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Review

Sustainability Assessment for Wastewater Treatment Systems in Developing Countries

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Abstract: As the assessment of the economic, environmental, institutional, and social sustainability of wastewater treatment systems may have several conceivable goals and intended recipients, there are numerous different approaches. This paper surveys certain aspects of sustainability assessment that may be of interest to the planners of wastewater treatment systems. Here, the key criteria assess the system's costs and financing, including its affordability for the users, the environmental impact, the benefits for health and hygiene, the cultural acceptance of the system and its recycled products, the technical functioning, and the administrative, political, and legal framework for its construction and operation. A multi-criteria approach may then be used to analyze possible trade-offs and identify the most suitable system for a certain location.

Keywords: analytic hierarchy process (AHP); net present value (NPV); wastewater treatment system (WWTS); best available technology; ISO standards

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Citation: Starkl, M.; Brunner, N.; Das, S.; Singh, A. Sustainability Assessment for Wastewater Treatment Systems in Developing Countries. *Water* **2022**, *14*, 241. https://doi.org/10.3390/w14020241

Academic Editor: Carmen Teodosiu

Received: 6 December 2021
Accepted: 11 January 2022
Published: 14 January 2022

1. Introduction

1.1. Goal

Massive upscaling of wastewater treatment systems (WWTS) is required to cope with the increasing global sanitation crises [1]. Worldwide, the sustainability of investments in WWTS is a major concern, and many examples exist which show that, without considering key sustainability aspects, WWTS may fail during the operational phase [2,3]. Hence, to ensure that investments in WWTS will have a long-lasting impact, it is crucial to consider their sustainability during planning, construction, and during operation to learn from these experiences for future projects.

There is much research about sustainability criteria and sustainability assessments. In this review we summarize selected aspects of this work that may be of interest in the context of developing countries. We present various criteria for sustainability assessment and discuss possible opportunities and limitations in their application. Our conclusions pertain to the application of sustainability assessment to planning.

1.2. Method

There is a large body of literature with different approaches to "sustainability assessment" (Google Scholar: 1.7×10^5 hits), which demonstrates the importance of this topic in environmental science. Therefore, a review is generally a subjective selection from this material. The present paper is no exception; it reflects the common experiences and interests of the authors. The regional focus is on newly industrialized developing countries [4], such as China, India, Mexico, or South Africa. In these countries there is a demand for decentralized WWTS that serve growing communities with still inadequate water and wastewater services, such as peri-urban areas, smaller rural towns, and larger rural communities [5,6]. Moreover, other than many of the poorer developing countries, these countries have sufficient means to choose between different technologies for this purpose. The elimination of pollutants and recovery of resources from wastewater and sludge uses different physical, chemical, and biological means. During planning, the most suitable mix of technologies needs to be identified. Consequently, there is a demand for the sustainability assessment of different decentralized solutions. Many frameworks have been (and still are) developed to guide this assessment under different definitions of sustainability [7]. This paper does not decide or recommend which of these frameworks or definitions should be chosen, but it focuses on their common ground. Most of the current frameworks accept that the notion of sustainability broadly encompasses environmental, economic and social aspects, as outlined in Table 1. We therefore survey selected sustainability criteria, whereby we distinguish two main groups: local impact during operation and local plus global impact during the entire life cycle of a WWTS. For instance, technical issues matter for the local impact, while health matters for both groups.

Table 1. Organization of criteria for the presentation in this paper.

Pillar of Sustainability	Criteria Group	Examples of Criteria	
		Local Impact	**Local & Global Impact**
Environment (Section 2.1)	Technical Environmental Health & hygiene	Fit to existing system Concentration of water pollutants Count of indicator organisms	Durability (lifetime) Aquatic ecotoxicity Disability-adjusted life years (DALYs)
Economy (Sections 2.2, 3.1 and 3.2)	Costs Financing Affordability	Capital costs Cost sharing Willingness to pay (WTP)	Life cycle costs (NPV) Environmental justice Income distribution
Society (Sections 2.3 and 3.3)	Social & cultural Institutional	Working conditions at the WWTS Enforcement of water quality regulations	Social human rights Water policies
Aggregation (Sections 2.4 and 3.4)	Multi-criteria assessment	Decisive criterion	Cost-benefit analysis

Note: The first column informs about the section numbers.

We also consider reuse options, where (fecal) sludge treatment matters. Wastewater is a resource from which water (for irrigation, toilet flushing, or potable uses), fertilizers (treated sludge), and energy (from methane) can be recovered [8]. If assessment takes care of recycling, then technology selection (e.g., between urine separation or activated sludge technology for nitrogen treatment) may depend on the quality of the produced fertilizer [9].

