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# Decentralized Wastewater Management in India: Stakeholder Views on Best Available Technologies and Resource Recovery

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**Abstract:** Three workshops with representatives of stakeholders from academia, business, civil society and government in India were organized in Chennai, Kolkata, and Mumbai with the aim to identify and elaborate on key barriers to resource recovery in wastewater treatment (WWT). A structured questionnaire was designed to capture the views of participating stakeholders. Using a new *Mathematica* function, namely, *Around*, the responses of the representatives of each stakeholder were aggregated to an approximate number representing that stakeholder's view. Overall, the stakeholder consensus on WWT technologies was rather conservative, with a focus on the functioning of WWT. Concerning the drivers and barriers for resource recovery and policies to support the implementation of recycling technologies in WWT, stakeholders expected government action to drive recycling. A social network analysis identified potential conflicts between the stakeholder groups.

**Keywords:** *Around* function; best available technology (BAT); social network analysis; logistic regression; resource recovery; urban local bodies (ULBs); wastewater treatment (WWT)

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## 1. Introduction

Decentralized wastewater management and resource recovery play an important role in achieving sustainable sanitation services. In the Global South, technologies have often failed for various reasons. For instance, literature mentioned planning that did not consider the priorities of users, operational failures resulting from insufficient maintenance or other mishandling of technologies, and "improved technologies" that nevertheless caused hygienic risks.

The project Saraswati 2.0 (details in the Funding section) is therefore piloting candidates for best available technologies (BATs), whereby it uses a flexible approach in defining the BAT, as proposed in Starkl et al. [1]: it identifies reference plants amongst the existing ones (in India) that inform about the achievable quality of the treated wastewater with respect to environmental and hygienic indicators, the costs of the plants (affordability) and their social acceptance (e.g., working conditions). According to the hypothesis underlying this research, aiming at the implementation of a "flexible BAT" in the water sector may help in achieving Target 2 of Sustainable Development Goal 6 (by 2030, achieve access to adequate and equitable sanitation and hygiene for all and end open defecation, paying special attention to the needs of women and girls and those in vulnerable situations). However, the definition of the BAT ought to be flexible insofar as it should consider what can be achieved given the site-specific and the general economic, social and institutional constraints.

As part of this study about institutional and governance aspects, workshops were conducted in Chennai (Tamil Nadu), Kolkata (West Bengal) and Mumbai (Maharashtra). The topic was the implementation of technologies for decentralized wastewater treatment (WWT) and resource recovery in India. Institutions from these states with an interest in this topic were invited to take part. The workshops started with presentations about certain technologies that were piloted in these cities, explaining the motives for their choice, including the criteria of technology selection and the concept of BAT in relation to standards. The focus was on possible barriers and drivers toward more resource recovery (treated wastewater for irrigation or toilet flushing, digested sludge for soil amendment or as a fertilizer, biogas for cooking or other purposes). At the end of the workshops, in total, fifty participants from 26 organizations (each took part in one workshop only), filled in a questionnaire with ninety questions about potential criteria for the selection of technologies, the feasibility of BAT in the Indian context and perspectives for resource recovery. The data are available in the Supporting Information.

We expected that the stakeholder views would inform us about their support for implementing the BAT; their views on legal thresholds and standards; and their views on the relative importance of criteria for the selection of WWT technologies in relation to economic, social and institutional issues (e.g., financing infrastructure for the poor). The focus was on resource recovery: Should it be used as a criterion in technology selection? What were the most important drivers for and barriers to implementing more resource recovery in WWT?

As a note on methodology, we developed a new aggregation to transform the views of the respondents coming from the same stakeholder organization into a "stakeholder view". For instance, other than in Carifio and Perla [2], we did not consider whether Likert scales were interval or ordinal scales. Rather, we interpreted them as imprecise numbers and aggregated these numbers. Further, we conducted a social network analysis to identify possible conflicts between different stakeholder groups; c.f. Lienert et al. [3].

## 2. Materials and Methods

### *2.1. Data*

The questionnaire was structured as follows. The question numbers (#) refer to Tables A1 and A2 in the Appendix A. More detailed informationis provided in a supporting information.

(A) General questions: these questions included inquiries about the background of the stakeholders (#4–9) and their views toward the concept of the BAT (#10–13).
(B) Questions related to technology selection (#14–43): the perception of stakeholders regarding the importance of criteria used for technology selection, the importance of options for resource recovery and the views about standards were inquired about.
(C) Questions related to financing (#44–46): as financing in the wastewater sector has been identified as a key barrier in India (the authors have pointed out this repeatedly), the views of stakeholders toward financing capital and operational costs for wastewater treatment technologies were inquired.
(D) Questions related to existing drivers for recycling (#47–56) and policy aspects that may be future drivers (#70–87): the views of stakeholders toward existing and potential driving forces to enhance the implementation of resource recovery for wastewater management across India were asked for.
(E) Questions related to barriers to recycling (#57–69): these questions focused on the task in question regarding identifying and elaborating key barriers for resource recovery.

Figure 1 tallies the respondents and stakeholders by their background. The fifty participants came from 26 stakeholders: civil society organizations (NGOs), academic institutions, municipal or state government, and private sector companies (business). At all the workshops, respondents from the government formed the largest groups. Respondents confirmed that their organizations were interested in different WWT technologies in the context of approval, selection or research (questions #5 and #9), whereby approval only interested a minority (#6). Rather, most stakeholders were interested in the selection of WWT and research about WWT technologies (#7, 8). Further, most stakeholders were interested in WWT technologies and standards, and they knew of the BAT (#4, 10, 39).


