Decision support system to select sustainable point-of-use/point-of-entry treatment systems (D4SPOUTS)
Mohamed A. Hamouda, William B. Anderson and Peter M. Huck

ABSTRACT

Point-of-use (POU) and point-of-entry (POE) devices are, in some situations, considered to be a viable solution for drinking water suppliers and consumers alike to deal with site specific drinking water issues. This paper introduces a newly developed decision support system (DSS) that employs decision making techniques to select among the various devices based on their characterization and sustainability assessment. Careful illustration of the various aspects and components of the DSS is provided and the decision process is explained. Aspects of validity, usability and sensitivity analysis are demonstrated through a hypothetical case study for removing lead introduced in the distribution system of municipally treated drinking water. The output of the DSS helps to determine the more sustainable treatment devices which should have positive implications for the application of POU and POE devices. Other potential uses of the DSS are described to illustrate its versatility and usefulness. The DSS is not intended to replace common engineering practice in selecting POU and POE treatment systems, but rather to give support to the users by providing the necessary information about all possible solutions.

Key words | analytical hierarchy process, decision support system, point-of-entry, point-of-use, sustainability

INTRODUCTION

The drinking water supply industry experiences many challenges, including quality deterioration of source water, financial and energy constraints, emerging contaminants, contaminants introduced in the distribution system, etc. (MacGillivray et al. 2006; Chung et al. 2008). There are certain key measures that are important in overcoming today’s challenges in project planning. In general these are to: (1) decentralize solutions to overcome major system failures; (2) increase redundancy to increase probability of overcoming unforeseen issues; (3) develop and implement sustainable solutions; (4) rely on systems analysis to incorporate all the factors that may influence a planned project; and (5) preserve the knowledge acquired from previous projects and from investigations to retrieve it during future planning and evaluation.

In the water supply industry, point-of-use (POU) and point-of-entry (POE) treatment represent a potential part of the solution to water supply challenges. These devices provide a decentralized and responsive solution that can, in some cases, be used independently without central municipal treatment. In addition, when used in combination with centralized treatment, they can also increase the redundancy or robustness of water supply systems (Pontius et al. 2003; McEncroe 2007; Chung et al. 2008; Hamouda et al. 2010). However, there is a need to incorporate other key measures in order for POU and POE devices to be seriously considered as viable solutions for challenges facing the water industry. These measures include looking into the sustainability of these devices, following a systems analysis approach in assessing their viability, and preserving the knowledge from the systems analysis in a tool made available to all stakeholders.

In an attempt to investigate the sustainability of POU and POE devices, Hamouda et al. (2010) explained a
developed framework employing a systems analysis approach to screen and rank POU and POE alternatives based on their comparative sustainability. The results of the systems analysis were coded in a multi-criteria decision analysis (MCDA) model for assessing the sustainability of POU and POE alternatives and are fully described in Hamouda et al. (2012). The model considers a number of sustainability objectives categorized under four main criteria groups (Table 1). A list of 20 indicators categorized under the four criteria group was developed based on stakeholders’ response to a questionnaire on the most relevant sustainability aspects to the selection of POU and POE devices (Hamouda et al. 2012). The decision variables were formulated into categorical or mathematical equations to calculate the indicators’ values.

Finally, the knowledge generated from the systems analysis and sustainability assessment MCDA model needs to be preserved, automated, and provided in an interactive tool to be used when POU and POE devices are considered for drinking water supply. This paper demonstrates the completed interactive Decision Support System to assist water stakeholders (such as water utilities and regulators) in Selecting Sustainable Point-Of-Use and point-of-entry drinking water Treatment Systems (D4SPOUTS). The authors recognized the importance of sharing what has been learned during the process of developing D4SPOUTS and have not made any attempt to protect the intellectual property associated with its development.

