of training for workers and farmers, lack of monitoring programmes, lack of local community education on behavioural changes needed for compliance, and lack of governmental initiative and stakeholder support.

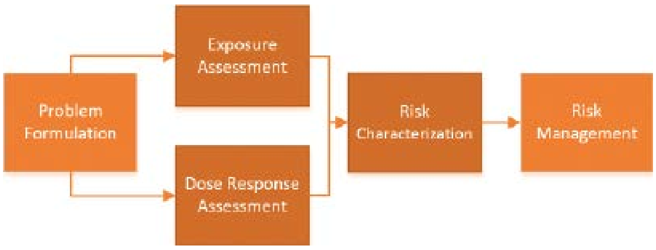


Figure 3: Risk management framework for determining whether a system meets tolerable risk levels (adapted from [10])

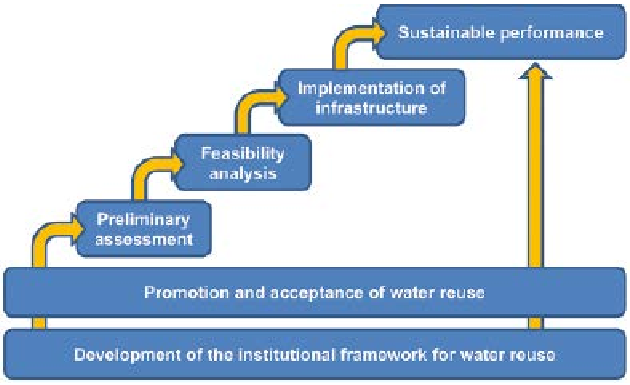


Figure 4: Steps of the development of water reuse schemes

3 Development of Water Reuse Schemes

In most cases, the development of water reuse schemes follows a typical order of development steps. These steps should be supported by qualified consulting experts (Figure 4). These steps are briefly described in the following. More detailed information is given in the DWA Topics issue [6].

Preliminary Assessment

The implementation of water reuse must be rooted in an adequate institutional framework and in sufficient acceptance by relevant stakeholders (e. g., the regulatory authority, the operator, the water user as well as the consumer of produced products). Therefore, within the preliminary assessment an initial analysis is required to determine existing regulatory frameworks for water reuse. Adequate means of public engagement for acceptance of water reuse should also be compiled. Thus, once a water reuse opportunity is proposed, a preliminary assessment of the existing local water resources and infrastructure as well as economic, institutional, legal, and social conditions should be conducted to determine whether the project is practical and necessary. If so, an in-depth feasibility analysis is carried out.

The preliminary assessment includes a rough analysis of the main elements of a potential reuse project, clarifying the need and crucial aspects for water reuse. It mainly includes the following tasks:

- Assessing the need for reclaimed water use
- Quantity and quality of potential reclaimed water
- Options for infrastructure
- Rough economic assessment
- Screening of institutional and regulatory framework

- Screening of environmental and social impacts
- Overall analysis, support of decision process

Feasibility Analysis

Based on the results of the preliminary assessment, a decision process of mainly authorities and political decision-makers sets the basis for the further steps of development. In case of a positive decision, a feasibility analysis is carried out. Occasionally, the preliminary assessment and the feasibility analysis are integrated into one study. The aim of the feasibility study is mainly to analyse thoroughly all relevant aspects and to develop a concept which can be taken as basis in further development steps (design, implementation phase). Crucial aspects of the feasibility study are:

- Water quality and water quantity aspects
- Technology and infrastructure
- Economic analysis
- Environmental and social impact assessment (ESIA)
- Public involvement and public awareness
- Monitoring system
- General institutional and organizational aspects related to the use of reclaimed water
- Relevant aspects on the water user's side

In the case of reclaimed water being used in agriculture, there is a range of additional topics to be analysed in this subject area, mainly:

- Institutional analysis and concept for development
- Extension and advisory activities
- Support of farmers in day-to-day work
- Information systems

Based on the results of the feasibility analysis, a concluding decision is taken. This decision is based on positions of the relevant stakeholders and other key aspects of a large infrastructure project (such as the cost-benefit ratio, interests of the user groups, options for financing and environmental criteria).

