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APPLICATION OF STRUCTURED DECISION MAKING AND VALUECHARTS TOOL FOR SELECTING SANITATION SYSTEMS

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Abstract

Due to the population growth and urbanization's trend, peri-urban areas that surround major cities are haphazardly increasing without proper infrastructure in the developing world. Even though the literature review points out that there are several suitable wastewater treatment system (WWTS) alternatives which could mitigate that issue, one of the main problems lies on the process of making decisions. Thus, this study applies the Structured Decision Making (SDM) instrument through the use of a particular tool for supporting the evaluation. In this view, the ValueCharts is a user-friendly tool that can easier narrow down comparable Overall multi-attributes values, mainly obtained from the performances and preferences given by participants of the decision. The outcomes from the cited tool's application have indicated the propensity to succeed WWTS alternatives that bear efficient processes in terms of environmental removals indicators.

Key words: decision making analysis, user-friendly tool, wastewater treatment system

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1. Introduction

Sewerage and drainage network systems have a long history and examples of sanitation infrastructure were found in various ancient cultures. Despite the increment and development of new technologies related to wastewater treatment systems (WWTS) at the present time, around 2.5 billion people still lack access to basic sanitation services (WWAP, 2017), in particular in the developing world. In this view, a possible overall cause that has been widely reported is the demographic trends – i.e., the rapid and haphazard unplanned urbanization. The consequences are irregular settlements by communities who establish in so-called 'peri-urban' areas (Koop and van Leeuwen, 2016), which there is not proper sanitation infrastructure. The uncertainty that arise is concerning the process of selecting the most appropriate WWTS alternative into a needed scenario. Since there is no ideal WWTS applicable to all cases, many researches have been paying a relevant attention to the use of decision-making analysis (DMA) through the use of tools to support decision-makers in the field of sanitation. There are several different DMA processes to support alternatives decisions, wherein the Table 1 summarizes important ones applied in environment approaches. Firstly, it depicts if they were adequately experienced in terms of complex decisions. Secondly, it characterizes whether the processes have acknowledged features for integrating them, or not. Thirdly, if they have considered cyclical aspects within their evaluation processes differentiation.

In spite of the fact that all of the mentioned processes can be used in complex decisions, specific criteria have defined the structured decision making (SDM) as the selected evaluation process for this

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research. In particular, the importance of the elaboration of the main approaches of the decision content. For instance, the definition of participants, indicators and alternatives. Additionally, within the SDM it is highly recommended the adaptation of the evaluation of the alternatives by the use of methods, modelling or systems (Gregory et al., 2012), as performed and seen further in this research, that can support the hierarchization of the analysis.

According to Gregory et al. (2012), the SDM can be summed up into six steps: i) clarifying the decision context and establishing the process scope; ii) assignment of indicators and weights – i.e., scores or preferences – that reflects its expected importance in determining outcomes; iii) development of the alternatives; iv) aggregating the performance of each option across all criteria; v) conducting a sensitivity analysis by varying scores and weights among the group of participants; vi) identifying the mechanisms of monitoring and reviewing the process.

Moreover, some tools are widely recognized and used for supporting the DMA processes. In this context, the Table 2 summarizes tools used within evaluation process. As cited in Table 2, the main obstacle found was that all have focused on visualization processing without contemplating interactive concerns and user-friendliness. Conati et al. (2014) argue that statement, by arguing that previous research has applied basic visualizations in a non-interactive manner (e.g., bar and radar charts), whereas in more complex scenarios, advanced and necessary interactive visualizations tools are still limited.

For those reasons, Chamberlain et al. (2014) and Lallé et al. (2016) have approached the ValueCharts tool as a set of visualizations and interactive techniques and hence targeted to support DMA. Additionally, Chamberlain et al. (2014) reported that by using the ValueCharts tool, aspects of participation, transparency, and comprehensibility can be easier achieved. In summary, the tool basically consists of a user-friendly instrument with internal process capable to support general approaches of multi-criteria and alternative analysis (Chamberlain et al., 2014). In other words, the tool permits comparison analysis regarding any field of study, since the creation of the evaluation process consists in determining multiple indicators and their respective preferences related to multiple and unrestricted alternatives.