(**a**) Composition of the respondents (**b**) Composition of the stakeholders

**Figure 1.** Characteristics of the sample.

### *2.2. Using the Around Function*

Although the questionnaire asked about the preferences of the stakeholders ("In the view of your organization") rather than about the personal views of the respondents, responses from the same institutions differed (there were up to six responses from the same organization; we expected them not to be independent). Thus, a naïve statistical analysis of the fifty questionnaires could result in misleading statements about the institutions and it could result in false estimates for significance. For instance, in Kolkata, there were two academic institutions with different involvement in technology selection, but the higher number of participants from one institution generated a bias about the interests of academic institutions. To overcome this issue, all responses from the same institution were aggregated into a "stakeholder view". As such, responses were already coded numerically. For most questions, the responses were coded using Likert scales, such as "highly agree" (1), "agree" (2), "disagree" (3), or "strongly disagree" (4). We were interested in whether the stakeholders would rather agree (1 or 2) or disagree (3 or 4). The obvious candidates for the aggregation were the median and the mean. For example, consider a stakeholder with five respondents that answered {1, 2, 2, 4, 4} on a Likert scale. Did this mean that the organization would rather agree or disagree? The answer was dependent on which threshold $T$ between 2 and 3 was preset, say $T = 2.5$. Then, for the above sample, the median (2) indicated agreement and the mean (2.6) indicated disagreement. However, both aggregations assumed a precision that was not warranted. We, therefore, chose a different approach.

To aggregate the different responses coming from the same stakeholder institution into a "stakeholder view", we applied the *Mathematica* 13.3 [4] function *Around*. It was introduced in 2019 and updated in 2023. Given a sample of numbers, it defines an approximate number, $x = m \pm s$, as the mean value $m$ of the sample together with its standard deviation $s$ as a measure for uncertainty. In computations, uncertainties are propagated using a first-order series approximation, assuming no correlations. Here, we were interested in inequalities: the inequality $x < r$ is true for a real number $r$ if $m + s \cdot \sqrt{2} \leq r$. Further, $x > r$ is true if $m - s \cdot \sqrt{2} \geq r$ (and false, otherwise). We used this function to aggregate, for each stakeholder, the responses $\{r_1, r_2, \ldots\}$ of its representatives to $x = Around\,[\{r_1, r_2, \ldots\}]$. We then recoded the results as follows.

(1) For responses using a Likert scale with four degrees, the imprecise number $x$ was coded as "+1" (the stakeholder would rather agree) if the statement $x < 3$ was true, as "−1" (would rather disagree) if $x > 2$ was true, and as indeterminate (code "0") otherwise. As we used the largest and smallest thresholds possible, this removed the arbitrariness in the selection of thresholds.

(2) For responses that ranked the alternatives from the most to the least preferred (rank 1 = best), we were interested in whether the stakeholder would have ranked the alternative high or low. For each stakeholder, we aggregated the rankings of its representatives to give an imprecise number $x$. We coded the response as "+1" (would rather select high) if $x < 3$ (five or six alternatives) or $x < 4$ (nine alternatives). We

coded the response as "−1" (would rather select low) if $x > 3$ (five alternatives), $x > 4$ (six alternatives) or $x > 6$ (nine alternatives). Otherwise, the answer was recorded as indeterminate (code "0").

(3) For yes/no questions (coded as 1 or 0), we aggregated them to give an imprecise number $x$ and recorded "+1" or "−1" (would rather select yes or no, respectively) if $x > 0$ or $x < 1$ was true, respectively. For questions offering multiple non-exclusive alternatives, we recorded in this way if the stakeholder would have rather selected an alternative or not.

Open-ended responses were not coded. They clarified and commented on previous responses. Further, for all aggregations, we ignored "NA", meaning "no answer", or "NB", meaning "do not know" (In *Mathematica*, it was replaced by *Nothing*). In the trivial case where all responses were "NA", the outcome of any aggregation would be indeterminate. The novelty of our aggregation was an indeterminate outcome also in non-trivial cases.

For the above sample {1, 2, 2, 4, 4}, the outcome of the aggregation was $x = 2.6 \pm 1.3$ and it was coded as indeterminate, as neither $x < 3$ nor $x > 2$ were true (however, imprecise numbers did not always result in "indeterminate"). We did not consider the case where both $x < 3$ and $x > 2$ were true (again: "indeterminate"), as owing to the discrete character of our data, this case did not occur (the standard deviation of a sample with six or fewer integers was either $s = 0$ or $s \geq 1/\sqrt{6}$; in the first case, $x$ would be an integer, making $2 < x < 3$ impossible, while in the second case, $2 < x < 3$ would imply $s \leq 1/\sqrt{8}$, whereas $s \geq 1/\sqrt{6}$).

### 2.3. Analysis

In view of the small sample size, for the interpretation of the survey outcomes, we did not further differentiate between the 26 stakeholders (e.g., background, city). Further, questions 57 to 69 about the implementation of new technologies were asked in relation to the pilots that were different for each city, while the answers given suggested that the respondents took the questions as general. Therefore, we pooled these responses too.