In the case of confirmation of the feasibility, an appropriate water reuse infrastructure is installed, and measures for sustainable performance, including continuous promotion of acceptance and updates to regulatory and institutional frameworks, can be implemented.

Implementation of Water Reuse Facilities

The steps of implementation (preliminary and detailed design, tendering, and infrastructure implementation including supervision works) are basically the same as in all larger infrastructure projects.

Also, the first phase of operation is basically similar to other infrastructure projects in the water sector. Nevertheless, special reuse-related topics have to be focused upon, such as trainings of the operational staff, support in the operation of the special treatment steps and the water quality control system, as well as support of the farmers (if related to agriculture).

Operation of Water Reuse Facilities

When the effluent of a wastewater treatment plant is used by third parties, the operation of the plant changes its established role. The plant now enters the water supply market as a "water seller". Thus, the offered product – reclaimed water – requires reliable quality and introduces new, additional stakeholders into the management and operation of the plant. In general, the plant must consider at least the following reuse-specific issues in addition to the operation of conventional wastewater treatment plants:

- Water quality requirements: The production of reclaimed water places more emphasis on pathogen removal with absolute limits. Higher nutrient concentrations may be allowed when the water is used for irrigation purposes.
- Continuous availability of reclaimed water supply: The plant must guarantee quality and quantity at any time and in the long term.
- Reliable, independent quality control: A stringent internal monitoring structure as well as an external monitoring by independent supervisory bodies must be implemented.
- Additional facilities: Facilities for further treatment, storage, and distribution of reclaimed water are necessary. They might be controlled by a separate operator.
- Additional stakeholders: Since the use of the reclaimed water results in several additional processes for treatment, transport, and storage, the need for contractual clarification of responsibilities arises between the operation of the treatment plant, the operation of the subsequent facilities, and the use of the water. Hence, the number of involved stakeholders significantly increases (e. g., operators of storage and distribution systems, water users, water user associations, regulators and supervisory authorities, both from the water sector as well as the sectors the reclaimed water is used for).
- Form of organization: To ensure sustainable and coordinated operation of the related facilities, the organizational structures and, more precisely, the chosen operator model are to be adopted, particularly in the context of the regional logistical, institutional, and legal conditions.

4 Technical Barriers for Pathogens

Multi-Barrier Treatment Approach

To achieve reliable protection against harmful microorganisms, disinfection procedures must significantly reduce pathogens through removal, destruction, or inactivation processes. Also considering possible by-product formation, a multi-barrier treatment approach should be utilized in all water reuse applications. The various barriers include wastewater load control, appropriate wastewater treatment, disinfection, bacterial regrowth prevention, reclaimed water quality control, occupational safety measures, as well as monitoring of soil, groundwater, and final effluent quality in water reuse systems. Following the above-mentioned Hazard Analysis and Critical Control Points (HACCP) approach to risk management, relevant parameters (or control points) such as disinfectant concentration, integrity of membranes or seals, and water quality parameters influencing pathogen removal efficacy are to be defined. Appropriate operational ranges for these identified parameters must be documented within a monitoring programme based on existing national and local regulations, as well as international recommendations.

Assessment Matrix of Treatment Technologies

Treatment technologies for pathogen removal or inactivation include membrane filtration, microscreening, cloth filtration, sand filtration, as well as additional disinfection processes, such as UV disinfection, ozonation, or chlorination.

In order to support planners and decision-makers with the selection of appropriate treatment processes for safe water reuse, an assessment matrix of various wastewater treatment processes has been compiled. The matrix included in [6] provides a general evaluation of technological options, which may serve as a basis for further detailed investigations considering site-specific conditions. Each process step is assessed with regard to aspects such as water quality, costs, consumption of materials and energy, and expenditure for preventive maintenance, among others. The assessment matrix is intended to provide fast and simple support for an initial evaluation of treatment options. It is not exhaustive and will not replace the engineering investigation for site-specific decisions. However, it should be applicable for most cases and enable reasonable decisions, even when access to expert knowledge is limited.

