Employing multi-criteria decision analysis to select sustainable point-of-use and point-of-entry water treatment systems

M. A. Hamouda, W. B. Anderson and P. M. Huck

ABSTRACT

Point-of-use (POU) and point-of-entry (POE) drinking water treatment systems are gaining prominence, particularly from the point-of-view of technical appropriateness and consumer acceptance. They are becoming an increasingly viable alternative for small water treatment systems or in individual homes. However, sustainability concerns have been voiced in a number of studies investigating these devices. In this paper, sustainability is examined with respect to the fulfillment of treatment systems for a set of technical, economic, environmental and socio-cultural objectives. Consequently, the use of a hierarchy of sustainability indicators to compare various POU and POE water treatment alternatives is proposed. The indicators’ definitions, as well as calculation and normalization methods are explained. The paper also presents a decision model that is capable of selecting the most sustainable treatment option. The model employs the analytical hierarchy process (AHP) to help in the analysis of indicators’ relative importance with regard to sustainability and to develop the indicators and criteria weights required for aggregating a sustainability score. The generated sustainability scores essentially level the playing field when comparing POU and POE systems for technical and economic appropriateness for a particular water treatment case, in addition to incorporating more difficult to quantify system traits, such as environmental and socio-cultural sustainability.

Key words | analytical hierarchy process, multi-criteria decision analysis, point-of-entry, point-of-use, sustainability indicators

INTRODUCTION

Traditional water treatment and supply follows a centralized model, where water in most instances is treated in relative proximity to a source and then distributed through a complex pipe network to the point of use. This centralized model has been successful for decades; however, several recent changes have accelerated the need to find, in certain situations, complementary and alternative solutions to this traditional model (Cotruvo 2003; Hamouda et al. 2010). These changes include the rise in consumer awareness of drinking water quality issues, the identification of new classes of emerging contaminants, and the need to alleviate the risk from contaminants forming, growing or leaching from pipes and fittings in the distribution system, or those deliberately or accidentally introduced. In addition to these changes, there is the persistent challenge of finding a feasible treatment solution for small, rural and remote communities, which often suffer from financial constraints that would preclude the construction of full-scale centralized treatment plants (Hamouda et al. 2010).

With these pressing challenges and changes, non-traditional solutions are now at least being considered. Point-of-use (POU) and point-of-entry (POE) water treatment systems represent two of the non-traditional options available (Cotruvo & Cotruvo 2003; Raucher et al. 2004).
In general, POE systems are defined as those that are installed at or near where water enters a building and is connected to the plumbing, whereas POU systems are those installed at or near where water is directly used and may be connected to plumbing or not. In North America, the growing interest in POU and POE units has led to a rapid increase in the number of units marketed as potential solutions to real or perceived drinking water issues. In 1968, NSF International was asked by US state drinking water administrators, and later by the US Environmental Protection Agency (USEPA) to issue a series of standards to ensure the effectiveness of POU and POE systems (Hamouda et al. 2010). Since then, there has been steady progress in the field of POU and POE treatment in terms of research conducted, standards issued, and finally acceptance for compliance with drinking water regulations.

Many studies have investigated target contaminant removal efficiencies of POU and POE systems and their potential to comply with regulations (Sobsey et al. 2008; Deshommes et al. 2010). However, in selecting among the various POU and POE alternatives, ideally the decision should result in the most sustainable solution, which is not confined to aspects of technical performance. ‘Sustainable’ in this context refers to a hierarchy of parallel criteria that capture the relative fulfillment by various POU and POE treatment systems of the following objectives: (a) provides safe drinking water to help maintain good human health and hygiene; (b) having minimum negative impact on the environment; (c) making better use of human, natural and financial resources; (d) having a high degree of functional robustness and flexibility; and (e) gains cultural acceptance, thus encouraging responsible behavior by the users. Hamouda et al. (2010) suggested a framework (Figure 1) that encompasses a number of criteria that assess the sustainability of POU and POE treatment systems to help compare and select the most sustainable solution to a specific treatment case.