Additionally, the ValueCharts tool can be defined as an open-source web model/tool in which its code is freely available for viewing, downloading and changing at https://github.com/ValueChart/WebValueCharts. Rather, the features of the application can be freely used or simulated over the Internet by simply accessing the URL http://valuecharts.cs.ubc.ca.

Table 1. Summary of relevant DMA used in environment evaluation process

Instrument	***Feasible to complex decisions***	***Has considered specific attention in the first steps of DMA***	***References***
Multi Criteria Decision Analysis	✓	-	Kalbar et al. (2012); Marttunen et al. (2015)
Analytic Hierarchy Process	✓	-	Loetscher and Keller (2002)
Life Cycle Assessment (LCA)	✓	✓	Amaral (2018); Ortiz-Rodriguez et al. (2018); Zang et al. (2015)
Benchmarking	✓	✓	Malano et al. (2004)
Structured Decision Making (SDM)	✓	✓	Gregory et al. (2012); Musiyarira (2012); Robinson et al. (2017)

Table 2. Summary of relevant tools within DMA used in complex evaluation decisions

Tool's name	***Open to insert indicators and alternatives***	***Does not require advanced technical background***	***Allows weighting and preferences restatement***	***Considers both visual and interactive features***	***References***
Electre	-	✓	-	-	Kalbar et al. (2012); Comanita et al. (2015)
Promethee	✓	-	-	-	Kalbar et al. (2012)
TOPSIS	-	-	✓	-	Kalbar et al. (2012)
OpenLCA	✓	✓	-	-	Dubcová et al. (2017), Li and Feng (2018)
Capdet-Works	-	-	✓	-	Hydromantis (2017)
Benchmarks	✓	✓	-	-	COST (2018)
ETEx	-	✓	✓	-	ETEX (2018)
ValueCharts	✓	✓	✓	✓	Conati et al. (2014)

Therefore, this study has transcended the regular application of SDM by inserting tools that bear user-friendliness, visualization and interactive techniques within the process specific steps. The main contribution was to propose the use of the ValueCharts for accomplishing the evaluation process of most scored WWTS alternative into a peri-urban scenario.

2. Methods

The overall research's design basically follows the steps of the original SDM (Gregory et al., 2012) methodology. Therefore, the framework shown in Fig. 1 introduces each step of the process within the application study and hence how the data collection was performed. The sequence and each step are elucidated subsequently.

2.1. Scenario description step

In light of the problematic conjuncture previously discussed, the first step has comprehended in the description of the scenario selected. It is related to areas that surround urbanized settlement zones in the developing world, that lack basic needs. Since examples of these scenarios are commonly found in many developing countries, this study has focused on a Brazil's community, namely Jardim Arapongas, located within the municipality of Colombo, state of Parana.

This step also considers identifying groups that somehow provide relevant information to the process. As stated by World Bank (2006), "any group that asserts an interest can be treated as a stakeholder" of the decision content. In the water services context, they can be consumers, community-based organizations, workers, private firms, politicians, specialists, amongst others. In this view, the existing literature on defining stakeholders is extensive and focuses particularly on stating that the most important group of participants are usually customers (Guest et al., 2009; Muga and Mihelcic, 2008; OECD, 2015; World Bank, 2006). Therefore, the stakeholders were divided into three different groups, in which the engagement has occurred as follows:

- Community's group (CG) of 16 households, including just residents who live within the area and owners of small local enterprises, that have applied only the ValueCharts tool. The participants live in the selected peri-urban scenario, and the information was collected through the application of a semi-structured interview and thereafter inserted into the tool;
- Likewise, the outcomes within the government group (GG) were collected through the application of the ValueCharts tool. The size of this group, as well as the third group (specialists), was different given its representability in the context of the scenario. The entire inquiry process has considered 5 public servants from different areas. However, all associated with basic infrastructure management, financial resources, and politics of that specific area that generally make decision in water governance. For instance, biologist, environment engineering, administrator and city councilors. This research approaches only local representatives given the national mandatory regiment that specify that the responsibility for providing basic sanitation services for the population is responsibility of the municipality government level (Brazil, 2007);
- Finally, both PS-WWTS and ValueCharts tool were applied with the specialists' group (SG). Similarly of the government group, this was represented by 7 general technicians. Between the participants, civil and environmental engineers with background in sanitation field. Also, a biologist and another chemical technician who both operate with solid waste management.