5 Ecological and Agricultural Aspects

Substitution of Freshwater

Consuming around 70 % of total available freshwater, the global agricultural water demand exceeds private and industrial consumption. The specific irrigation water demand depends on factors like the type of crop grown, climate, soil moisture content, and the crop's growth stage. According to an exemplary calculation included in [6], the crop water demand of an agricultural area of about 25-30 m^2 per capita can be covered by reclaimed water (assuming a rather high specific wastewater production of 200 litres per capita and day). However, although water reuse can only cover a limited proportion of the agricultural water demand, it contributes to the substitution of valuable freshwater resources.

Substitution of Fertilizers

The use of reclaimed water for irrigation provides nutrients free of charge for farmers. In the context of steadily increasing fertilizer prices over the past years, substitution of fertilizers by wastewater nutrients may play a more pronounced role in the future.

The most important nutrients in wastewater irrigation are nitrogen, phosphorus, and potassium. The nutrient concentrations in reclaimed water depend on the degree of the wastewater treatment. Efficient nutrient management depends on the type of crop grown, the soil structure, the expertise and training of the farmer, as well as the awareness about marginal-quality water as a nutrient source. A systematic and targeted nutrient supply by reclaimed water is sophisticated, since the crops' nutrient demand shows strong seasonal differences for both perennial plants, such as those grown in orchards, and field crops, which have different nutrient demands depending on their growth phase. In the context of water reuse, it is therefore recommended to count on only partial nutrient application and avoid applying in excess. In the case of partial supply, the farmers may additionally fertilize with mineral fertilizer. In case of excess application, the groundwater can possibly be impacted.

Suitable Irrigation Methods

In addition to the substitution of irrigation water and fertilizer, further agricultural aspects regarding different irrigation methods, as well as the risk and management of salt accumulation in the soil are discussed in [6].

Increased salinity of reclaimed water often requires measures for minimizing the risk of salt accumulation in the soil. This includes the selection of appropriate irrigation methods, e. g., drip or sub-surface irrigation, which can also provide an additional barrier against the microbial contamination of farmers and crops.

6 Energetic Aspects

Water and energy are inevitably interlinked. Water is required for exploring and processing conventional primary energy sources and for cooling when converting them into electric power, as well as in hydropower or biomass generation. On the other hand, energy is needed for running the water cycle.

Water reuse can reduce energy demands in the water cycle, especially where energy consumption for conveyance, transport, treatment and distribution of freshwater is high. Comparing the energy demands associated with conventional freshwater production and distribution with the potential energy demands for provision of reclaimed water allows decision-making bodies to determine whether water reuse is feasible, from an energetic point of view, for specific applications.

Figure 5 exemplarily summarizes energy demands for all stages of the urban water cycle from water supply to wastewater treatment and discharge, taken from experiences in California and other locations. Utilization of reclaimed water (pink boxes) can be more energy efficient than supplying freshwater (blue boxes). In California, energy consumption associated with recycling (0.11-0.32 kWh/m³) is comparable to that one associated with water extraction, treatment, and distribution, which ranges from at least 0.21 (= 0.18 + 0.026) kWh/m³ to more than 4.5 kWh/m³, when assuming either long distance transport or desalination for treatment.

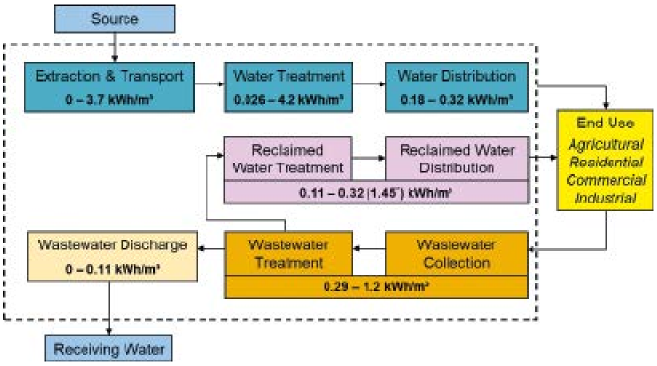
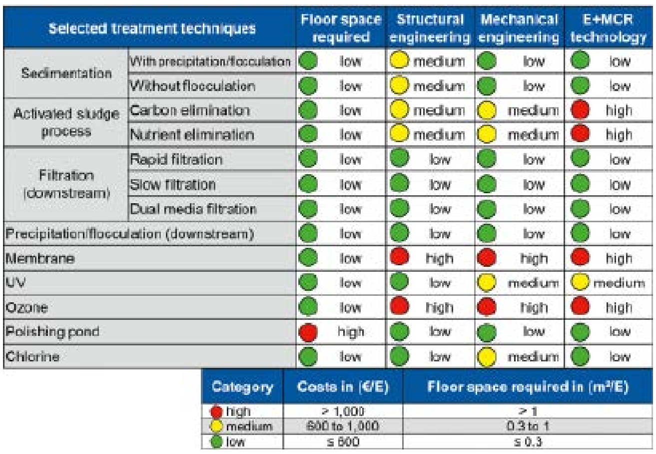