Moreover, we used the exact Clopper and Pearson confidence intervals, as these are conservative (the confidence level is higher than stated) and suitable for small samples (according to Reiczigel [5], it is suitable for sample sizes up to $n = 1000$). In *Mathematica*, we computed them as follows, using a two-sided $p$-value = 0.05 (95% confidence level):

```
clopperpearsonlow[samplesize_, success_, pvalue_] =
If[success == 0, 0, 1–InverseBetaRegularized [1–pvalue/2, samplesize–success + 1, success]]
clopperpearsonup[samplesize_, success_, pvalue_] =
If[success == samplesize, 1, InverseBetaRegularized [1–pvalue/2, success + 1, samplesize–success]]
```

For a stakeholder analysis, we first defined a graph that linked the stakeholders (the vertices) with similar views with undirected edges. In *Mathematica*, the graph was computed with the command *AdjacencyGraph* using an adjacency matrix (c.f. Godsil and Royle [6]), whose components were defined as $a_{m,n} = 1$ for linked stakeholders $m$ and $n$, and $a_{m,n} = 0$ otherwise.

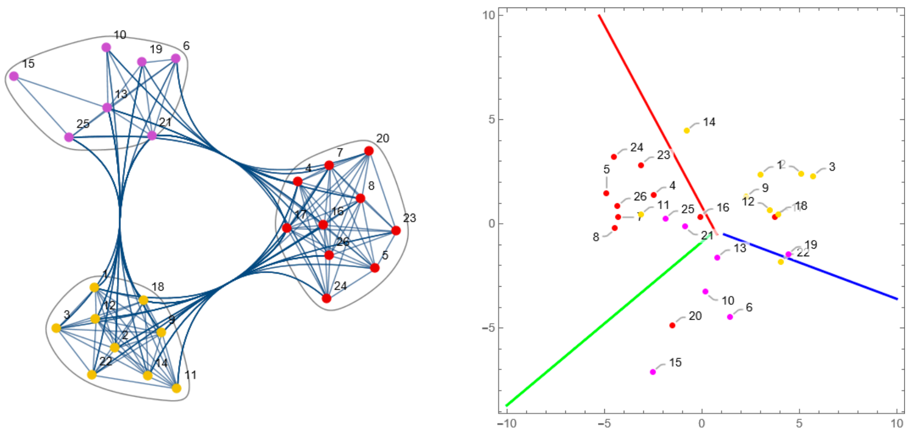
"Similar" meant significantly ($p$-value > 0.05) positive correlations between the coded stakeholder views. As such, we removed irrelevant questions. Thus, we did not consider questions #1–6, as they did not inquire about views, and we removed #12 and 14, as all answers were "yes" (+1). Still, there remained 79 questions, resulting in a vector for each stakeholder, where the 79 components ±1 or 0 were the coded views. For them, we tested different definitions of "correlation". For example, using Hoeffding's dependence measure $\boldsymbol{D}$, see Wilding and Mudholkar [7], resulted in a graph with five isolated vertices (19% of stakeholders). This meant that using $\boldsymbol{D}$, we could expect that up to 39% of stakeholders might be classified as idiosyncratic (using the upper limit of the Clopper–Pearson confidence interval at 95% confidence). As we considered this unrealistic, we disregarded $\boldsymbol{D}$.

Next, we searched for a partition of the stakeholders into groups with many links within the groups and few links between the groups. The search for the best partition is a well-known problem of discrete optimization, known as the problem of "modularity maximization". It is believed to be NP-hard; see Brandes et al. [8]. However, the command *FindGraphCommunities* of *Mathematica* offers several search strategies to find reasonable (close to optimal) solutions for this discrete optimization problem. Given an adjacency graph defined from a certain definition of "correlation", we checked them all. Very often, the strategy *VertexMoving* provided reasonable results. The idea behind this algorithm can be found in a preprint of Goerke et al. [9]. For example, using the Blomqvist beta as a definition of "correlation" (see Schmid and Schmidt [10] for generalizations) and using the *VertexMoving* strategy resulted in a partition of the stakeholders into two groups of equal size. However, we refuted this outcome, as we could not clearly distinguish the stakeholder groups in terms of their stated preferences (we could not determine which statements were accepted/rejected by all stakeholders of one group, but not by all stakeholders of the other group).

The most suitable combination for our purposes was the Spearman rank correlation, together with the *VertexMoving* strategy, resulting in three clusters of stakeholders (note that 79 questions were a sufficient sample size for using Spearman rank correlation, see Bonett and Wright [11]).

We also compared the error rate from our characterization of the stakeholder groups by stated preferences with the error rates from machine learning methods. Thereby, we first applied a traditional statistical method for detecting differences between stakeholders, namely, principal component analysis based on Jolliffe [12]. Given the matrix of correlations between each pair of stakeholder responses, it identified a coordinate transformation so that the maximal variation in correlation values occurred in the first dimension, followed by smaller variations in the second dimension (*Mathematica* employs it as one of its options for the function *DimensionReduction*). For our data, the responses of the stakeholders defined 26 vectors (one for each stakeholder) in a vector space of dimension 79 (considered responses). We used this method to reduce the data to dimension two.

Then, we applied a method of pattern recognition to characterize the stakeholder groups from these two-dimensional data. The *Mathematica* function *Classify* learns from given classifications of clusters, offering various options. We applied it to the three clusters of stakeholders in two-dimensional space using logistic regression based on Agresti [13], which is amongst the simplest methods of pattern recognition and defines neat geometric regions to localize the clusters (see Figure 2b).