To operationalize the selection framework, there are several decision making techniques that can be implemented to quantify the various criteria and make an informed decision (Lai et al. 2008; Hamouda et al. 2009). Defining criteria and indicators is the basis for constructing the selection mechanism. Sustainability indicators have been used by many researchers and managers in water and wastewater treatment (Loucks & Gladwell 1999; Balkema et al. 2002). While previous studies have improved on the understanding of the use of sustainability indicators in the context of water treatment, indicators developed to assess the sustainability of POU and POE treatment need to address issues that are specific to this type of treatment. Hamouda et al. (2010) explain the development of a list of 25 indicators that can be used to evaluate the sustainability of POU and POE water treatment systems. Stakeholders were involved through the use of a questionnaire to solicit the opinion of 15 experts, in the field of water treatment in general and POU and POE water treatment in particular, on the developed indicators. The questionnaire successfully stimulated a discussion of the proposed indicators and resulted in improving the indicators to more effectively assess the sustainability of various POU and POE water treatment alternatives.

This paper describes stages 2, 3 and 4 of the selection framework (Figure 1), which deal with evaluating and quantifying the sustainability criteria and indicators, and applying a multi-criteria decision analysis (MCDA) method to compare various treatment alternatives and select among them. Particularly, this paper sheds light on the various aspects of the calculation of indicators using quasi-quantitative techniques and implementing the analytical hierarchy process (AHP) as a MCDA method. The work presented here provides the basis for a user friendly decision support system (DSS) that the authors plan to describe in a future publication.
Calculation of indicators

While the conceptual relevancy of the indicators is important, it is also crucial to define methods of evaluation of these indicators through a practical and preferably quantitative approach. Quantitative, quasi-quantitative and qualitative indicators, like those used in our study, require special attention to design an effective calculation method that best reflect the indicators’ description. The list of 25 indicators developed by Hamouda et al. (2010) was revisited and refined using a number of logical filters; these are:

1. overlapping which leads to exaggeration or over-emphasis of one factor and its contribution to the overall rating of sustainability;
2. availability of data in the required format; and
3. existence of sufficient variability among POU and POE devices in the aspect measured by the indicator, such that discrimination among devices in terms of sustainability can be attained. For example, if the POU and POE devices certified to remove contaminants all do so with the same or very similar removal efficiency (i.e. no variability in their efficiency), then it will not be a factor in selecting among these devices, and thus it would not be a valid selection indicator.

Clear and detailed methods of calculation for the 20 refined indicators were designed to allow for characterizing current and future POU and POE alternatives added to the knowledgebase. Calculation of the indicators took into consideration that: the result should be a value that represents what the indicator is intended to measure; the method of calculation is clear and not too complicated; and the indicators are normalized for the purpose of aggregation into one score to be used to compare the various alternatives.

In this study it was decided to normalize all the indicators within the range from 0 to 1, where a higher value indicates a contribution to a more sustainable treatment system (i.e. is more desirable). The selection of the normalization method is not trivial and depends on the variables used in evaluating each indicator (Nardo et al. 2005). Different normalization methods were explored; however, only two were chosen. These are: (1) rescaling: normalizing with respect to the range of scores of all the alternatives being compared – the normalized value is calculated as the ratio of the difference between the raw variable (or indicator) value and the minimum value, divided by the range; and (2) categorical scales: a variable (or indicator) is assigned a categorical score, which is qualitative (e.g. ‘None’, ‘Low’, ‘Moderate’, ‘High’, and ‘Very high’) with a corresponding numerical value (e.g. 0, 0.25, 0.5, 0.75 and 1).

Normalization should consider the data properties and the objectives of the aggregated score. Nardo et al. (2005) outlined the issues that could guide the selection of the normalization method: whether quantitative or qualitative data are available, whether exceptional values need to be rewarded or penalized, and whether the variance in the indicators needs to be accounted for. For example, in this study, when the indicator values were within a small interval and small changes in the indicator’s value could have a significant effect on the sustainability score, the rescaling method was used. On the other hand, when the indicator was assessing soft qualitative aspects or when small changes in such aspects should not affect the aggregated sustainability score, the categorical scale method was used. The choice of normalization method for a given indicator is discussed below.