2. Criteria

2.1. Environment

We follow [10], who considered environmental criteria together with technical ones (local impact) and with health and hygiene. The local impact during operation is often regulated by means of emission thresholds set by international, national and/or local authorities for common pollutants. An overview and discussion of various national and international standards can be found in [11,12]. As a minimal requirement, treated wastewater ought to satisfy the relevant legal requirements.

Technical criteria are often constraints for the selection of systems, as decision makers expect that certain specifications are met [13]. Examples of such criteria are the adequate scale (onsite, decentralized, centralized), the complexity of the system with respect to the ease of construction, use, maintenance, and durability (lifetime), the performance, such as reliability, safety, and robustness (e.g., shock loads leading to sewer overflows), the flexibility (later adaptions with respect to the treatment capacity and treatment quality) and the fit to existing systems. Certain site characteristics are known to constrain the configuration choices and affect the eco-suitability of WWTS [14]. Examples are location=related issues (proximity to discharge points, other topographic constraints, infrastructure availability) and climate related issues (e.g., water scarcity). The frontend (toilet) matters, too: While there is consensus that open defecation is not sustainable, it may be a rational choice for individuals that only have access to inadequate frontend: "*A farmer may perceive defecating in the open on the way to his field as convenient and refreshing compared with a claustrophobic and smelly latrine*" [15]. Further, technology choices (e.g., urine separation, low or no water use for flushing) may affect the ease of use (cleaning).

Common physical and chemical water quality criteria are concerned with temperature and pH (in relation to the receiving water), water clarity (total dissolved solids), dissolved oxygen, organic pollution (biological and chemical oxygen demand), and nutrient load (ammoniacal and total Kjedahl nitrogen). Additional parameters of interest (also for treated sludge) are, for instance: phosphorus and potassium for possible recovery [16], arsenic, cadmium, chromium, copper, lead, mercury, nickel, selenium, or zinc, and gaseous emissions such as methane (a greenhouse gas, if not recovered) or hydrogen sulfide (bad smell). The removal of micropollutants (examples: pesticides, pharmaceuticals, personal care products) from wastewater is an emerging issue. Currently, they are addressed by soft law, such as by an European Union watchlist [17], and innovative treatment technologies are developed, c.f. [18–20]. Microplastic pollution is another emerging issue with active research on removal technologies [21].

The local plus global impact during the entire life cycle of a WWTS is usually assessed by means of a life cycle analysis. A life cycle assessment following the international standard ISO 14040 of 2006 compiles and evaluates inputs, outputs, and potential environmental impacts of a WWTS throughout its entire life cycle, such as the use of energy, material and land. ISO 14040 includes impact categories related to global warming, acidification potential, aquatic and human toxicity potential, ozone depletion, and others. Examples can be found in [22,23].

Public health has always been a main concern for installing a WWTS. It is also an important aspect for the support by the public at large for a WWTS. To assess health under a local perspective, the load of pathogens that is released into the environment with or without the system is estimated. This assessment is also important for indirect exposures, e.g., health impacts for consumers, if farmers irrigate food crop with sludge or with recycled wastewater [24,25]. Typical pathogens that may occur in treated wastewater or in sludge are *Campylobacter*, *Enterococci*, *Escherichia coli*, helminth eggs (e.g., hookworm, *Schistosoma*), *Protozoa* (e.g., *Cryptosporidium* oocysts, *Giardia*), *Rotavirus*, *Salmonella*, *Shigella*, or *Vibrio cholerae*. Not all pathogens are equally important, but in unfortunate circumstances each one may cause serious damage. Regulations provide thresholds for the count of certain indicator organisms. In India, regulations for the quality of treated wastewater prescribe thresholds for the count of fecal coliforms. Rules of thumb allow to use this count to estimate the count of other pathogens [26]. Health concerns emerge from multi-drug resistant pathogens (e.g., *E. coli* from hospitals) that may occur in treated wastewater [27]. The use of chlorinated (waste)water for irrigation may give rise to concerns about chlorate that accumulates in certain vegetables [28]. The exposure of people to these pathogens (e.g., irrigation with treated wastewater) is evaluated for different populations (e.g., farmers, consumers of farm products). For common pathogens there are specific dose-response models to compute the risk of infections; [29] surveys and discusses them.

Under a local and global perspective, as for a live cycle assessment, the health impact of wastewater infrastructure is evaluated in terms of the achieved reduction of DALYs (disability-adjusted life years) for the targeted population [30]. Certain health aspects may also be monetarized in terms of direct costs (medication, hospitalization) and opportunity costs (income losses during sickness). Household surveys may be used to verify such estimates.