*Figure 5: Range of energy consumption for segments of the water use cycle, based on values from California (blue: freshwater; pink: recycled water, brown: wastewater; adapted from [12]; values converted in metric units; *[13]: energy consumption for direct potable reuse including microfiltration, reverse osmosis and advanced oxidation)*

Energy consumption for adequate reclaimed water generation varies considerably depending on the raw water source (e. g., treated or untreated wastewater) as well as on the required quality of the reclaimed water. Tertiary treated, disinfected wastewater, especially after membrane bioreactors, often needs almost no additional treatment for agricultural irrigation or non-potable intra-urban uses, like street cleaning, irrigation or even toilet flushing. The more stringent the effluents standards are (i.e., the more energy is already embedded in the wastewater treatment), the less energy is required to produce reclaimed water.

7 Economic Aspects

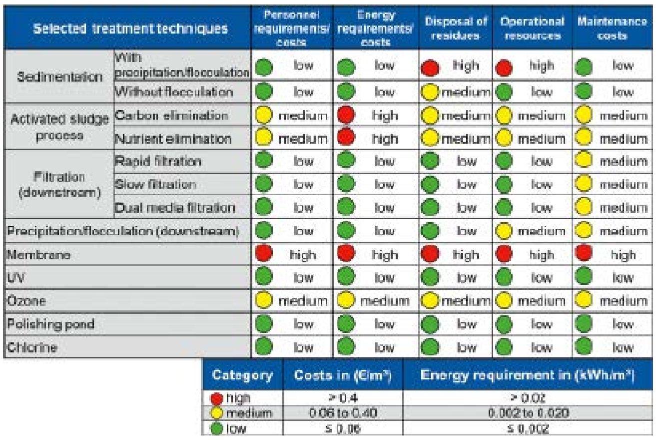
As crucial step of the preparation of a reuse project, an economic analysis has to be carried out. In the context of the detailed analysis of a reuse project (cf. chapter 3), a cost estimation based on potential alternatives of a reuse scheme is required. The cost estimation represents the basic data for an economic analysis. Tables 1 and 2 categorize the costs for investment as well as for operation and maintenance.



Selected treatment techniques		Floor space required	Structural engineering	Mechanical engineering	E+MCR technology
Sedimentation	With precipitation/flocculation	low	medium	low	low
	Without flocculation	low	medium	low	low
Activated sludge process	Carbon elimination	low	medium	medium	high
	Nutrient elimination	low	medium	medium	high
Filtration (downstream)	Rapid filtration	low	low	low	low
	Slow filtration	low	low	low	low
	Dual media filtration	low	low	low	low
Precipitation/flocculation (downstream)		low	low	low	low
Membrane		low	high	high	high
UV		low	low	medium	medium
Ozone		low	high	high	high
Polishing pond		high	low	low	low
Chlorine		low	low	medium	low

Category	Costs in (€/E)	Floor space required in (m²/E)
high	> 1,000	> 1
medium	600 to 1,000	0.3 to 1
low	≤ 600	≤ 0.3