Application of multi-criteria decision analysis

Numerous MCDA techniques have been employed in DSSs developed to design or select among water and wastewater treatment systems. These are reviewed elsewhere (Lai et al. 2008; Hamouda et al. 2009). The AHP and its generalized form, the analytic network process (ANP), are two MCDA methods that were developed by Saaty (2008). AHP was selected in this study because it is a well-established method in the literature and it is sufficiently logical to structure the problem and decision model in a hierarchical form that contains the various indicators and criteria influencing the decision. Moreover, the hierarchical structure of the AHP process allows for utilizing aggregation of sub-categories of indicators influencing the decision, which enables blocking indicators that may be thought of as irrelevant by different users. This adds to the flexibility and utility of a DSS and enables user interactiveness.
illustrates our hierarchy of indicators, objectives, criteria groups and general goal of sustainability.

**Figure 3** summarizes the entire process of implementing the AHP technique, including the weighting and aggregation of indicators to calculate a sustainability score. To establish the relative importance of each indicator, a questionnaire was designed to explain the objectives of the study and request stakeholders’ judgment on which of two criteria groups, objectives or indicators is more important in fulfilling the overall sustainability goal or any of its underlying objectives (pairwise comparison). The stakeholders were previously outlined in Hamouda et al. (2010) and included: (1) government monitoring agency, (2) water purveyors (3) POU and POE systems supplier/manufacturer associations, (4) independent certification organization, (5) water associations, and (6) consumers and consumer organizations.

![AHP hierarchy used to evaluate the sustainability of a POU/POE device.](image1)

*Figure 2* | The AHP hierarchy used to evaluate the sustainability of a POU/POE device.

![Summary of AHP implementation method.](image2)

*Figure 3* | Summary of AHP implementation method.
The participants were asked to tick a box that represented the relative importance between two indicators based on Saaty's scale (Figure 4). In Saaty's scale, a judgment that two indicators are equally important is given 1, moderately more important 3, strongly more important 5, very strongly more important 7 and extremely more important 9. The pairwise comparisons result in a (NxN) positive reciprocal matrix, where the diagonal $a_{ii} = 1$ and reciprocal property $a_{ji} = (1/a_{ij})$. The result is a clear priority statement of a participant. This technique is employed by DSS developers, sometimes even by those who are not using AHP (Simon et al. 2004).

Nineteen participants representing various stakeholders in POU and POE water treatment – particularly in the North American context – responded to the questionnaire and their responses were recorded in a Microsoft Excel® spreadsheet. The responses were used to build a decision matrix for each objective and each criteria group, and for sustainability (Albright 2004). The next step was to obtain the relative weights of the indicators, objectives and criteria groups. Saaty (2003) has shown that solving the principal eigenvector of the matrix will provide an excellent estimate of the relative weights of the indicators indicating their priority level. The principal eigenvector was calculated using a simple iterative method that we designed in Microsoft Excel®. The method used calculates in each iteration an even power (squaring) of the matrix $A^{2x}$ ($x=1, 2, ..., m$). The resulting matrix is then used to estimate the eigenvector by summing the rows and then normalizing the resulting vector (Ishizaka & Lusti 2006). The iteration was stopped when differences between iterations were not detected to the third decimal place with a minimum of three iterations. Table 1 shows the eigenvector calculated in three iterations for the pairwise comparison matrix for the maximizing performance objective. The third iteration eigenvector can be used as an estimate of the principal eigenvector which is the relative weights vector. This procedure was applied to all the decision matrices to calculate their principal eigenvector and the relative weights of all the indicators ($w_i$), objectives ($w_j$) and criteria groups ($w_k$).