2.2. Economy

According to the international standard ISO 30500 of 2018 (c.f. ISO 15686 of 2017, ISO 31800 of 2020), "the estimated expenditures for the sanitation system should be based on a calculation of the life cycle costs encompassing CAPEX and OPEX." Capital costs (CAPEX) include "all initial investment costs required for implementation of the sanitation system." Operational costs (OPEX) include "all running costs to keep the system in continuous working order." Different models for life cycle cost analysis [31] provide strategies that help in defining a complete inventory of all costs; these models originate from [32]. There are also specific models for waste management [33] and wastewater treatment [34,35]. Typical examples are the capital costs for sewers and buildings, for pumps and other technical equipment, for the land used, for the transport of materials and system components, for their assembly and installation, and for the initial recruitment and training of staff. As [36] pointed out, there may be considerable non-construction expenses such as legal expenses (e.g., about ownership of land), fees for preliminary studies, or costs of planning. Examples of running costs are the costs for staff (salaries, technical training), for energy, for materials and maintenance tools (additives for the cleaning processes and disinfection), and for regular servicing (spare parts). Depending on the model of life cycle cost analysis, monetarized costs for water pollution and benefits (e.g., cost savings for health) may also be considered.

The above-mentioned costs specify a stream of a certain number (n) of future cashflows (p_i) within the given time span (T) of planning (typically the lifetime of the system or longer). Life cycle costs are then defined as the net present value (NPV) of this stream [37]. Thereby, NPV informs about today's value of the stream, based on a discount rate, d, that quantifies the time trade-off. The additional parameters (T and d) may be interpreted as proxies for the preferences of the principal [38,39], whereby different choices of the parameter values may result in different decisions: If the discount rate d is low and the time-span T is high, then lower running costs and higher capital costs (for instance to ensure the longevity of technologies) is assessed as more beneficial. Therefore, generally the parameters are taken from guidelines (e.g., funding institutions). NPV is then computed from Equation (1):

$$NPV = \sum_{i=1}^{n} \frac{p_i}{(1+d)^{t_i}} \quad EAC = d \cdot NPV / \left(1 - \frac{1}{(1+d)^T}\right) \tag{1}$$

Equation (1) assumes that payment (or revenue) p_i is due at point t_i of time (today is $t = 0$ and $t_n = T$). The annualized net present value, EAC (equivalent annual cost), is a mathematically equivalent formulation. It expresses NPV in terms of T constant annual payments, which means the substitution of $p_i = EAC$ into (1) results in NPV.

To assess the economic sustainability of a WWTS, financing also needs to be considered. Many countries fund a large share of the capital costs for municipal wastewater treatment infrastructure and their typical perspective is "costs for society", considering capital and running costs, public health, protection of the environment, and scarcity of clean resources [40]. However, with respect to running costs there is an international consensus that water infrastructure projects shall be demand-driven [41], as otherwise infrastructure might not be used or maintained. Therefore, national water policies in general require the beneficiaries of (waste)water infrastructure to contribute significantly to the running costs in the form of e.g., volumetric charges (based on water consumption), property taxes, or water taxes per household.

If infrastructure is provided to slums, then financing is particularly challenging. Therefore, affordability for the users may be an important constraint for the viability of a municipal WWTS. Affordability relates the needed user contributions to the socio-economic situation of the users. The needed contribution may be estimated from the water and sanitation tax per household or from the expected volumetric charge for the estimated household consumption. It is compared with the household income and the household expenditures. Information may be obtained from household surveys and interviews about the willingness to pay (WTP) for sanitation services.

2.3. Society

Social and cultural barriers may matter in contexts, where the end-users are directly involved [13], such as the use and maintenance of the frontend, or the use of recycled products (treated water for toilet flushing). Further issues may be the working conditions at treatment plants (including possible exploitation of children or forced laborers), or the acceptance of a treatment plant by its neighbors (odors, reduced value of the property). Institutional considerations, such as about law enforcement of water quality guidelines or about enabling participation, matter for the implementation of a WWTS.