The results were analyzed in both particular (each group) and total participants perspectives. It has intended to seek the behavior and trends of each group, and also if there have been common interests when performed the combination of each group concern.

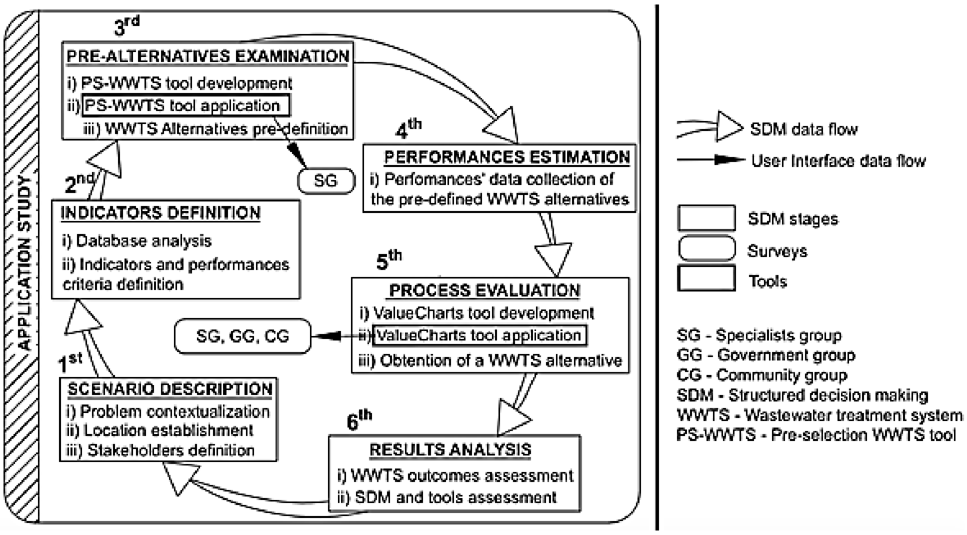


Fig. 1. Overall research's design

In addition, in order to characterize the representativity of the community population sample, and hence evaluate the results of the application of the evaluation method (as further detailed), a statistical analysis supports the findings based on 95% confidence (Eq. 1).

$$\left| n = \frac{N.\sigma^2.(Z\,{}^{a}\!/_{2})^2}{(N-1).E^2 + \sigma^2.(Z\,{}^{a}\!/_{2})^2} \right| \quad (1)$$

where: according to Levin (1987), *n* is the sample size and *N* is the size of the total individuals' sample, is the critical value correspondent to the confidence level, α is the standard deviation and *E* is the admitted error.

The results of the application of the statistical analysis is discussed further with the analysis of the tools' application.

2.2. Indicators definition step

The second SDM's step is related to the definition of the indicators' set. According to Muga and Mihelcic (2008) and Venkatesh et al. (2014), it is consistent to define a set of most commonly used indicators from another research. Thus, an extensive examination was performed in academic literature associated with DMA and WWTS definitions.

In this view, the database assisted design has considered the use of the free access ASCE (2019) mechanism. Moreover, some terms such as "indicators", "WWTS", "comparison", "evaluation", "treatment performances" were merged and hence inserted in the ASCE for accessing the database. A subsequent assessment of the obtained set of manuscripts was achieved, and from several different ones, only a limited group of peer-review studies was selected.

Finally, based on the defined group of selected research, the four principles for defining the final set of indicators were (i) representativeness, specifically in terms of the percentages of repetition based on a delineated borderline of 18% of repetition for this research (the indicators equal or above this value are represented in bold in Table 3), and hence those ones above that line were disregard; (ii) overlaps and similarities; (iii) the indicators should contemplate the three main groups (environmental, economic and social); (iv) the availability of performance's data. The Table 3 describes the outcomes related to the frequency of occurrence of indicators commonly used in sanitation systems decisions.