A consistency ratio (CR) was calculated for each pairwise comparison matrix to check the consistency of each participant’s judgment. Careless or exaggerated judgments during the process of pairwise comparison may result in such inconsistencies. The ratio can range from 0.0, which reflects perfect consistency, to 1.0 which indicates no consistency; 0.1 is recommended as the maximum acceptable value for the CR (Saaty 2003). Since there was no preference given to one stakeholder’s opinion over the other, the authors decided to consider participants’ responses of equal importance. Thus, the averages of indicators’ weights resulting from all consistent participants’ responses to the questionnaire were used to calculate the aggregated score evaluating a POU and POE water treatment system’s sustainability. Aggregation was done using a simple linear function based on an alternative’s score on the various indicators ($a_{ij}$) and the indicators’ weights ($w_i$). Thus, to evaluate

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**Table 1** | Calculating the eigenvector for indicators influencing system performance

<table>
<thead>
<tr>
<th>Indicators influencing performance</th>
<th>IE</th>
<th>RL</th>
<th>RB</th>
<th>MR</th>
<th>Eigenvector Iteration 1</th>
<th>Eigenvector Iteration 2</th>
<th>Eigenvector Iteration 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incidental effect (IE)</td>
<td>1.00</td>
<td>0.20</td>
<td>0.20</td>
<td>0.20</td>
<td>0.0558</td>
<td>0.0598</td>
<td>0.0596</td>
</tr>
<tr>
<td>Reliability (RL)</td>
<td>5.00</td>
<td>1.00</td>
<td>1.00</td>
<td>0.33</td>
<td>0.3863</td>
<td>0.3823</td>
<td>0.3825</td>
</tr>
<tr>
<td>Robustness (RB)</td>
<td>5.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>0.3863</td>
<td>0.3823</td>
<td>0.3825</td>
</tr>
<tr>
<td>Microbial regrowth risk (MR)</td>
<td>5.00</td>
<td>3.00</td>
<td>1.00</td>
<td>1.00</td>
<td>0.1717</td>
<td>0.1756</td>
<td>0.1753</td>
</tr>
</tbody>
</table>

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Figure 4 | Excerpt from an actual participant’s response to the pairwise comparison questionnaire.
an aggregated value of sustainability of a POU and POE water treatment system, the following equation was used:

\[
\text{Sustainability score} = \sum_{k=1}^{4} w_k \left[ \sum_{j=1}^{m} a_i w_j \left( \sum_{i=1}^{n} a_i w_j \right) \right]_{j, k}
\]

where: \( a_i \) = normalized alternative’s score for the various indicators under objective \( j \), \( n \) = number of indicators under objective \( j \), \( w_j \) = indicators’ weights denoting their relative importance with respect to achieving objective \( j \), \( w_k \) = objectives’ weights denoting their relative importance under the technical, economic, environmental or socio-cultural criteria group, \( m \) = number of objectives under criteria group \( k \) and \( w_k \) = weights of criteria categories denoting their importance with respect to achieving sustainability.

Similar weighted sum equations were used to get the scores of an alternative for a particular criteria group (technical, economic, environmental or socio-cultural) and for a particular objective (performance, implementability, etc.).

### RESULTS AND DISCUSSION

**Indicators and their calculation**

After applying the logical filters for the 25 indicators developed by Hamouda et al. (2010), the final list of indicators was narrowed down to 20. The five indicators removed from the list either had overlapping effect (e.g. indicator of system complexity), insufficient data availability or insufficient variability among alternatives (e.g. indicator of removal efficiency). Indicator information sheets are one of the most significant outcomes of the decision analysis exercise. Information sheets for each of the 20 indicators were developed and are summarized in Figure 5 and Table 2. Figure 5 lists the indicators’ type (qualitative, quantitative or quasi-quantitative) and their definitions, while Table 2 lists their characteristics, including:

1. variables used in an indicator’s calculation;
2. type of normalization used for purpose of aggregation: rescaling or categorical scales (‘None’, ‘Low’, ‘Moderate’, ‘High’, and ‘Very high’ with a corresponding numerical value of 0, 0.25, 0.5, 0.75, and 1); and
3. type of aggregation of variables to calculate the indicator’s value: mutual equivalence, weighted sum or complex categorical scales.