(**a**) Community graph. (**b**) Dimension reduction and classification of data.

**Figure 2.** Stakeholder analysis. (**a**) Community graph computed from an adjacency graph (stakeholders as nodes and ties linking stakeholders with significantly positive Spearman rank correlated responses). (**b**) Illustration of the communities using a dimension reduction by means of a principal component analysis of these responses (class 1 yellow, upper right; class 2 red, upper left; class 3 magenta, bottom; colored lines indicate the same probability to be classified in one of the neighboring classes).

Finally, we checked the stability of our results. As we defined the ties between stakeholders by 95% significant associations, up to 5% (16 of potentially 325 links) might have been spurious (falsely "significant" by chance only). To explore their impact, we altered the adjacency graph at random (to simulate spurious outcomes) and repeated the identification of classes. Using 1000 simulations, we then identified stakeholder pairs that were in the same group for at least 950 simulations.

## 3. Results and Discussion

### *3.1. Outcomes of the Questionnaires*

#### 3.1.1. Overview

Tables A1 and A2 in the Appendix A summarizes the aggregated outcomes from 26 stakeholders about the 84 questions that could be coded. Recall that for each stakeholder, the outcome was an imprecise number that collected the answers from the persons that came from the respective institution. These numbers were then interpreted as "yes", "no" or "indeterminate". Amongst 2184 responses (26 stakeholders each responded to 84 questions), 1128 questions were answered with "yes" or with "high rank" (coded as +1), 330 questions with "no" or "low rank" (coded as $-1$), and 726 answers were indeterminate (coded as 0). This defined, for each question, a sequence of 26 values $\pm 1$ or 0.

The stakeholder responses were in general affirmative. However, we could detect differences in the strength of approval. In the following, we discuss the outcomes in the order of uncertainty, starting with the least contested outcomes.

(1) We noted "unanimous yes" for two questions (#12 and #14 in Tables A1 and A2).
(2) Next, we considered significant absolute majorities (strongly yes or no), where the lower confidence intervals for approval/high rank or disapproval/low rank, respectively, were 50% or higher. There were two questions with "strongly no" (#5 and #9) and 16 responses were "strongly yes".
(3) We then identified the significant relative majorities, where 50% or more of the stakeholders agreed about "yes" or "no" and the confidence intervals for the percentages of "yes" and "no" were not overlapping. We denoted these outcomes as simply "yes" (24 questions) or "no" (one question: #6).
(4) For nine questions with a 50% majority for "yes" or "no", there were overlapping confidence intervals with "no" or "yes", respectively. We highlighted these questions for potential conflicts as "CF/Yes" (seven questions) or "CF/No" (two questions: #8 and #43). Not all CF questions may generate conflicts. To find out which ones were problematic, we conducted a further stakeholder analysis to assess the conflict potential between the majority and a potentially large minority.
(5) If there was no 50% majority but the confidence intervals for "yes" and "no" were not overlapping, we denoted the significantly more frequent outcome by "Rather Yes" or "Rather No". There were four "rather yes" responses.
(6) For the remaining questions, we reported "perhaps yes" or "perhaps no" if the outcome was net positive or net negative, respectively (i.e., the average of the sequence was positive or negative). There were nine questions with net-negative outcomes and 16 responses were net positive.
(7) There remained one indeterminate (net zero) response (question #35).

For comparison, we also applied the *Around* function and aggregated the responses to imprecise numbers. A sequence of 26 coded stakeholder responses of $\pm 1$ s and 0 s defined an imprecise number $x$, which we interpreted as approval for $x > 0$ and as disapproval for $x < 0$ (otherwise: "indeterminate"). All approvals and disapprovals were unanimous or with a significant absolute majority. Conversely, there was one "strongly yes" answer (#4), where the imprecise number indicated an indeterminate outcome. In view of this strength, for the stakeholder subgroups, strong yes/no outcomes were defined by *Around*.

#### 3.1.2. Technology Assessment

With 100% approval, stakeholder organizations considered a flexible BAT as suitable (question #12). This concept was introduced by Starkl et al. [1]. Further, they deemed environmental impact as an important criterion for WWT technology assessment (#14).

With a significant absolute majority, the BAT was deemed as important (#11). Amongst the selection criteria, stakeholders deemed costs, acceptance by users, ease of operation and health as important (#14–18). Further, they confirmed the importance of the environment with a high rank (#20). Recycling wastewater for toilet flushing was considered an important feature of WWT (#27).

With a significant relative majority, recycling was deemed as important and the criteria costs, ease of use and health were highly ranked (#19, 21, 23, 24). The reuse of treated wastewater for irrigation, digested sludge and biogas was deemed to be important and the rankings of recycling treated wastewater for irrigation and toilet flushing were high (#26, 28, 29, 31, 32). For irrigation, this outcome confirms previous studies of the authors. Further, according to Ijoma et al. [14], there is a high potential for electricity production from biogas. Responses to the open-ended questions suggested that treated water may be used for other domestic purposes too (e.g., washing), and may be used for industrial applications and groundwater recharge. In Tamil Nadu (Chennai), groundwater recharge is highly accepted; see Brunner et al. [15].