Table 3. Frequency of occurrence of widely used indicators within the set of 28 papers related to WWTS field

Nr. Crt.	*Environmental Indicators*	*Frequency (%)*
1.	**Nitrogen removal – N**	**54**
2.	**Phosphorus removal – P**	**54**
3.	**Organic matter removal – BOD**	**46**
4.	**Organic matter removal – COD**	**32**
5.	**Land Requirements**	**29**
6.	**Consumption of Electricity**	**25**
7.	**Pathogens removal – Fecal coliforms**	**21**
8.	**Total suspended solids removal – TSS**	**18**
9.	Global warming potential	14
10.	Chemicals consumption	14
11.	Biogas generation	14
12.	Total solids removal – TS	14
13.	Sludge bed height	7
14.	Availability of material and components of the WWTS	7
15.	Resources recovery	7
16.	Production of sludge	7
17.	Acidification	7
18.	Environmental benefits	7
19.	Sulfides production	4
20.	Availability of power source	4
21.	Availability of land	4
22.	Topography	4
23.	Average of temperatures	4
24.	Biogas recovery	4
25.	Promotion of sustainable behavior	4
26.	Abiotic depletion	4
27.	Residuals management	4
28.	Water reuse	4
29.	Heavy metals removal	4
30.	pH	4
31.	Conductivity	4
32.	Alkalinity	4
33.	***Social Indicators***	

34.	**Staffing requirements to operate the WWTS**	**18**
35.	**Odor**	**18**
36.	Community size served	11
37.	Acceptance	11
38.	Local waterborne diseases (hepatitis, cholera etc.)	11
39.	Participation	11
40.	Availability of professional skills	7
41.	Population density	7
42.	Endemic vector-borne diseases (yellow fever, malaria, etc.)	4
43.	Population growth	4
44.	***Economic Indicators***	
45.	**Operational and Maintenance (O&M) costs**	**57**
46.	**Capital costs**	**54**
47.	User costs	7
48.	Land costs	4

Sources: Ali et al. (2015); Balkema et al. (2012); Biswas et al. (2007); Chen and Chen (2013); Ellis and Tang (1991); Engin and Demir (2006); Foley et al. (2010); Gallego et al. (2008); Garrido-Baserba et al. (2016); Hellström et al. (2000); Hernández-Sancho et al. (2010); Juznic-Zonta et al. (2012); Kalbar et al. (2012); Katukiza et al. (2010); Khan et al. (2015); Kiker et al. (2005); Li et al. (2013); Lienert et al. (2016); Loetscher and Keller (2002); Massoud et al. (2009); Mills et al. (2014); Muga and Mihelcic (2008); Nogueira et al. (2009); Molinos-Senante et al. (2010); Rodriguez-Garcia et al. (2011); Shiban et al. (2010); Tanner et al. (2012); Venkatesh et al. (2014).

2.3. Pre-alternatives examination step

The third step comprehends the pre-definition of the WWTS alternatives. For reaching that, it was subdivided into two additional stages. Firstly, in the development of the PS-WWTS tool by using Microsoft Office Excel software. The tool was prepared accordingly to the procedure of a similar one created by Tilley et al. (2014), especially in terms of linking variables to possible alternatives. In other words, the PS-WWTS tool defines compatible combinations of WWTS alternatives from users' inputs. In summary, the PS-WWTS basically consists in supporting to pre-selecting a set of available WWTS alternatives associated with three basic characteristics of a constituted scenario.

Two levels summarize the PS-WWTS tool application: i) the user is inquired to insert the characteristics, namely population size, urban characteristics and organic matter loads; ii) the user is required to build the WWTS alternatives, as their own sense and considering all WWTS stages – i.e., preliminaries, primaries, secondaries, post-secondaries, and tertiaries treatment devices – given the variables imputed at the previous level. Moreover, the tool also presents summarized info regarding each device when selected by the user.

Among a set of well-known WWTS proposed in the cited tool, the Ecologically Engineered Treatment System (EETS) was included as an unconventional alternative. Previous research has established that the EETS is basically composed by tanks connected in series which have diversified ecological functions in order to treat wastewater (Mohan et al., 2010; Kumar et al., 2011). Its treatment process incorporates aeration and activated solids recycling into a design that combines aquatic plants and constructed wetland components without the use of chemicals. Kumar et al. (2011) add that the particularity of the design comprehends sequential integration of different ecological microenvironments granted by floating macrophytes (Eichhornia crassipes), submerged–emergent macrophytes (Oriza sativa) and submerged-rooted microphytes (Limna gibba). They are cultivated jointly, or in separated aeration tanks, wherein they support the organic matter and nutrients removal. Finally, given the technical specificities of this tool, it was only applied with the specialists' group of participants.