**Sample outcome of developed AHP model**

The aggregated sustainability score is valued for its ability to integrate large amounts of information into one value that is useful for a general or comparative judgment. However, one of the main issues discussed in the literature is the problem of compensation which may lead to weak sustainability assessment (Boggia & Cortina 2010). The weighted sum method used to aggregate the sustainability score assumes a compensatory relationship between the four criteria groups (technical, economic, environmental and socio-cultural), meaning that performing well on one criteria group would compensate failure to perform well on another. The utility of the resulting sustainability assessment can be enhanced through visualization of sub-indices, thus avoiding compensation. Figure 6 is an example of a basic display of the sustainability assessment results of four shortlisted POU treatment alternatives used to remove lead from drinking water. The models and types of devices used in this example are not shown; they are only presented as numbered alternatives because the AHP framework was run on a limited number of devices listed in the knowledgebase and the authors wanted to avoid the results being interpreted as a recommendation for use of a particular marketed device. The alternatives are ranked in descending order from the one with highest sustainability score (alternative 1) (and consequently the best solution in this case), to the one with the lowest sustainability score (alternative 4). Looking at the criteria groups’ scores, it is interesting to see that, had environmental criteria been the only aspect for consideration in this selection problem, alternative 4 would have had the highest rating. Also, if the user was looking for the alternative with the more uniform score on all criteria, alternatives 2 or 3 would be a better choice than alternative 1. Similar figures and analyses can be generated for the objectives’ scores and indicators’ scores to compare the devices achievement on the various levels.
Another visual display that summarizes the performance of a particular alternative on a number of indicators, objectives or criteria groups is the radar diagram presentation technique. A radar diagram displays an alternative's scores on various sustainability criteria groups or objectives in a radial system of axes. If an objective has 'n' underlying assessment indicators, a regular n-sided polygon is formed. Each radius ending at a corner of the polygon is a measuring axis for each indicator. The point where the axes meet corresponds to a value of 0 – the lowest score in terms of sustainability. The value corresponding to the corners of the polygon is normalized with a value of 1 – the highest score in terms of sustainability. The normalized scores of different indicators and sub-indices of the POU alternative for a particular case are plotted on the corresponding axes. The joining of point scores on all the axes forms a new polygon. Figure 7 displays an example of a radar diagram developed for the same four alternatives considered in the lead removal hypothetical case. The figure shows the score of the four alternatives based on the three technical sustainability objectives ignoring the objectives' relative weights. It is clear that even though alternative 1 had the highest sustainability score, it lacks in fulfilling the objective of maximizing implementability, more so than other alternatives.