### D4SPOUTS DEVELOPMENT – COMPONENTS AND DATA FLOW

Developing a decision support system (DSS) requires gathering and integrating knowledge from several disciplines to ensure the success of the developed DSS (Mysiak et al. 2005; McIntosh et al. 2011). Determining the decision process that best fits the purpose of the decision making process is a critical task in developing a DSS. The purpose of D4SPOUTS is to shortlist feasible POU and POE alternatives that are suitable for a particular water treatment case, and then outline the more sustainable of the available alternatives for the user to select from. Microsoft® Excel® was used to develop D4SPOUTS components and automate the decision process. The superstructure of the D4SPOUTS includes three main components (Figure 1): (1) multiple user interfaces; (2) a knowledgebase containing heuristic and numerical characterization of POU and POE devices, including modules to quantify sustainability indicators, screen alternatives, and rate and rank devices based on sustainability; and (3) an output module. Figure 1 illustrates the interaction and data flow.

<table>
<thead>
<tr>
<th>Criteria groups</th>
<th>Objectives</th>
<th>Focus of the indicators</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technical</td>
<td>Maximizing performance</td>
<td>Assessing system's incidental effect, reliability (redundancy), robustness, microbial regrowth risk</td>
</tr>
<tr>
<td></td>
<td>Maximizing implementability</td>
<td>Assessing the skill required to install the system and the area and volume it occupies (footprint)</td>
</tr>
<tr>
<td></td>
<td>Maximizing operability</td>
<td>Assessing the skill required to operate and maintain the system and maintenance frequency</td>
</tr>
<tr>
<td>Environmental</td>
<td>Minimizing resource consumption</td>
<td>Assessing resource consumption (energy and chemicals)</td>
</tr>
<tr>
<td></td>
<td>Minimizing environmental footprint</td>
<td>Assessing the amount and hazardousness of solid and liquid residuals produced by the system</td>
</tr>
<tr>
<td>Economic</td>
<td>Minimizing life cycle cost</td>
<td>Assessing capital cost, operating and maintenance cost, and potential savings with bulk purchases</td>
</tr>
<tr>
<td>Socio-cultural</td>
<td>Maximizing consumer acceptance</td>
<td>Assessing consumer acceptance of the aesthetics of the produced water, the system's configuration, and the system's attractiveness and interactivity</td>
</tr>
<tr>
<td></td>
<td>Maximizing product availability</td>
<td>Assessing the availability of the system in the market in terms of: (1) system availability through different sales methods; (2) number of certified systems with the same treatment train</td>
</tr>
</tbody>
</table>
flow between these components that are described in the following sub-sections.

**Multiple user interfaces**

D4SPOUTS is designed to allow users to manipulate any of the data used in the decision process. There are three user interfaces that allow for separate user input. D4SPOUTS starts with a welcome screen where the user identifies which input interface to run. The first input interface is for case input, the interface is composed of five pages:

1. **Case information page**: includes general case information such as: case name, organization name, state or province, community name, source water type (centrally treated, surface, deep ground water, shallow ground water, or rain water), consumer health (normal or immunocompromised), facility type (residential, commercial, educational, or health), and community type (rural or urban).

2. **System operation page**: requests specific system operation information that may represent constraints on the type of device selected, such as: operating pressure, water temperature, number of units to be installed, available funds, required flow, available space, availability of electric supply, and the type of sewer management system (domestic sewer, septic tank, or tile sewer).

3. **Source quality page**: is used to collect information on the quality of water to be treated by the device, it includes identifying a number of contaminant concentrations that may affect a device’s operation (e.g. hardness) as well as a categorized list of contaminants that the device is certified to remove (aesthetic parameters, metal contaminants, volatile organic contaminants, other chemical contaminants, and disinfection requirements). The list of contaminants was populated using NSF/ANSI standards used to certify POU and POE devices (Standards 42, 44, 53, 55, 58, and 62). The interface lists three disinfection options: (a) primary (Class A UV devices certified to Standard 55), (b) polishing (Class B UV devices certified to Standard 55), and (c) cyst removal (devices certified to Standard 53). It is important to point out that only Class A UV devices certified to Standard 55 can be used to ensure microbiological safety of untreated surface water or groundwater under the direct influence of surface water, and that they can only be used where permitted by regulation or for unregulated private systems.

4. **Device preferences page**: includes a list of options a user can select to specify a preferred device configuration (there are eight configuration types specified by NSF/ANSI standards), a treatment train (a sequence of processes that a device can be composed of), a manufacturer, or a device model (only those certified to NSF/ANSI standards).