For several questions, we noted the possibility of a strong minority opposing the majority views (CF in Tables A1 and A2). Possible conflicts may arise about the majority views, that the enforcement of water quality standards in India was lenient (#43), or that existing WWT technologies used in India were the BAT (#13). Another CF response suggested that the recycling of biogas ought to be a high-ranking priority for WWT (#34).

As for the next weakest level, user acceptance as a criterion for technology selection was ranked rather high (#22), and the reuse of digested sludge was ranked as a rather important feature of WWT technologies (#33).

At the weakest level of approval/disapproval, recycling as a criterion for the selection of WWT technology was ranked low by more stakeholders than ranked high (#25).

Further, most questions about the standards achieved only this weak level of approval. Thus, there were more yes than no responses to the suggestion of adding certain pollutants to the existing standards (#37), more suggested not to keep standards as they are (#38) and not to remove pollutants from standards (#39). Owing to indeterminate responses, answers to thresholds appeared contradictory: More stakeholders suggested not to keep the current thresholds for standards (#41), but not to relax the thresholds (#40) and not to sharpen them (#42). Further net-positive responses deemed that "other criteria" were important and of high rank (#30, #35).

Therefore, answers to the open-ended questions with respect to standards referred to norms and guidelines from the Central Pollution Control Board, Central Public Health and Environmental Engineering Organization, National Green Tribunal, and regulations at the state and municipal level. Some suggested more flexibility in relation to the situation of the receiving rivers and suggested norms for digested sludge. There were concerns about bacteriological aspects (fecal coliform, E-coli, helminth eggs), nutrient loads and organic pollution (biological/chemical oxygen demand, nitrogen, phosphate, total organic carbon, oil and grease), other frequent pollutants (arsenic and other heavy metals, sulfate) and emerging pollutants (e.g., pharmaceutical residuals, microplastics).

Question #35 about the ranking of "other" reuse options had indeterminate results.

#### 3.1.3. Drivers and Policies for Recycling

A significant absolute majority of stakeholders approved of making recycling mandatory, penalizing ULBs that do not care about recycling, letting Union and state governments subsidize the ULBs, providing more international technical assistance, and increasing awareness and capacity building (#70–73, #75, #77, #78). The view about mandatory recycling was supported by a high ranking (#79). The proposed combination of government subsidies with "soft" support (increasing awareness and capacity building) is a traditional approach to Indian water policy, but stakeholders apparently realized that selective control is also needed to ensure successful funding (see Brunner et al. [16]), such as obligations for beneficiaries and enforcement (penalties).

A significant relative majority of stakeholder organizations considered that the Union government, the state governments and the ULBs would drive recycling; the stakeholders ranked them high too (#47–49, #52–54). As for policy instruments toward more recycling, most stakeholders considered loans by international donors as suitable and they ranked subsidies by the Union and the state governments highly; the ranks of increasing awareness and penalties for incompliant urban local bodies were high too (#74, #80–82, #86).

Stakeholders responded with "rather yes" to the questions regarding whether loans by international donors or international assistance could be considered high-ranking policy instruments to promote recycling (#83, 84).

The policy question regarding whether users should pay for more recycling (#44) received more negative than positive responses. Concerning possible drivers toward more recycling, the private sector and "other" were net negative (#50, #51). There were net-positive responses about financing: users should pay most O&M costs and recycling would provide substantial revenues (#45, 46). Indeed, in another study the authors estimated significant revenues from selling treated wastewater for irrigation. However, according to Breitenmoser et al. [17], revenues from selling treated wastewater to farmers may not suffice to cover the costs of innovative technology. With respect to drivers, the ranks of the private sector and other drivers were high (#55, 56). As for policy instruments toward more recycling, there were net-positive responses for financing recycling by user fees and taxes, ranking them highly too, as well as for capacity building in terms of ranks (#76, 85, 87).

Possible additional drivers for recycling were specialized research and development institutes and startup enterprises. Many respondents considered that citizens may be both drivers and, in the case of unawareness, barriers. Cost advantages, high quality and easy availability of recycled products would promote their spread.

#### 3.1.4. Barriers for Recycling

Significant relative majorities of stakeholders considered the possible failure to fulfill standards and the high costs as barriers to the uptake of innovative WWT technologies for recycling (#57, 60). On the other hand, certification based on established standards may help in promoting innovative recycling technologies.

Most stakeholders considered O&M costs, the lack of qualified personnel, missing certifications and the distrust of the public in water recycling as barriers, but the majorities were not significant, giving rise to concerns about conflicts (CF responses: #61, 63, 66, 67). Similarly, Robbins [18] identified public resistance, along with a lack of regulations and high costs, as major barriers to the reuse of treated industrial wastewater.

Net-positive barriers to taking up new technologies were over-fulfillment of standards and the perceived irrelevance of nitrogen removal (both causing unnecessary costs), lack of capacity and demand, prohibitive procurement, lack of incentives for water reuse and other barriers (#58, 59, 62, 64, 65, 68, 69). Currently, nitrogen in the wastewater is not a problem, but owing to changes in lifestyle, it may become an important pollutant, and treatment plants may need an upgrade to handle it; see Brunner et al. [19].

The open-ended responses added that a lack of information about recycling technology, including a lack of performance data, may hinder their implementation.

### *3.2. Stakeholder Analysis*

To identify possible coalitions and conflicts between the stakeholders, we linked stakeholders with significant positive correlations ($p$-value < 0.05) between their coded responses ($\pm 1$ and 0). As explained in the section about methods, we used the Spearman rank correlation. Together, these links defined a graph.