There are international guidelines for the social impact assessment (of projects) and for the social life cycle assessment of goods and services [42]. More specific approaches have been developed for wastewater treatment [43]. Social impact assessment examines the attitudes and behaviors of the stakeholders (e.g., management, workers, communities) and their impact on the implementation of a WWTS [44]. The review [45] lists 25 criteria for assessing the social impact of a WWTS. Broadly, these criteria are related to internal factors (they are subject to direct control), such as management attitude (e.g., commitment to environmental issues, dynamic working environment, image return), workers' concern (e.g., in house expertise, social benefits), or community concern (local development responsibility) and to external factors. Examples for (not necessarily cultural) external factors [46] are regulatory issues (see institutional assessment), or incentives (availability of funding, non-economic stimuli, such as other support that may affect the easiness to access certain technologies). Human rights of workers at wastewater treatment plants matter, too, such as the rights under CESCR (International Covenant on Economic, Social and Cultural Rights) to safe working conditions and fair wages, working hours and leisure (art. 7), association and collective bargaining (art. 8), or social security (art. 9). The qualification of the workforce is an important aspect for the successful implementation of more complex technology, whence personal development and training of workers are considered as criteria.

Cultural issues are particularly important in decisions about reuse options [47]. Some authors recommend a holistic approach, considering environmental, economic, social, cultural and institutional factors that may shape the perception of stakeholders [48]. For instance, farmers choosing between recycled water or freshwater for irrigation may consider the costs, whence some farmers might be willing to use treated wastewater unless they must pay for it [49]. However, others might be concerned about health risks and not be willing to irrigate with treated wastewater, unless communication about the risks is improved, e.g., through awareness campaigns [50]. Concerns about health are also important aspects for consumers to accept treated wastewater for household uses, such as for cleaning the home or for toilet flushing [51]. Furthermore, the source may matter. For example, treated rainwater appears to be more acceptable for consumers than recycled water from other sources, although rainwater collected from roofs may be contaminated by bird droppings [52]. In the Tamil Nadu state of India there is a strong cultural preference for traditional (indigenous) technologies for rainwater harvesting and a popular movement for the revival of temple tanks for this purpose [53].

Thus, there are multiple sociocultural factors that may influence decisions about the use of treated wastewater. Examples from [54] are attitudes towards and priority of the environment, trust of authorities and knowledge, the recycling terminology used with the public, socio-demographic factors, political context, local history, or the degree of public involvement in strategy development. Stakeholders from industry could promote recycling by innovations, while stakeholders at the communities (residents, farmers, local business) may mobilize resources that may either drive or hinder recycling [55].

As shown in the seminal work of the late Nobel laureate Elinor Ostrom [56,57], institutional and management issues may be decisive for the success of public infrastructure projects. As [58] concluded, "*institutional and organizational issues are of high importance for the sustainable functioning of [...] natural treatment systems in India*". Water institutions are made up of three interacting components, law, policy, and governance. These components create norms, rules, and legal systems that affect the administration and management of water resources. The Institutional Decomposition Analysis [59,60] further distinguishes various aspects under each component (see Figure 1). Based on this framework, institutional assessment identifies the possible impact of policies and legal regulations (e.g., requirements regarding effluent quality, emissions, waste disposal, or personnel safety) and governance (e.g., complexity of bureaucracy and length of regulatory procedures to obtain operating permissions) at the national or state level. Key criteria are [61] clear institutional objectives, appropriateness of scales, capacity, adaptability, and interconnectivity.