5. **Sustainability hierarchy page**: displays of the hierarchy of indicators, objectives, and criteria groups and their relative weights. D4SPOUTS gives the option of either using the default weights that were a result of a questionnaire response by 19 stakeholders (Hamouda et al. 2012), or using user-defined weights that are a result of the response to a built-in pairwise comparison questionnaire which is the third user interface described later.

A hypothetical case was run to demonstrate the utility of the DSS. The case requires 20 POU devices to be installed at an educational facility to remove lead from centrally treated water. The available funds for this project are $20,000 CAD and other characteristics include: normal consumer health...

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**Figure 1** | D4SPOUTS components and data flow.
(i.e. no immunocompromised), domestic sewer system, and an urban setting. No additional preferences or constraints were specified and default weights were used to calculate the sustainability scores (Figure 2). This case study is an example of a potential use of D4SPOUTS.

The second user interface is a knowledgebase editor that users, particularly manufacturers, can use to input new POU and POE devices or change the characteristics of devices that already exist in the knowledgebase. The interface has four main pages:

1. General characteristics and constraints page: includes information on the device's manufacturer, model, country of manufacture, picture, and operation constraints (e.g. minimum operating pressure, or maximum operating concentrations of iron, manganese, etc.).
2. Specific characteristics page: includes information that is commonly used to calculate the values of sustainability indicators such as: device's energy consumption, installation skill required, configuration type, treatment train, and number of replacement components.
3. Standards certification page: includes information on which NSF/ANSI standards the device is certified to and the specific contaminants which the device claims to reduce.
4. Sustainability indicators page: includes an explanation of how each indicator is calculated and information that is specific for calculating an indicator.

The third user interface is a questionnaire that a user can use to assign relative weights to the sustainability indicators, objectives, and criteria groups. Establishing the relative importance is essential for aggregating a sustainability score. The pairwise comparison method, an Analytical Hierarchy Process technique, is used for developing relative weights (Lai et al. 2008; Saaty 2008). The user selects a circle that represents the relative importance between two indicators based on Saaty’s scale. Saaty’s scale assigns scores ranging from 1 for equally important factors to 9 when one of the factors is extremely more important than the other. The interface also automatically checks for the consistency of the pairwise comparison and requires that the user revise the input if the results are inconsistent. The results feed into another sheet that employs matrix algebra to calculate the relative weights based on the user’s response (Hamouda et al. 2012).

**POU and POE knowledgebase**

Figure 1 illustrates how the knowledgebase is at the core of D4SPOUTS and that it includes three critical modules that constitute the ‘brain’ of D4SPOUTS, namely: the sustainability evaluation module, the Pass/Fail screening module, and the rating and ranking module. The knowledgebase is a large worksheet in the Excel® based DSS with around 750 columns of data relevant to the three modules. User input updates data in the knowledgebase, making it ready to feed into the output of D4SPOUTS. To ensure a comprehensive sustainability assessment of the POU and POE alternatives, D4SPOUTS was designed to include many sustainability variables. This consequently requires numerous data to be gathered for each device to have a full description that allows for proper assessment. The required data were not readily available, thus currently the knowledgebase only has a small number of devices with complete information to allow for screening and sustainability evaluation. This is the main reason why the knowledgebase editor was developed, to add more devices and ensure their proper characterization.

The sustainability evaluation module uses data from the knowledgebase editor and from the case input user interfaces to calculate the values for the 20 sustainability indicators (Table 1 and Figure 2). The Pass/Fail screening module then triggers a number of rules to check if any of the devices in the knowledgebase fails to satisfy any of the...
constraints set for the case under analysis. Table 2 shows a list of constraints and the corresponding device characteristic that is required for the device to pass the screening rule used in the screening module. The rules help reduce the number of alternatives such that only feasible alternatives that pass all the screening rules are then run through the rating and ranking module. This final module evaluates the objectives’ scores and the aggregated sustainability score using the weights ($w$) specified by the user earlier (user defined or default weights). The aggregation is based on a simple weighted sum equation:

$$\text{Sustainability Score} = \sum_{\text{groups}} w_{\text{criteria group}} \left( \sum_{\text{objectives}} w_{\text{objective}} \left( \sum_{\text{indicators}} \text{Value}_{\text{indicator}} \times w_{\text{indicator}} \right) \right)$$

The case study that was entered only triggered one screening rule which considered contaminant reduction claims. Out of the 10 devices in the knowledgebase, only four devices removed lead and thus only these four were considered among the feasible devices. Sustainability scores for the feasible devices are then calculated and used to rank them. Results are then copied to D4SPOUTS output.