2.4. Performances estimation step

Regarding each indicator of the set of the pre-defined WWTS alternatives, as depicted in the 3rd step, the analysis of the performances was achieved by accessing data from literature reviewing. The only particular indicator which was differently defined is the 'odor removal'. Muga and Mihelcic (2008) have provided a worthwhile definition which is basically based on principles of the treatment within the system analyzed. In other words, it consists in to investigate whether the selected WWTS alternative contemplates aeration devices or anaerobic technologies.

2.5. Evaluation process step

Regarding the tool application, both managers of the analysis and applicants of the evaluation must participate. In Fig. 2 is shown how the data flow of the cited tool operates.

The feasibility of the cited web chart tool derives from the intrinsic design of the whole establishment and application process. Initially, the manager of the decision content must create the evaluation process and hence to insert different indicators and criteria types inputs, and afterwards their respective performances of each alternative. From the perspective of the comparison's evaluator, multiple and diverse users are firstly required to insert their score functions from each indicator by only dragging bars. Sequentially, the participant is required to set priorities between those indicators from the most preferred indicator, to subsequently go to the chart result. Finally, the user can modify their preferences in the chart result section, again by dragging bars if desired.

The ValueCharts has been developed concomitantly with this study by a group of research of the Faculty of Science of the Department of Computer Science at UBC, in Vancouver, BC (Canada). Basically, the ValueCharts modeling process simply converts ranks into weights based on the rank order centroid model (Mustajoki, 1999). The cited authors describe how to use the model in order to obtain the final results (Eq. 2):

$$V(A_i) = \sum\nolimits_{k=1}^{K} \upsilon_{ik}\omega_k \tag{2}$$

where: V are the overall multi-attribute values for each alternative (A_i = 1, 2, …, m) and υ_{ik} are the performances multiplied by the participants preferences associated with the i^{th} alternative and k^{th} indicator. The ω_k represents the weights' values of the k^{th} indicator and are obtained from applying the Eq. (3):

$$\omega_k = \frac{1}{k}\sum\nolimits_{l=k}^{K} \frac{1}{l} \tag{3}$$

where: l is the given order of the k^{th} indicator, K is the total number of indicators within the analysis process.

The Table 4 exemplifies with a hypothetical analysis how the cited rank order centroid model works. Firstly, it presents three fictitious alternatives (A, B and C) and their inherent performances of assumed indicators (X, Y and Z). Subsequently, it depicts an assumed performances' values given by theoretical users (USER_1, USER_2, USER_3). The values are between 0 and 1, in which 0 is given to the correspondent lowest performance while 1 is provided for the highest preferred one, of each indicator. Afterwards, it details the hierarchy in terms of relevancy also given by the users between those same indicators, through the application of Eq. 3.