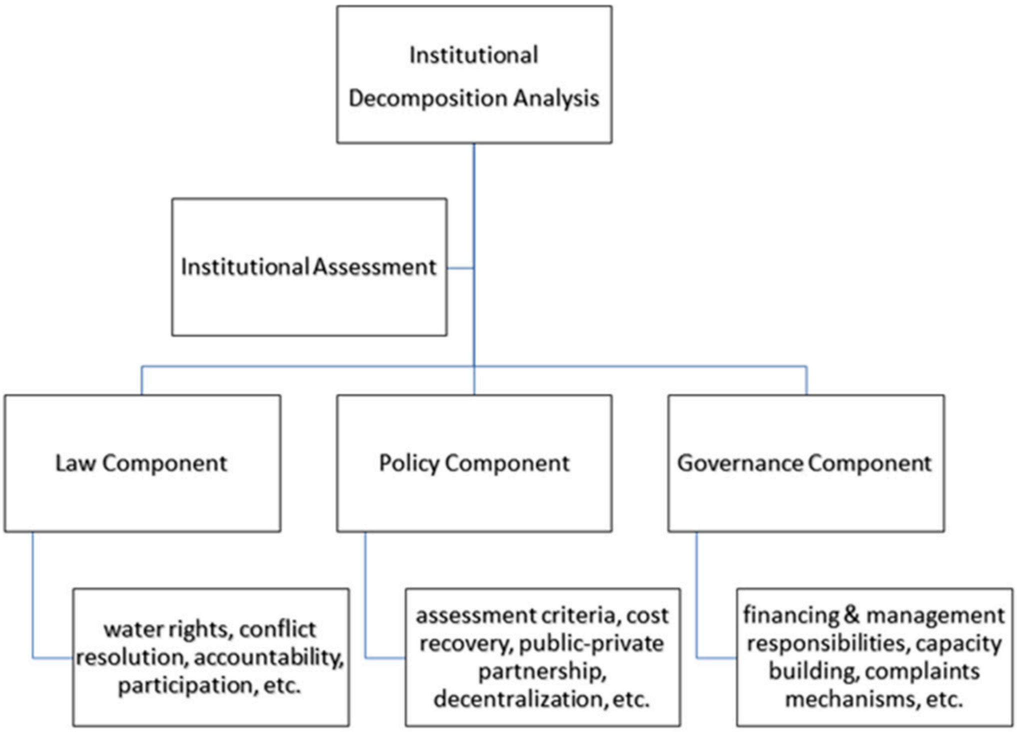

Figure 1. Framework for the institutional assessment.

Further aspects for institutional assessment are the availability of financing, the focus of funding programs, the interests of involved NGOs, and preferences of local stakeholders [2]. For instance, the following governance conditions were identified as essential for a successful upscaling of a water reuse project [62], as public acceptance for recycling would depend on these conditions. These are the availability of financial resources, awareness of a problem, the presence of a public forum, policy leadership, and coordination. For additional indicators for the assessment of (waste-)water governance, see [63,64].

Public participation [65] may promote better water governance. For example, in the USA, participation in public hearings is part of the regulatory process [66]. Participation did even result in better technical solutions, as citizens drew attention to otherwise not considered aspects [67]. However, a lack of political cohesion (meaning the tendency by individuals to connect with others, to participate in political and civic activities, and to trust in the mutual support in the case of a need) may be a barrier to participation.

2.4. *Aggregation*

In real world decisions, decision-making often boils down to a simple comparison of alternatives. Thus, the decision for or against a natural WWTS may depend on the availability of land. The decision for or against complex technology may depend on the availability of skilled workers. The choice between a centralized system, a decentralized system, or an on-site system (e.g., septic tanks) may depend on the availability of funds. In each of these examples, there was one criterion that was decisive.

In situations where several perhaps conflicting criteria matter, multi-criteria methods aim at a synthesis of different subject-specific assessments. Cost-benefit analysis did reach this goal through monetization, but this did not always result in satisfactory output. To allow for a more flexible weighing of the criteria, alternative approaches were developed [68]. The most common concepts are utility-based aggregations and outranking.

The simplest example of an aggregation is the weighted sum model [69], which first measures the utilities of the different alternatives with respect to the different criteria and then compares the alternatives by a weighted sum (nonnegative weights that add up to 1) of the criteria-utilities. To define reasonable weights, hierarchical approaches are used (the weight of a criterion is the sum of the weights of its lower-level criteria). Outranking methods are based on pairwise comparisons of the alternatives, which they input into a sort of election rule, as for the ELECTRE [70,71] and PROMETHEE methods [72,73].

One of the most popular methods for decision aid is the analytic hierarchy process (AHP) of Saaty [74]; a search in Google Scholar found more than 2×10^5 papers. In the following sense AHP combines the ideas of aggregation and outranking. It defines the criteria weights (and if needed, also the utilities of alternatives) by outranking: Pairwise comparisons of n criteria (at the same level of the hierarchy) are qualified from 1 to 9 (times important) for equal importance to much higher importance, and by the reciprocals for lower importance. This defines a pairwise comparison matrix (dimension n) with a largest positive eigenvalue λ_{max} ($\geq n$). Its eigenvector (scaling: nonnegative components that add up to 1) defines quantitative criteria weights. These are used for an aggregation that defines a ranking of the alternatives and the identification of the most important criteria.

As for another notable feature, AHP is capable of handling contradictory information, whereby the consistency ratio CR of Equation (2) defines a measure for the inconsistency of the qualitative assessments:

$$CR = \left(\frac{\lambda_{max} - n}{n-1}\right) / RI \tag{2}$$

In Equation (2), the numerator is a consistency index, CI, and the denominator, RI, represents the expected value of CI. The paper [75] summarizes research on CR. For instance, using a different scale (instead of 0 to ± 9) may result in more consistent responses.

3. Discussion

3.1. Cost Issues

Cost uncertainty is a major issue for life cycle cost analysis [76]. The actual assessment and aggregation of costs is far more flexible than Equations (1) and (2) would suggest. This discussion points out several common sources of cost uncertainty.