### D4SPOUTS output

D4SPOUTS has two output modules. The first output module is the ‘Device characteristics information’ which is presented to the user when a device is entered, updated, or selected by the user in the knowledgebase editor. The module is also set to show the details of the top device in the shortlisted results from a case run. The module provides a summary of all the characteristics of a device entered through the knowledgebase editor. In addition, it displays the sustainability scores of that device from the latest case run. This type of output can be useful to users requiring details on devices being considered for pilot study or for purchase and installation. The second output module presents a case summary (Figure 3) which includes: most of the information from the case user interface; a shortlist of the six top rated devices and their sustainability objectives, criteria groups, and sustainability scores; and other details. This type of summary report is useful for users who require a simple recommendation as to which device to choose, without having to understand the reasons for the recommendation.

To understand the reasons behind D4SPOUTS recommendations, additional illustrations reveal underlying characteristics influencing the decision. Figure 4 shows radar diagrams for the sustainability criteria groups’ scores of the top four devices. The diagram has four axes representing the four criteria groups, each ranging from 0 to 1. The point where the axes meet corresponds to a value of 0 – the lowest score in terms of sustainability. The highest value is 1, representing the highest score in terms of sustainability. The device’s score in each criteria group is plotted on its corresponding axis then a polygon is formed by joining the scores on the four axes. The radar diagram shows the device scores without considering the criteria groups’ weights. For example, even though the device model PNRQ15FBL was ranked at the top of the devices, it is clear from the figure that it is weak in terms of socio-cultural sustainability and may not be readily accepted by consumers. This insight into the underlying criteria groups’ sustainability scores may influence the decision by relying on visual judgment not obscured by aggregation techniques. This abstract...
The display of scores is further expanded in histogram plots that D4SPOUTS generates to display a complete picture of the comparative sustainability of the devices and their achievement of the sustainability objectives (Figure 5). This provides the user with more information that can help in justifying the results. Furthermore, a user may choose to rely on these un-weighted values instead of the aggregated scores in selecting the device to install.
Other potential uses of D4SPOUTS include the ability to check if a previously installed device is capable of removing a contaminant other than the one it was installed to remove, or if it can sustain a drop in system pressure or a turbidity spike, or simply to learn more about the characteristics of the device and its sustainability. Such information is available from the knowledgebase editor, and by selecting the device being investigated, the user can get answers to all the above questions. For example, it may be the case that after selecting and installing the top ranked device (GE Model # PNRQ15FBL) for lead removal, it was discovered that the source water included elevated concentrations of hexavalent chromium. The question in this case would be: Is the installed device certified to remove this contaminant? The knowledgebase provides confirmation that the device is certified to remove hexavalent chromium.

**ASPECTS OF USABILITY OF D4SPOUTS**

Ease of use is critical in ensuring that a DSS is successful in serving end users. There are many aspects of DSS usability and success discussed in the literature (e.g. Denzer 2005; Mysiak et al. 2005; McIntosh et al. 2011), the most important of which are: (1) the validity of the output; (2) the user-friendliness of the DSS’s interface and output; and (3) the sensitivity of the outcome to input changes (Heller et al. 1998). Evaluating the validity and usefulness of D4SPOUTS is difficult because there are limited published studies on quantifying the sustainability of POU and POE devices; and D4SPOUTS’ incomplete knowledgebase due to the lack of freely accessible data on many proprietary POU and POE devices. Completing the list of POU and POE devices and their full characterization using the built-in knowledgebase editor is an essential step to precede the practical application of D4SPOUTS. However, even at its current stage of development, several factors support the validity and user-friendliness of D4SPOUTS:

1. The involvement of POU and POE stakeholders in the early development phases to ensure the relevance of the sustainability indicators to the selection of devices.
2. The appropriateness of the systems analysis approach followed in the selection process of D4SPOUTS.
3. The various tweaks added to enhance D4SPOUTS’ level of interactivity, such as: the ability to set constraints that reflect user preferences, set user defined weights to sustainability indicators, and the generation of warning messages if any required information is missing.
4. The comprehensive design of D4SPOUTS’ output is to include not only a list of devices with highest sustainability rating, but also information that helps understand the reasons behind the sustainability rating.
Although a rigorous evaluation of D4SPOUTS is not yet attainable, its performance was verified by going through a typical process of program debugging, error analysis, and data input and output analysis (Heller et al. 1998; McIntosh et al. 2011). Furthermore, the sensitivity of the devices’ ranking to variations in criteria weights was investigated by altering the user defined indicators pairwise comparisons. Results are given in Table 3. The first case uses the built-in default weights of D4SPOUTS which reflect the desire to maximize technical sustainability while maintaining an acceptable level of economic and environmental sustainability, but with little regard for socio-cultural sustainability. In the second case all criteria categories are equally weighted which represents the basic approach in alternatives’ evaluation when faced with conflicting criteria. Equal weights assume equal importance of all criteria and it is clear that such an approach may change the results, as shown in Table 3. The third case assumes technical compliance is sufficient and other technical and economic factors bear no weight in the selection process, rather the focus is on environmental and socio-cultural sustainability. With environmental criteria being the most important, the bottom ranked device from the first case becomes the top ranked device.

Comparisons of the criteria group scores of these three cases indicate that varying criteria weights greatly influence the outcome of D4SPOUTS, which shows that the outcome is tailored to user requirements. Thus D4SPOUTS satisfies an important function of a DSS, which is the ability to produce case sensitive outcomes.

Table 3 | Sensitivity analysis for D4SPOUTS

<table>
<thead>
<tr>
<th>Case 1</th>
<th>Case 2</th>
<th>Case 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technical weight</td>
<td>0.42</td>
<td>0.25</td>
</tr>
<tr>
<td>Economic weight</td>
<td>0.21</td>
<td>0.25</td>
</tr>
<tr>
<td>Environmental weight</td>
<td>0.27</td>
<td>0.25</td>
</tr>
<tr>
<td>Socio-cultural weight</td>
<td>0.10</td>
<td>0.25</td>
</tr>
<tr>
<td>Device rank</td>
<td>1st</td>
<td>4th</td>
</tr>
<tr>
<td>POU device model</td>
<td>PNRQ15FBL</td>
<td>GNSV70RBL</td>
</tr>
<tr>
<td>Sustainability score</td>
<td>0.729</td>
<td>0.684</td>
</tr>
<tr>
<td>Technical score</td>
<td>0.687</td>
<td>0.596</td>
</tr>
<tr>
<td>Economic score</td>
<td>0.782</td>
<td>0.645</td>
</tr>
<tr>
<td>Environmental score</td>
<td>0.848</td>
<td>0.876</td>
</tr>
<tr>
<td>Socio-cultural score</td>
<td>0.469</td>
<td>0.620</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Case 2</th>
<th>Case 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technical weight</td>
<td>0.25</td>
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<tr>
<td>Economic weight</td>
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<tr>
<td>Environmental weight</td>
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<td>0.620</td>
</tr>
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</table>

**DISCUSSION**

There are many challenges to DSSs’ adoption and practical implementation (McIntosh et al. 2011). Nevertheless, there have been considerable efforts to develop decision support tools that employ quantitative and qualitative sustainability criteria and indicators to compare between alternative water treatment strategies (Makropoulos et al. 2008). In this paper we introduced D4SPOUTS which is intended to initiate a discussion among practitioners in the POU and POE water supply industry to highlight the importance of sustainability considerations. D4SPOUTS has been the subject of presentations/demonstrations to industry stakeholders where the focus of the discussion was on the sustainability of POU and POE systems. NSF International, the independent organization responsible for issuing POU and POE device standards, has taken a major step towards incorporating sustainability into its standards. In 2008 the NSF Sustainability program, part of which focuses on sustainability tools for the water treatment and distribution products industry, including POU and POE systems, was launched. It is envisioned that with the mainstreaming of sustainability concepts into product certification standards, the use of DSSs such as D4SPOUTS will become more valuable as the volume of data increases and decision making becomes more complex.