<table>
<thead>
<tr>
<th>Sustainability</th>
<th>Incidental effect</th>
<th>Reliability</th>
<th>Robustness</th>
<th>Microbial regrowth risk</th>
<th>Installation skill</th>
<th>System footprint</th>
<th>Operating &amp; maintenance skill</th>
<th>Maintenance frequency</th>
<th>Capital cost</th>
<th>Operating &amp; maintenance cost</th>
<th>Bulk purchase discounts</th>
<th>Energy use</th>
<th>Chemical use</th>
<th>Solid residuals</th>
<th>Liquid residuals</th>
<th>Aesthetics</th>
<th>Configuration</th>
<th>Cosmetics</th>
<th>Market availability</th>
<th>Market penetration</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A qualitative assessment of the treatment device's ability to remove additional contaminants other than those targeted in the influent water.</td>
<td>A qualitative assessment of the sensitivity to malfunctioning by measuring redundancy in the treatment device.</td>
<td>A qualitative assessment of the sensitivity of the treatment device concerning shock loads, and seasonal effects.</td>
<td>A qualitative assessment of the potential for growth of heterotrophic bacteria (EPC), and the existence of a mitigating technique in the treatment device.</td>
<td>A qualitative assessment of the level of skill required to install the treatment device.</td>
<td>A quantitative assessment of the volume and area occupied by the treatment device.</td>
<td>A qualitative assessment of the level of skill required to operate and maintain the treatment device.</td>
<td>A qualitative assessment of the frequency of maintenance required for the treatment device.</td>
<td>A quasi-quantitative assessment of the cost of purchase and installation of the treatment device.</td>
<td>A quasi-quantitative assessment of the operating and maintenance cost of the treatment device.</td>
<td>A quasi-quantitative assessment of a potential quantity discount on the treatment device bulk purchase.</td>
<td>A qualitative assessment of the energy used by the treatment device to treat water.</td>
<td>A qualitative assessment of chemicals used by the treatment device to treat water.</td>
<td>A quasi-quantitative assessment of the production of solid waste by the treatment device.</td>
<td>A qualitative assessment of the production of liquid waste by the treatment device.</td>
<td>A qualitative assessment of aesthetic issues associated with water produced by the treatment device.</td>
<td>A quasi-quantitative assessment of the degree of consumers satisfaction with the treatment device configuration.</td>
<td>A qualitative assessment of the attractiveness and communication features of the treatment device to the user.</td>
<td>A qualitative assessment of the market availability of the treatment device.</td>
<td>A quasi-quantitative assessment of the availability of other devices of the same treatment trains as the treatment device in the market.</td>
</tr>
</tbody>
</table>

**Figure 5** | Refined list of sustainability indicators and their definitions.
<table>
<thead>
<tr>
<th>Indicator</th>
<th>Variables</th>
<th>Normalization</th>
<th>Aggregation</th>
<th>Calculation Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>IE: Incidental effect</td>
<td>1. CR: Number of contaminants removed by the treatment device (as certified to NSF/ANSI standards)</td>
<td>Rescaling</td>
<td>N/A</td>
<td>$IE = \frac{CR - CR_{\text{min}}}{CR_{\text{max}} - CR_{\text{min}}}$</td>
</tr>
<tr>
<td>RB: Robustness</td>
<td>1. SR: Risk of shock loads emanating from source water type</td>
<td>Categorical scale</td>
<td>Mutual</td>
<td>$WR = PC + FA - PC \times FA$</td>
</tr>
<tr>
<td>MR: Microbial regrowth risk</td>
<td>1. RR: Regrowth risk which depends on the processes in the treatment device</td>
<td>Categorical scale</td>
<td>Complex</td>
<td>$RB = SR + WR - SR \times WR$</td>
</tr>
<tr>
<td>IS: Installation skill</td>
<td>1. IS: Ease of installing the treatment device</td>
<td>Categorical scale</td>
<td>N/A</td>
<td>$SF = \frac{V_{\text{max}} - V}{2V_{\text{max}} - V_{\text{min}}} + \frac{A_{\text{max}} - A}{2A_{\text{max}} - A_{\text{min}}}$</td>
</tr>
<tr>
<td>SF: System footprint</td>
<td>1. A: Area occupied by the treatment device</td>
<td>Rescaling</td>
<td>Weighted sum</td>
<td>$OC = \frac{2RC_{\text{max}} - RC}{3RC_{\text{max}} - RC_{\text{min}}} + \frac{1}{5}EC + \frac{2}{5}SC$</td>
</tr>
<tr>
<td>OS: Operation &amp; maintenance skill</td>
<td>1. DC: Level of difficulty associated with changing the device's components</td>
<td>Categorical scale</td>
<td>N/A</td>
<td>$MF = \frac{3}{4}SL - SL_{\text{min}} + \frac{1}{4}CO_{\text{max}} - CO_{\text{min}}$</td>
</tr>
<tr>
<td>MF: Maintenance frequency</td>
<td>1. PC: Purchase cost estimated</td>
<td>Rescaling</td>
<td>Weighted sum</td>
<td>$CC = \frac{2}{3}PC_{\text{max}} - PC$</td>
</tr>
<tr>
<td>CC: Capital cost</td>
<td>1. IC: Installation cost which is estimated based on the installation skill indicator</td>
<td>Categorical scale</td>
<td>N/A</td>
<td>$OC = \frac{2}{3}RC_{\text{max}} - RC_{\text{min}} + \frac{1}{5}EC + \frac{2}{5}SC$</td>
</tr>
<tr>
<td>OC: Operation &amp; maintenance cost</td>
<td>1. RC: Replacement components' cost divided by the service life of the device</td>
<td>Rescaling</td>
<td>N/A</td>
<td>$BO = \frac{1}{2}DC + \frac{1}{2}CL$</td>
</tr>
<tr>
<td>BPD: Bulk purchase discounts</td>
<td>1. OP: Discount percentages based on intervals of order value</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>EU: Energy use</td>
<td>1. EU: Quantity of energy use by the device</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>CU: Chemical use</td>
<td>1. CU: Quantity of chemicals used by the device</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>SR: Solid residuals</td>
<td>1. TC: Whether or not there is a target contaminant to be removed from the source water</td>
<td>Categorical scale</td>
<td>Complex</td>
<td>$N/A$</td>
</tr>
<tr>
<td></td>
<td>2. HS: The presence of any hazardous substance in the non water contacting device materials</td>
<td>Categorical scale</td>
<td>N/A</td>
<td>$N/A$</td>
</tr>
<tr>
<td></td>
<td>3. SQ: Quantity of solid residuals produced by device replacement components</td>
<td>Rescaling</td>
<td>N/A</td>
<td>$N/A$</td>
</tr>
</tbody>
</table>
alternatives. Similar radar diagrams can be developed for other objectives and indicators. This insight into the fulfillment of underlying objectives can help decision makers and POU and POE device manufacturers identify the reasons for having a lower sustainability rating.