Next, we divided the stakeholders into groups with many links within each group and few links between the groups. We used the *Mathematica* command *FindGraphCommunities* and the optimization strategy *VertexMove*, as explained in the section about methods. The outcome is given in Figure 2a. It displays three groups of stakeholders. We aimed at characterizing them in terms of their common preferences. For each group, we identified three to five responses as characteristic (whereby stakeholders with the same characteristic responses also agreed regarding certain other responses).

Group 1 comprised nine stakeholders (nos. 1–3, 9, 11, 12, 14, 18 and 22). All of them were concerned with the selection of WWT technologies (#4), they deemed recycling of sludge as important (#28) and suggested international technical assistance as a suitable policy instrument for more recycling (#75). Two stakeholders from other groups shared these views too (nos. 4 and 21). Stakeholders who shared these views also had an interest in the approval of, selection of or research about WWT technologies (#9); they considered a flexible BAT as suitable (#12); considered environmental impacts and costs as important criteria for technology selection (#14, 15); and they supported the following policy instruments to promote recycling: penalties for non-compliant ULBs, subsidies by the Union government, awareness rising and capacity building (#71, 72, 77, 78).

Group 2 was comprised of ten stakeholders from academia and government only (nos. 4, 5, 7, 8, 16, 17, 20, 23, 24 and 26). All of them had an interest in WWT technologies (#5) and they agreed that acceptance by users (#16) and health (#18) should be important criteria for technology selection. Further, they considered that by law, resource reuse should be made mandatory (#70). Seven stakeholders from other groups shared these views too (no. 3, 12–14, 18, 19 and 21). All stakeholders, who shared these views also agreed about the suitability of a flexible BAT and the importance of the environment for the assessment of WWT technology (#12, 14). Further, they considered that more capacity building may promote recycling (#78).

Group 3 comprised seven stakeholders (nos. 6, 10, 13, 15, 19, 21 and 25). They were all interested in standards (#36) and considered BAT as rather important (#11). Further, they deemed ease of use, health and recycling as important criteria for the selection of WWT technology (#17–19). Four stakeholders from other groups shared these views too (nos. 2, 4, 9 and 12). All stakeholders who shared these views also agreed about the suitability of a flexible BAT and the importance of the environment for the assessment of WWT technology (#12, 14).

Considering the views of these groups on questions with conflict potential (CF responses), for two questions, one of the groups may take sides in possible conflicts: most stakeholders of group 2 agreed that existing WWT technologies were the BAT (#13), and most stakeholders of group 1 agreed that the reuse of biogas ought to be ranked rather high, while for the other stakeholder groups, opinions were split. For the other CF questions, we did not identify a similar conflict potential.

As was noted above, 10 out of 26 stakeholders could not be classified uniquely by their adherence to the characteristic group opinions (and nos. 4, 12 and 21 concurred with all three opinions). However, these classifications used unanimous opinions only. By assigning stakeholders at random to one of the suitable groups (e.g., no. 2 with 50% probability to either 1 or 3), 98% of 1000 simulations resulted in at most eight misclassifications.

As Figure 2b illustrates, more accurate classifications were possible when the vectors of stakeholder responses were used; these vectors were comprised of 79 responses of $\pm 1$ or 0 per stakeholder. To avoid overfitting (differences in 79 dimensions used to allocate merely 26 vectors into three classes), the vectors in 79 dimensions were projected onto a suitably chosen two-dimensional plane. It was constructed in *Mathematica* using the command *DimensionReduction* with *PrincipalComponentAnalysis* as the method.

Using three lines, the plane could be separated into three regions, representing one group each. The lines were computed in *Mathematica* with the *Classify* function, using *LogisticRegression* as the method. It estimated the probabilities that $(x, y)$ from the two-dimensional plane would originate from group $g = 1, 2$ or 3, as shown in Equation (1). The lines indicated where two of the three probabilities from Equation (1) were equal. As is seen in Figure 2b, there were only seven misallocations. Within the two-dimensional projection, the achievable accuracy for the prediction of the largest group ($g$ = 2) was estimated to be 77 ± 8%. Better (but perhaps overfitted) outcomes could be obtained in higher dimensions and with more complex regions.

$$\text{Probability}((x,y) \in \text{group}(g)) = \begin{cases} \frac{1.4895e^{0.4358y}}{e^{0.3355x}+1.4895e^{0.4358y}+0.8935e^{0.677x+0.975y}} & g = 1 \\ \frac{0.8935e^{0.3415x+0.975y}}{1+1.4895e^{-0.3355x+0.4358y}+0.8935e^{0.3415x+0.975y}} & g = 2 \\ \frac{1}{1+1.4895e^{-0.3355x+0.4358y}+0.8935e^{0.341x+0.975y}} & g = 3 \end{cases} \quad (1)$$

Finally, we investigated the stability of these groups. In 1000 simulations, we altered the adjacency matrix at random (change of 0 to 1 or 1 to 0 with 5% probability at each of the 319 stakeholder pairs with positively correlated views). We identified five stakeholders of group 1 (nos. 1–3, 12, 14), where each pair of them were in the same group for at least 95% of simulations. Further, there were seven stakeholders of group 2 with this property (nos. 5, 7, 8, 16, 20, 23, 26). Thus, these stakeholders formed the cores of their groups, whereas group 3 had no comparable core. The core of group 1 came from Chennai and its members had unanimous views about several issues. They agreed with group 2 about #16 and 70; they agreed with group 3 about #17 and 19; they approved #24, 26, 27, 29, 34, 49 and 53; and they rejected #43. By contrast, the core of group 2 did not share more common views than the whole of group 2.