In general, capital costs for a complete system are known well from the public tendering procedure, but the real costs and the expected lifetime of the system components may remain unknown or be disregarded. As an example for the latter case, certain capital costs may be irrelevant for tendering, but ignoring them may result in a biased comparison of different technologies. Thus, if a system is built on public land, alternative land uses should also be considered (e.g., revenues from selling the land at market prices), as otherwise there may arise a bias against compact solutions.

Often, systems are tendered as a package (including e.g., assembly, installation, and perhaps several years of operation), and lifetime and future maintenance and replacement costs of components remain unknown. This may result in unrealistic estimates for lifetime costs (*NPV*, *EAC*). Public-sector customers could reduce such cost uncertainties by cooperation, building up and maintaining a database of current costs of existing technologies and their components. (Older systems may be included, too, using price indices to adjust costs.) The database may also be applied to obtain cost estimates for different technologies in relation to scale. (A simple approach uses nonlinear regression and fits power functions to the observed per capita costs.) To obtain reasonable estimates for such unit costs, under and over utilized systems should be disregarded. Furthermore, all compared systems should be at the state of the art, delivering about the same quality of treated wastewater.

For running costs, systems at different locations are more difficult to compare. For instance, hourly rates for professional service personnel may differ widely (c.f. rural systems vs. peri-urban systems). While the unit costs for chemical and biological additives and for cleaning and maintenance tools are transparent (price lists), in general, the quantity of used additives may depend on local circumstances (e.g., ratio of vegetarian vs. non-vegetarian users).

For subsidies to running costs (e.g., for electricity) there is always the risk that due to political changes they will be terminated on short notice. Furthermore, subsidies may differ regionally, which may distort cost comparisons for the above-mentioned database.

A notable variability for cost estimation is caused by different methodological approaches towards aggregation (*NPV*, *EAC*). The parameters for aggregation (T, d) in general are taken from guidelines. These guidelines may also instruct how to handle the residual value of the system (as it may still be operating after time T has passed); some guidelines disregard it [40]. Another methodological difference is between deterministic and stochastic aggregations. For instance, considering replacement only: a deterministic approach assumes a certain lifetime, LT, for a certain system component purchased at a certain price, p, and it defines a time-series of payments for the planned replacements of this component: $p_i = p$ at times $t_i = i \cdot LT$. A stochastic approach assumes that lifetime $(t_{i+1} - t_i)$ is a random variable (e.g., exponential distribution) with mean LT. In this case, Monte-Carlo simulations of (random) lifetimes allow for the estimation of average costs.

3.2. Affordability Issues

For municipal WWTS, the capacity of the beneficiaries to pay for the service provided by the technologies may be low. Therefore, the consideration of affordability may lead to politically sensitive decisions, particularly for poor neighborhoods. Already the question, if users should pay at all for water and sanitation is an issue of the political debate. If poverty is a reason to deny services, there arise concerns about environmental justice. Funding institutions in the past might have put too much focus on better-off neighborhoods, because they were more likely to comply in cost sharing [77]. This could have resulted in eco-racism, where certain populations (identified by race or caste) were denied public support for resolving their environmental problems [78].

As studies in South Korea have suggested, about 48% of the costs of expanding and modernizing WWTS could be covered by considering the social benefits [79]. Furthermore, the sale of products of the WWTS, or their use within the WWTS (generation of electricity from biogas), may reduce running costs and users' cost shares [80]. In rural areas, recycling of (treated) sludge may be an economically and environmentally sustainable option, as rural sewage contains fewer harmful pollutants (e.g., heavy metals) than municipal sewage [81]. In rural areas, food production in constructed wetlands for wastewater treatment is an option, too [82]. However, sometimes the resulting cost offsets are negligible [83]. Therefore, the market for such products needs to be analyzed, including the willingness to pay (e.g., of farmers for recycled wastewater for irrigation). An issue of current research is the pricing of treated wastewater. When it is implemented, it should take care of the interests of the consumers [84]. For instance, a rebate after installing recycling plants may motivate housing and apartment complexes to use recycled wastewater. Moreover, consumers lacking piped water services may consider treated wastewater as an alternative option.

Questions of affordability may also affect the choice of the system [85] and the mode of its financing: if capital costs are not fully funded, should households pay connection charges to contribute to the capital costs or should they pay higher water taxes instead? In the first case, should they pay in cash or in kind (labor)? Could they qualify for micro credits? Should poor households that cannot afford water or sanitation services be connected if the other households can pay more? Socio-economic studies may aid this decision-making, but the obtained information may not be accurate. Thus, responses to surveys about income, expenditures, and willingness to pay may be strategic, pretending poverty or prosperity, depending on the interest on the WWTS. Also, in rural or peri-urban areas typical sample sizes are small, while willingness-to-pay studies require large samples, resulting in a broad margin of statistical uncertainty.