CONCLUSIONS

Sustainability is currently a core objective in any industry. The water industry is no exception, especially in that it deals with a crucial and sensitive resource that is foreseen to shape the future of this planet. This paper explored a methodology for assessing sustainability with respect to a particular issue — the selection of a POU/POE device — through a quantified evaluation of treatment systems characteristics. The developed AHP-based model is intended to be a simplified and quantifiable system for operationalizing the framework of sustainability assessment of POU and POE treatment alternatives. The aim was to formulate a methodology for assessment of sustainability to compare and select POU and POE water treatment systems.

The aggregated sustainability score is valued for its ability to integrate large amounts of information into one value that is useful for a general or comparative judgment. However, in this paper we have employed visual display methods (Figures 6 and 7) to provide a decision maker with underlying information otherwise obscured by aggregation, to avoid compensation and enable proper interpretation of device (POU or POE) performance on all sustainability objectives. The developed AHP-based selection model can have several implications on the various POU and POE stakeholders:

1. Government monitoring agency: the model may encourage the expansion of the scope of acceptance of POU or POE systems in complying with regulations.
2. Water purveyor: the model can help in choosing systems that meet customer satisfaction goals, and ensure technical and economic sustainability.
3. POU and POE systems supplier/manufacturer associations: the use of the model can encourage manufacturers to strive to enhance the sustainability of their devices to increase their ranking on the shortlisted
devices. This can also increase consumer confidence in their products and their market share.

4. Independent certification organization: by adopting the selection model, an organization such as NSF International can provide better services to consumers in their search for sustainable POU and POE devices.

5. Water associations: the model can be used as a tool to increase consumer awareness with regard to POU and POE treatment. It can also help in outlining areas of research to increase the sustainability of POU and POE devices.

6. Consumers and consumer organizations: the model addresses many of the concerns and confusion
consumers may have about POU and POE devices. It can be tailored to be used as a consumer aid tool.

The developed model is being integrated into a decision support tool to select sustainable POU and POE systems. This tool may be used to help users, regulators and water purveyors to ensure a sustainable choice of a POU and POE water treatment system. The MCDA model, when coupled with other decision tools such as alternative screening using minimum and maximum performance values, will help make the decision process more realistic and solve the issue of compensation.

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