The development of D4SPOUTS follows a typical approach for developing DSSs. The contribution of this work is not in the form of developing a new approach, but rather in the development, for the first time, of a set of
sustainability criteria, objectives, and quantifiable indicators to properly assess the sustainability of the various POU and POE alternatives and incorporating the assessment process in an automated, user-friendly DSS suitable for a particular water treatment case. As more data on sustainability variables become available for use in D4SPOUTS, more methods or combinations of methods should be derived to incorporate the new data in the selection process. Also, data uncertainties and reliability can be included by adopting a probabilistic or fuzzy logic knowledge representation approach to increase the validity and credibility of the D4SPOUTS output (Chowdhury 2012).

It is critical that the advancement of D4SPOUTS be through an impartial organization that has the necessary expertise to restructure, update, and maintain the DSS. While the knowledgebase editor allows any user to describe and input any POU or POE device, there has to be some quality control in place to ensure proper product description, as follows:

1. Should D4SPOUTS be available for public use, data entry has to be undertaken by an independent organization and by individuals with the necessary expertise to characterize POU and POE devices.
2. Should the device characterization require some decision-making, a record log should be kept describing the issues that arose, and how the user chose to handle the situation, and which cases it applies to.
3. Should D4SPOUTS be used for characterizing and selecting among devices available as alternatives for a particular case, then the device characterization has to be carried out by an individual with the necessary expertise who will assume responsibility for the data correctness. Moreover, the updated knowledgebase should not be available for the public unless reviewed by the aforementioned independent organization.

To the best of our knowledge, D4SPOUTS is the first system to utilize decision tools that are directly and explicitly based on sustainability aspects of POU and POE systems. By linking between device and case characteristics through sustainability based decision logic, D4SPOUTS can enable more transparent and sustainable device selection. D4SPOUTS can also help create reports on the reasoning of the selection process and on device characteristics to allow for periodical reviews of its components since they are represented explicitly in its designed output (e.g. device characteristics information sheet).

**CONCLUSIONS**

This paper demonstrates a DSS that is designed to assist with the selection of suitable and sustainable POU and POE treatment devices. The ultimate purpose of D4SPOUTS is to help water suppliers, consumers, and other stakeholders to obtain ‘a short list of the most sustainable solutions’ for a given problem without having to familiarize themselves with the mathematical complexities associated with the model or the solution method.

In order to improve its usefulness, D4SPOUTS has been designed to have an effective interface built with Microsoft® Excel®. Some of the strengths of D4SPOUTS are as follows:

1. It provides comprehensive decision analysis and support, incorporating the user’s preferences, constraints, and device performance and limitations.
2. The design of the user input can help users think about decisions in a structured and systematic way.
3. The operational features of D4SPOUTS are quite user-friendly and involve a series of interactive steps to input the data as well as illustrations to enhance interaction with the user.
4. It allows the user to thoroughly explore the shortlisted alternatives and gain a better understanding of the decision reasoning.

On the other hand, some current limitations of D4SPOUTS are as follows:

1. Limited number of alternative devices in the knowledgebase. This is mainly due to lack of device characterization data, which, at least in theory, can be obtained from manufacturers or NSF International.
2. Inability to form a treatment train composed of several devices. Due to lack of data, the algorithm could not be completed.
3. Reliance on proxy indicators that may not effectively assess a particular aspect of sustainability. An example would be the indicator of market availability, which instead of relying on real market data, was assessed using information on...
marketing capabilities like store coverage and the effectiveness of online and phone sales. A full account of indicators used is given in Hamouda et al. (2012).

Even with these limitations, D4SPOUTS is envisioned to help make an informed decision based on sustainability analysis of alternative POU and POE devices. The continuous enhancement of D4SPOUTS can also help in shaping the industry’s future development by making overcoming sustainability issues a main focus for manufacturers in their product development strategies. Furthermore, D4SPOUTS is freely available to be adopted by an arm’s length association or organization to fully populate it with information and advertise it as a useful tool for selecting sustainable devices.

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**DISCLAIMER**

Mention of trade names or commercial products does not constitute endorsement or recommendation for their use by the authors or funding agencies.

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**REFERENCES**


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