## 4. Conclusions

Stakeholders largely agreed on the importance of the presented issues. This was insofar not surprising, as these issues are discussed in the literature and, in some contexts, they may have been decisive. We, therefore, interpreted only the first three levels of approval/disapproval as common sense amongst the stakeholders (unanimity or significant absolute or relative majority), while the three weakest levels (rather yes/no, perhaps yes/no, undecided) were interpreted as indicating issues that were not so interesting for the stakeholders. Further, stakeholders appeared to be more critical when they ranked the same alternatives (rather than just stating their importance). Therefore, if there were discrepancies between the ranks and stated importance, we took the pessimistic view.

- With respect to technology assessment and selection, stakeholders shared the views that the BAT was important for the WWT sector, but that allowing for some flexibility in the definition of the BAT would be suitable. However, for the question regarding whether the existing WWT technology of India was already the BAT, our stakeholder analysis indicated a conflict potential, with group 2 advocating the response "yes". Thus, some stakeholders may not yet be aware of the full consequences of requiring the BAT for WWT technology.
- The criteria groups environmental impact, costs, ease of use and health were considered as important and highly ranked for technology assessment, but acceptance by users and recycling were not. Nevertheless, amongst recycling options, the reuse of treated wastewater for irrigation and toilet flushing was considered important and highly ranked, but not any of the other recycling options (sludge, biogas), where there was conflict potential regarding whether the reuse of biogas ought to be ranked high, as was promoted by group 1. Thus, overall, the stakeholder consensus on WWT technologies was rather conservative, with a focus on the functioning of WWT, while it appears that acceptance by users and recycling were just nice to have for the stakeholders. This attitude may become a barrier to the implementation of technology that supports resource recovery because, in the perception of the stakeholders, the additional costs of such technology (see below) seem to outweigh the achievable benefits.

- Concerning drivers for and barriers to recycling, as well as policy measures to support recycling, stakeholder organizations shared the view that the possible failure to fulfill standards and the high costs of innovative technology would be barriers to the uptake of innovative WWT technologies for recycling. On the other hand, the Union government, the state governments and the ULBs would drive recycling (important and highly ranked). Stakeholders also agreed on several policy measures to promote recycling (important and of high rank), namely, making recycling mandatory, charging fines to ULBs that do not comply, providing subsidies by the state and Union governments, and increasing awareness. Other policy measures (capacity building, international technical assistance, loans from international donors, and financing recycling through user fees and taxes) appeared to be of less interest. Again, these were rather conservative views that basically expected the government to take action to drive recycling: if the government pays for resource recovery, then added costs seem to become acceptable.

The aggregation using the *Around* function tended to reinforce the general tendency of stakeholders to agree to the importance of the presented issues because it often transformed the dissent of respondents into undecided stakeholder responses. By contrast, our previous study Brunner et al. [15] based on conventional aggregations noted an impact from respondents with a political agenda. However, there was no indication that the use of the *Around* function would have changed the general picture.

**Supplementary Materials:** The following supporting information can be downloaded from https://www.mdpi.com/article/10.3390/w15213719/s1: Excel file SI_CodedData.xlsx; Word file SI_DetailedResultsTable.docx. The Excel file coded the outcomes of the surveys from workshops in Chennai, Kolkata and Mumbai. As sensible data related to political views were processed, both the respondents and the organizations were anonymized (some sent only one respondent). The Word file extends Tables A1 and A2.

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**Data Availability Statement:** The data for this paper are the outcomes of the surveys from workshops in Chennai, Kolkata and Mumbai. They are available as Supporting Information (see above).

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## Appendix A

Tables A1 and A2 summarizes the outcomes of the surveys. Column 1 starts with #4, as questions #1–3 were related to the respondents. Column 2 rephrases the questionnaires. "All" summarizes the outcomes on a scale with UY or UN (unanimous yes/no), SY or SN (yes/no for a significant absolute majority), CF/Y or CF/N for a non-significant majority with yes/no, Y or N (yes/no for a significant relative majority), RY or RN (rather yes/no), PY or PN (perhaps yes/no) and IN (indeterminate). Groups 1–3 were three groups of stakeholders. For them, the reported outcomes used the first two scales only (defining SY/SN with *Around*).