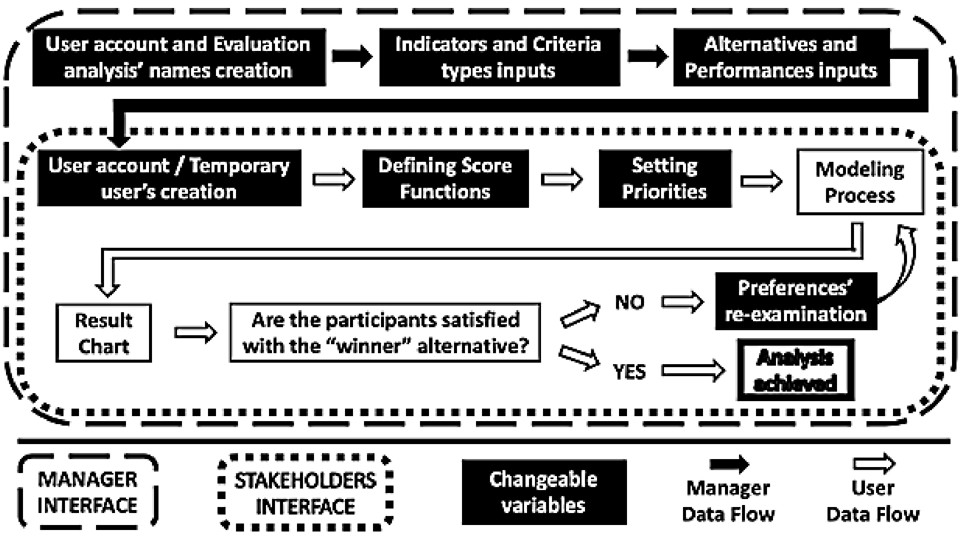


Fig. 2. ValueCharts tool scope

Table 4. Hypothetical analysis of the rank order centroid model

<table>
<tr><td rowspan="2">Alternatives (A_ith)</td><td colspan="6">Indicators' performances</td></tr>
<tr><td colspan="2">X</td><td colspan="2">Y</td><td colspan="2">Z</td></tr>
<tr><td>A</td><td colspan="2">10</td><td colspan="2">30</td><td colspan="2">60</td></tr>
<tr><td>B</td><td colspan="2">40</td><td colspan="2">50</td><td colspan="2">40</td></tr>
<tr><td>C</td><td colspan="2">80</td><td colspan="2">70</td><td colspan="2">30</td></tr>
<tr><td rowspan="2">Performances values of the X, Y and Z indicators</td><td colspan="6">Theoretical users' preferences</td></tr>
<tr><td colspan="2">USER_1</td><td colspan="2">USER_2</td><td colspan="2">USER_3</td></tr>
<tr><td>X (10, 40, 80)</td><td colspan="2">(0, 0.5, 1)</td><td colspan="2">(1, 0.5, 0)</td><td colspan="2">(1, 0.5, 0)</td></tr>
<tr><td>Y (30, 50, 70)</td><td colspan="2">(0, 0.5, 1)</td><td colspan="2">(0, 0.5, 1)</td><td colspan="2">(1, 0.5, 0)</td></tr>
<tr><td>Z (60, 40, 30)</td><td colspan="2">(0, 0.5, 1)</td><td colspan="2">(1, 0.5, 0)</td><td colspan="2">(0, 0.5, 1)</td></tr>
<tr><td rowspan="2">Indicators</td><td colspan="6">Users' Hierarchies</td></tr>
<tr><td>USER_1</td><td>ω_kth</td><td>USER_2</td><td>ω_kth</td><td>USER_3</td><td>ω_kth</td></tr>
<tr><td>X</td><td>1st</td><td>0.6111</td><td>2nd</td><td>0.2778</td><td>1st</td><td>0.6111</td></tr>
<tr><td>Y</td><td>2nd</td><td>0.2778</td><td>1st</td><td>0.6111</td><td>3rd</td><td>0.1111</td></tr>
<tr><td>Z</td><td>3rd</td><td>0.1111</td><td>3rd</td><td>0.1111</td><td>2nd</td><td>0.2778</td></tr>
<tr><td rowspan="2">Alternatives (Aith)</td><td colspan="5">Final individual scores V(A_i) in %</td><td rowspan="2">Average scores (%)</td></tr>
<tr><td colspan="2">USER_1</td><td colspan="2">USER_2</td><td>USER_3</td></tr>
<tr><td>A</td><td colspan="2">0</td><td colspan="2">39</td><td>72</td><td>37</td></tr>
<tr><td>B</td><td colspan="2">50</td><td colspan="2">50</td><td>50</td><td>50</td></tr>
<tr><td>C</td><td colspan="2">100</td><td colspan="2">61</td><td>28</td><td>63</td></tr>
</table>

Conclusively, the final scores of each alternative from the Eq. (2) application is shown. Moreover, the ValueCharts has encompassed the importance of isolating the application and accessing the results of participants individually, and in groups. For example, it allows to separate the specialists' preferences and hence to examine that from their point of view. However, a unified analysis considering all preferences was also performed as well. It was important since the tool highlights the diversity of agreements and controversies of the preferences within those different groups of stakeholders.

In this view, in order to collect the preferences and therefore to perform this current step of the method, the strategy was first to assemble specialists and government authorities (by directly applying the tool) and afterward the community group (by applying questionnaire and thereafter fulfilling the tool).