Further, the capacity of households to pay is not evenly distributed, not even in slums. The cumulative distribution function for this capacity, $CDF(x)$ is the fraction of households that can afford to pay at most x, e.g., for a sanitation tax. If it is assumed conservatively that users pay nothing, if they cannot afford the prescribed (nominal) tax, while users that could afford more do only pay the nominal tax, then the expected revenues per household, $r(t)$, from a prescribed tax, t, are computed from Equation (3):

$$r(t) = t \cdot (1 - CDF(t)) \quad (3)$$

Using this approach, a revenue maximizing tax may be estimated [77]. However, owing to the above-mentioned uncertainties, different distribution assumptions about *CDF* may be used for modeling. While the optimal tax, t, does not seem to depend strongly on the distribution function, if different distributions are fitted to the same data, the expected revenues per household may vary widely and remain way below the nominal tax [80].

3.3. Social and Institutional Issues

Already [86] has suggested that that water supply and environmental sanitation initiatives need to be evaluated based on their efficiency and sustainability including how they are influenced by socio-cultural norms and the environment. As [87] noted, communities lack motivation without demand, but they may lack demand without education and awareness, while successful project implementation requires awareness, motivation, maintenance, cost recovery and continuing support of local communities. Case studies in Thailand about constructed wetlands have confirmed the importance of the socio-cultural dimension of sustainability. Based on interviews with key stakeholders, questionnaires, and household surveys, ref. [88] could explain differences in the sustainability by different public perceptions, awareness, local expertise, and institutional roles.

In response to the complex interaction between multiple pressures on aquatic ecosystems, UN Water [89] has called for integrated approaches in water management. With respect to wastewater management this requires a coordination of different water treatment sectors (e.g., industrial, communal), whereby also different aspects of water protection (e.g., surface water pollution, ground water depletion), water use (e.g., municipal, agricultural, industrial) and water saving and recycling (e.g., rainwater harvesting for groundwater recharge, irrigation with treated wastewater) need to be considered. Institutional structures may be overtasked with integrated water management if the expertise for these issues is split over different administrative departments [90]. But an accumulation of responsibilities may be counter-productive, too. Often central authorities end up with too many responsibilities, which they are unable to meet, while local authorities are unable to take over because they might not have the mandate and the needed resources. Furthermore, officials at the central level may not always understand and represent the interests of the users. For these reasons, decentralization has become an important element of the discourse on (waste-)water governance [91]. Many studies in the Indian [92,93] and the international context [94] have examined the functioning and acceptability of small-scale decentralized units. Thereby, successful implementation of decentralization requires certain institutional settings [95,96], such as a supportive environment, the capacity to mobilize adequate resources (running costs, costs for emergency repairs), fair cost sharing, and effective institutional arrangements (including accountability of officials to the users). Wastewater reuse is another challenge for good governance. As illustrated in [97], here the critical conditions that support recycling are leadership, water availability, water pricing, regulations, and business savings.

In view of the above-mentioned difficulties, different countries have tried different institutional settings for their (waste-)water management.

- Israel (though not a developing country) has been a pioneer in water technology (e.g., desalination) and utilization (e.g., recycling of wastewater). Water resources are a public property under control of the state and the Water Authority overlooks all aspects of management, including water allocation [98]. The state has implemented large water reuse systems that provide treated wastewater to the agricultural sector [99]. Therefore, a good quality of the recycled water is deemed as essential for the protection of the water resources [100].
- In South Africa, water resources are public property, but temporary licenses may grant rights of access to water. Decentralization of water governance is established through catchment management agencies [101]. Although the country aims for a smart water management approach (water conservation, demand management, water reuse, etc.), service has remained suboptimal, leading to public protests [102,103].
- In Bolivia, the Cochabamba Water War of 2000 has pushed decentralization [104]. Water resources management is mainly communal, place-based, and adjustable in time and space, whereby owing to a lack of a formal legal framework, water for irrigation is basically managed by the users' communities based on customary laws [105,106]. Wastewater treatment remains problematic, resulting in the discharge of untreated wastewater into rivers and the re-use of this polluted water for irrigation, degrading the quality of surface water and groundwater [107,108].
- In India, each state translates the national water policy into state water policies. States are responsible for the planning, implementation, funding, and management of water resources development. Water quality is an important component of the national water policy, and the polluter pays principle is applied. However, enforcement remains deficient. For instance, downstream of Hyderabad the water of the Musi River *"constitutes a mixture of partially treated and untreated wastewater"* [24,109]. Owing to the lack of adequate infrastructure to collect and properly treat wastewater, the use of river water in agricultural irrigation (the prohibition of river water use was not effectively enforced) has created health risks for farmers and for consumers of raw crops.