**Table A1.** Summary of the survey outcomes, first set of questions.

| # | Abbreviated Question | All | G1 | G2 | G3 | # | Abbreviated Question | All | G1 | G2 | G3 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 4 | Concerned with the selection of WWT | SY | UY | IN | IN | 31 | Rank recycle for irrigation | Y | SY | IN | IN |
| 5 | No interest in WWT technologies | SN | IN | UN | SN | 32 | Rank recycle for toilet | Y | IN | IN | SY |
| 6 | Interest in approval of WWT | N | IN | IN | IN | 33 | Rank recycle sludge | RY | SY | IN | IN |
| 7 | Interest in selection | CF/Y | IN | IN | IN | 34 | Rank recycle biogas | CF/Y | SY | IN | IN |
| 8 | Interest in research | CF/N | IN | IN | SY | 35 | Rank other | IN | IN | IN | IN |
| 9 | Other interest about WWT | SN | UN | SN | SN | 36 | Interest in standards | Y | IN | IN | UY |
| 10 | BAT is known | Y | SY | IN | IN | 37 | Add pollutants to standards | PY | IN | IN | IN |
| 11 | BAT is rather important | SY | SY | SY | UY | 38 | Keep standards as they are | PN | IN | IN | IN |
| 12 | Flexible BAT is suitable | UY | UY | UY | UY | 39 | Remove pollutants from standards | PN | IN | IN | IN |
| 13 | Existing WWT is BAT | CF/Y | IN | SY | IN | 40 | Relax thresholds of standards | PN | IN | IN | IN |
| 14 | Environmental impacts matter for WWT | UY | UY | UY | UY | 41 | Keep thresholds | PN | IN | IN | SY |
| 15 | Costs matter for WWT | SY | UY | SY | IN | 42 | Sharpen thresholds | PN | IN | IN | SN |
| 16 | Acceptance by users matters for WWT | SY | IN | UY | SY | 43 | Enforcement of standards is rather strict | CF/N | IN | IN | IN |
| 17 | Ease of use matters for WWT | SY | SY | SY | UY | 44 | Users should pay most capital costs | PN | IN | IN | IN |
| 18 | Health matters for WWT | SY | IN | UY | UY | 45 | Users should pay most O&M costs | PY | IN | IN | IN |
| 19 | Recycling matters | Y | IN | IN | UY | 46 | Substantial revenues from recycling | PY | IN | IN | IN |
| 20 | Rank pollution | SY | SY | SY | IN | 47 | Union government should drive recycling | Y | IN | IN | IN |
| 21 | Rank costs | Y | IN | IN | IN | 48 | State government should drive recycling | Y | IN | SY | IN |
| 22 | Rank acceptance by users | RY | IN | IN | IN | 49 | ULBs should drive recycling | Y | IN | IN | IN |
| 23 | Rank ease of use | Y | IN | IN | SY | 50 | Private sector should drive recycling | PN | IN | IN | IN |
| 24 | Rank health | Y | SY | IN | SY | 51 | Other drivers | PN | IN | IN | IN |
| 25 | Rank recycling | PN | IN | IN | IN | 52 | Rank Union government as a driver | Y | IN | IN | SY |
| 26 | Recycling for irrigation is important | Y | SY | IN | IN | 53 | Rank state government as a driver | Y | SY | SY | IN |
| 27 | Recycling for toilet flushing is important | SY | SY | IN | SY | 54 | Rank ULBs as driver | Y | IN | IN | IN |
| 28 | Recycling of sludge is important | Y | UY | IN | IN | 55 | Rank private sector as a driver | PY | IN | IN | IN |
| 29 | Use of biogas is important | Y | IN | IN | IN | 56 | Rank "other drivers" | PY | IN | IN | IN |
| 30 | Other is important | PY | IN | IN | IN | 57 | Violation of standard is a barrier | Y | IN | IN | IN |

**Table A2.** Summary of the survey outcomes, secons set of questions.

| # | Abbreviated Question | All | G1 | G2 | G3 | # | Abbreviated Question | All | G1 | G2 | G3 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 58 | Futile over-fulfillment of standards is a barrier | PY | IN | IN | IN | 73 | State government should support recycling | SY | SY | SY | SY |
| 59 | Nitrogen is irrelevant if water is used for irrigation | PY | IN | IN | IN | 74 | International donors should provide loans | Y | SY | IN | IN |
| 60 | Capital costs are a barrier | Y | IN | SY | IN | 75 | International technical assistance for recycling | SY | UY | IN | SY |
| 61 | O&M costs are a barrier | CF/Y | IN | IN | IN | 76 | User fees and taxes for recycling | PY | IN | IN | IN |
| 62 | Lack of capacity hinders implementation | PY | IN | IN | IN | 77 | Increase awareness for recycling | SY | UY | SY | SY |
| 63 | Lack of qualified personnel is a barrier | CF/Y | IN | IN | IN | 78 | More capacity building for recycling | SY | UY | UY | SY |
| 64 | Lacking demand for unknown technology | PY | IN | IN | IN | 79 | Rank mandatory recycling | SY | SY | SY | IN |
| 65 | Procurement impedes implementation | PY | IN | IN | IN | 80 | Rank penalty for ULBs | Y | SY | IN | SY |
| 66 | Lack of approval or certification is a barrier | CF/Y | IN | IN | IN | 81 | Rank Union subsidies | Y | SY | IN | SY |
| 67 | Water reuse not accepted by the public | CF/Y | IN | IN | IN | 82 | Rank state subsidies | Y | IN | IN | IN |
| 68 | Lacking incentive for water reuse | PY | IN | IN | IN | 83 | Rank donors | RY | SY | IN | IN |
| 69 | Other barriers | PY | IN | IN | IN | 84 | Rank assistance | RY | SY | IN | IN |
| 70 | Make recycling mandatory | SY | IN | UY | SY | 85 | Rank fees and taxes | PY | IN | IN | IN |
| 71 | Penalize ULBs for insufficient recycling | SY | UY | SY | SY | 86 | Rank increasing awareness | Y | SY | IN | IN |
| 72 | Union government should support recycling | SY | UY | SY | IN | 87 | Rank capacity building | PY | IN | IN | IN |

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