2.6. Results analysis step

Firstly, the WWTS alternatives were analyzed by the application of both PS-WWTS and ValueCharts tool. In this view, the pre-defined WWTS alternatives were evaluated through the comparison with the mostly implemented WWTS from literature review data in Brazil and Latin American countries. Subsequently, the 'winner' WWTS alternative was also inspected from the ValueCharts tool appliance.

Secondly, the analysis has focused on the evaluation of the SDM process and the tools application. Considering the obtained outcomes, it was possible to provide improvements associated with both aspects.

3. Results and discussions

The organization of this section has followed the structure of the SDM defined for this research. Then firstly concerning the scenario characterization, the Jardim Arapongas community has approximately 247,000 m^2 wherein resides approximately 2,000 people. Even considering the poor rate related to sewerage coverage of the Brazilians households (around 50%), the cited community does not have any sanitation infrastructure at all. Turning now to the indicators' definition approach, Table 3 has described the outcomes related to the frequency of occurrence of the investigated set of indicators.

It has allowed the analysis of those commonly used in DMA concerning the sanitation subject. In this view, in order to define a compiled group of indicators to be implemented within the SDM, part of the whole set has had to be disregarded. Therefore, based on the four stablished principles, the defined indicators' set is shown in Table 5. The unities of measurement are summarized in two criteria. Firstly, Table 6 presents those related to the categories type.

However, those references' ranges must be interpreted with reservation since the source are empirical values from the literature and directives concerning organic or nutrients mass removal. Those references were adapted from earlier studies compiled in a novel method related to judge the performances, as adapted in Table 6 from Silva et al. (2014), and von Sperling (2005).

Secondly, the criteria of the indicators characterized as 'continuous' are strictly dependent on values. For instance, values of square meter and kWh by treated volumes (m^3), associated with 'land requirements' and 'consumption of electricity' indicators, respectively.

Furthermore, the second step is relating to the WWTS pre-definition through the application of the PS-WWTS tool application with the specialists' participants. The set of chosen scenario basic characteristics were uniform: i) 'intermediate' related to the size of the population variable, representing a community from 10 to 5,000 people; ii) 'peri-urban areas' in reference to the urban characteristics primary indicator; iii) 'medium concentrate' of organic matter loads, i.e. – COD concentrations between 150 mg/L and 600 mg/L. Regarding the set of pre-defined WWTS by the users, they were the Waste Stabilization Pound (WSP), Upflow Anaerobic Sludge Blanket (UASB), Activated Sludge Process (ASP) and the Ecologically Engineered Treatment System (EETS).

Moreover, comparing the pre-defined WWTS set obtained from the application of the PS-WWTS with conventional systems usually built in Brazil and Latin American Countries – LAC (e.g. Chile, Colombia, Guatemala, Mexico and Dominican Republic), it can be noted that the participants have corroborated the tendency regarding the most WWTS alternatives usually installed.

Table 5. Indicators definition and criteria info

Groups	*Indicators*	*Evaluation Criteria*	*Measure unities within the SDM*
Environmental	COD removal	Categories	I to III
	NH_3-N removal	Categories	I to III
	TP removal	Categories	I to III
	TSS removal	Categories	I to III
	FC removal	Categories	I to III
	Land requirements	Continuous	m^2 / m^3. day
	Consumption of electricity	Continuous	kWh / m^3. day
Economic	Capital costs	Continuous	$ / m^3. day
	Operational & Maintenance (O&M) costs	Continuous	$ / m^3. day
Social	Staffing requirements	Continuous	p. / m^3. day
	Odor potential	Categories	I to III

Table 6. Categories of the environmental indicators

Indicators	*Efficiency's ranges for the categories criteria*		
	I – Unsatisfactory	*II – Acceptable*	*III – High*
COD Removal[1]	[0, 75]	[76, 88]	[89, 100]
NH_3-N removal[1]	[0, 75]	[76, 88]	[89, 100]
TP removal[1]	[0, 70]	[71, 80]	[81, 100]
TSS removal[1]	[0, 70]	[71, 93]	[94, 100]
FC removal[2]	[0, 60]	[61, 90]	[91, 99.9]

SOURCES: Adapted from [1]Silva et al. (2014) and [2]von Sperling (2005).

Similarly, the group of mostly chosen WWTS alternatives by the tool application also represents approximately 85% of the total implemented technologies for Brazil and LAC (Noyola et al., 2014).