3.4. Multi-Criteria Issues

A theoretic weakness of multi-criteria approaches is the lack of "*indicator sets . . . backed by compelling theory, rigorous data collection and analysis*" [110]. Therefore, in the context of wastewater management, a planning-oriented sustainability assessment framework (POSAF) has been developed [111]. This approach uses multi-criteria decision aid, such as AHP, to facilitate the consensus-finding by the relevant stakeholders. Thereby, based on a pool of common criteria, AHP was used to identify the criteria weights of each stakeholder. This information was further processed by data-mining methodology, social network analysis [112], and related mathematical tools to identify and characterize clusters of stakeholders with similar preferences. This information then helped to identify conflicting interests at the local level, and it thereby aided planners in seeking solutions that would be acceptable to all relevant groups.

The experience of the authors with surveys of different groups has shown that health and pollution have mattered most to the stakeholders of a WWTS [113]. Surprisingly, in poor areas of developing countries, costs did not matter much for the users. However, there was a simple explanation, as they wanted the government to pay.

4. Conclusions

Experiences with the applications of different approaches towards sustainability assessment have led to attempts towards a standardization of sustainability assessment. Examples are the ISO Guide 82 of 2014 about sustainability, or the standard ISO 13065 of 2017 about sustainability criteria for bioenergy. Such standards may promote the implementation of innovative and more sustainable technologies [114]. However, while international consensus on key principles, sustainability indicators, and methods to measure these indicators may be possible, concrete thresholds remain controversial [115]. Among the reasons are the continued divergent interests and perceptions of industrialized and developing countries. Industrialized countries could afford standards that use the performance of the best available technologies (BAT) as a model to define sustainability. In developing countries, a major challenge is the rapid increase of demand for (waste)water services due to a growing population and increasing industrialization, whereas the public budgets remain limited. They would need low-cost solutions that nevertheless ensure that wastewater is adequately treated and can be recycled, as otherwise natural resources may become polluted or depleted.

This means that while the sustainability criteria are generally accepted, there is no generally accepted definition of sustainability. Such a general definition may not even be desirable, as this could prevent further evolution of the very concept of sustainability. Such a definition could even be misleading, as may be suggested from the fate of the narrow notion of economic sustainability based on a cost-benefit analysis. To give a specific example: Infant death due to childhood diarrhea is a common consequence of inadequate sanitation. The costs to treat it are relatively low [116]. Furthermore, there are barely indirect costs, as children do not contribute to household income. Could this finding justify the conclusion that wastewater treatment infrastructure would be too expensive [117] and that it would be more sustainable to spend for health education?

For planners of a WWTS, this means that, depending on the circumstances, certain economic criteria, such as affordability for the users, and technical criteria, such as the flexibility of the system and the prospect of future upscaling, may be more important. Consequently, planners aiming at sustainable solutions may use some of the general principles and indicators discussed in this paper and adapt them to the local context, as recommended by POSAF [111]. In a survey of experts, this view was shared by a core cluster [115], who asked for demand-driven planning with consideration of the local situation, cultural factors and affordability. Planners who do not share such views about planning may put more emphasis on the monitoring to ensure the proper functioning of a WWTS.

Author Contributions: All authors contributed equally to the paper. Conceptualization, methodology, investigation; data curation, writing (original draft, review and editing), and visualization all authors, software, formal analysis, supervision, and validation not applicable. Resources, project administration, and funding acquisition part of existing project. All authors have read and agreed to the published version of the manuscript.

Funding: The research was conducted under the collaborative project 'Identifying best available technologies for decentralized wastewater treatment and resource recovery for India (SARASWATI 2.0)'; co-funding from the European Commission within the Horizon 2020 Framework Programme (grant agreement number 821427) and from the Government of India (Department for Science and Technology and Department of Biotechnology, Sanction order DST/IMRCD/India-EU/Water Call2/SARASWATI 2.0/2018(G)) is gratefully acknowledged.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: The authors appreciate the insightful comments by the academic editor and four reviewers that helped to substantially improve this paper.

Conflicts of Interest: The authors declare that they have no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

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