Table 1: Assessment of investment costs



Selected treatment techniques		Personnel requirements/costs	Energy requirements/costs	Disposal of residues	Operational resources	Maintenance costs
Sedimentation	With precipitation/flocculation	low	low	high	high	low
	Without flocculation	low	low	medium	low	low
Activated sludge process	Carbon elimination	medium	high	medium	medium	medium
	Nutrient elimination	medium	high	medium	medium	medium
Filtration (downstream)	Rapid filtration	low	low	low	low	medium
	Slow filtration	low	low	low	low	medium
	Dual media filtration	low	low	low	low	medium
Precipitation/flocculation (downstream)		low	low	low	medium	medium
Membrane		high	high	high	high	high
UV		low	low	low	low	low
Ozone		medium	medium	medium	medium	medium
Polishing pond		low	low	low	low	low
Chlorine		low	low	low	low	low

Category	Costs in (€/m³)	Energy requirement in (kWh/m³)
high	> 0.4	> 0.02
medium	0.06 to 0.40	0.002 to 0.020
low	≤ 0.06	≤ 0.002

Table 2: Assessment of costs for operation and maintenance

In the economic analysis, quantitative methods, such as dynamic cost calculation (mainly the prime cost) and cash flow analysis, are applied. In comparison with other projects in the water sector, reuse projects face two specific obstacles:

- A high range of uncertainty of the input data: Methods such as sensitivity analysis, Monte Carlo method, and scenario analysis are usually applied to develop results considering the uncertainty.
- An unclear situation for the reference of the costs: The reference for a comparison of reclaimed water is difficult because tariffs (in particular for irrigation) are often much lower than the level required for cost-coverage. Therefore, it is recommended to compare the costs of the envisaged reuse project (e. g., prime cost) with different existing values, mainly the real costs of existing water production, the costs of other new water resources, and the tariffs.

For the financing of investment costs of reuse projects, besides existing financial resources of an authority or a company, also normal bank loans, loans from development institutions (such as development banks), subsidies, and BOT models play an important role.

For the financing of operation and maintenance (O/M), tariffs, taxes, and subsidies play the predominant role. The financing completely by tariffs is often seen as the ideal solution. Nevertheless, in reality subsidies play a major role particularly in developing countries, but also in industrialized countries. During the analysis of the feasibility, the stability of the O/M-financing has to be analysed, including a partial financing through subsidies.

8 Conclusion and Outlook

The implementation of water reuse projects is a complex undertaking. Therefore, a structured approach including comprehensive risk management and the early participation of all relevant stakeholders as well as the consideration of socio-cultural conditions are necessary to stimulate acceptance. Moreover, the permanent coverage of all costs for investment, operation and maintenance of water reuse systems has to be ensured in order to attain sustainable success.

Regarding the quality of the reclaimed water, microbial risks are of major concern in terms of water reuse. A variety of established processes for advanced wastewater treatment is available for pathogen removal in order to ensure the required effluent quality. Regulations and standards for water reuse have often been limited to the definition of quality requirements for reclaimed water. Recently, the multi-barrier approach focusing on health-based targets for risk management in water reuse recommended by the WHO has increasingly been adopted by standardization institutions (cf. [14]) as well as legislative bodies, e. g., the European Commission, which published the European minimum standards for agricultural water reuse in 2020 [1].

Water reuse can significantly contribute to the substitution of freshwater resources, reduce the demand for mineral fertilizer, and help minimizing the energy embedded in the water cycle, thus reducing greenhouse gas emissions.

Use of reclaimed water, especially for irrigation purposes, has been practised for a long time in regions suffering from water scarcity. With regard to changing rainfall patterns in consequence of the global climate change and an increasing need for seasonal irrigation, it is expected that water reuse will further gain relevance also in regions with rather high average water availability. Not least, the substitution of freshwater resources by reclaimed water contributes to securing future drinking water supply especially in arid and semi-arid regions, and therefore also to the realization of the United Nations' Sustainable Development Goals.

The DWA Topics issue [6] provides general recommendations for the international application of water reuse. For the implementation of the EU regulations [1] coming into force in 2023, in Germany a new specific set of regulations and technical rules is being developed, covering planning tasks and detailed requirements for the risk management of water reuse schemes as well as for the official approval procedures. These regulations and rules will be available by 2023 in the form of the new three-part DWA Guideline “Water reuse for agricultural and urban purposes in Germany” (DWA-M 1200-1 to 1200-3).

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