Those conventional ones are the WSP, UASB and ASP. Even though the Ecologically Engineered Treatment System (EETS) might not be designated as a widely well-known WWTS, it was also chosen as the fourth pre-defined alternative by the applicants. Furthermore, the fourth step has acknowledged the assessment of the efficiencies of the four pre-defined WWTS alternatives. Table 7 summarizes the average of the obtained performances, associated with the set of pre-defined WWTS alternatives. The data referred to the all the sets of WWTS alternatives was collected from literature review. The evaluation analysis was performed in the fifth step of the SDM, by using the ValueCharts tool. Initially, Fig. 3 illustrates the weights (ω_k) of each k^{th} indicator. It represents the values given by the users when applying the interface associated to the hierarchy between the indicators. As it can be seen, the four graphs were divided into groups, starting with the community, government, specialists and finally all of them collectively.

As seen in Fig. 3, the most addressed indicator by all participants is related to organic matter removals (in terms of COD), representing an average of 12.2% of the total applications. It indicates a relevant concern to protect the environment in not receiving loads of organic matter.

In other words, the participants are interested that the WWTS have the capacity to eliminate as maximum as possible the microorganisms that might consume high amount of oxygen from the receptor water bodies after the effluent discharging.

Another relevant and concerned preference also within the environmental indicators and associated to all applicants is the 'NH3-N removal' (9.6%). This nutrient indicator is mainly responsible for inducing the process of eutrophication in the water bodies. The other environmental indicators have embodied a preference's average of 8.8% also for all users. Furthermore, by looking to the groups of stakeholders separately, what stand out in Fig. 3 are the relative differences of the 'odor potential' and 'electricity consumption' indicators. While government and specialist groups are not aware of those, the community group is indicating distinct predilections. Another group that has notably weighted the 'staffing requirements' was the government group (13.5%). Even though this research has firstly assumed that the cited group may focus on economic aspects, this result is also coherent given social concerns. Subsequently, from the users' preferences and the application of the ValueCharts, Table 8 presents the overall multi-attributes $\mathbf{V}(\boldsymbol{A_i})$. In other words, it shows the interface of the result chart from the specialists' group application.

Table 7. Efficiencies of the set of four pre-defined WWTS alternatives

Indicators	*Performances' Averages (Categories)*			
	ASP[A]	*WSP[A]*	*UASB[A]*	*EETS[B]*
Environmental				
COD Removal	88% (III)	77% (II)	70% (I)	88.2% (III)
Nitrogen Removal (NH_3)	90% (III)	56% (I)	~ 0 (I)	91.5% (III)
Phosphorus Removal (TP)	89% (III)	19% (I)	23% (I)	68.9% (I)
TSS Removal	77% (II)	60% (I)	82% (II)	97.4% (III)
FC Removal	90% (II)	99.9% (III)	72% (II)	91-99.9% (III)
Land Requirements	0.90 m^2/m^3.day	20.08 m^2/m^3.day	1.63 m^2/m^3.day	2.8 m2/m3.day
Energy Consumption	39.5 kWh/m^3.day	~ 0	~ 0	44 kWh/m3.day
Economic				
Capital Costs	\$157/m^3.day	\$69/m^3.day	\$137/m^3.day	\$227/m3.day
Operational & Maintenance (O&M)	\$0.20/m^3.day	\$0.01/m^3.day	\$0.18/m^3.day	\$0.86/m3.day
Social				
Staffing Requirements[1]	0.0006 p/m^3.day	0.0006 p/m^3.day	0.0006 p/m^3.day	0.0006 p/m^3.day
Odor Potential	Low (III)	Moderate (II)	High (I)	Low (III)

[1] Based on a given plant capacity of 3,785 m^3/day;
SOURCES: [A)] Chiranjeevi et al. (2013); Hernández-Sancho et al. (2011); Khan et al. (2011); Mburu et al. (2013); Muga and Mihelcic (2008); Morgan and Martin (2008); Mohan et al. (2010); Noyola et al. (2012); Oliveira and von Sperling (2008); Tsalkatidou et al. (2009); Sala-Garrido et al. (2011); Silva et al. (2014); Rodriguez-Caballero et al. (2014); Romero-Pareja et al. (2017); [B)] Todd et al. (2003); Wrigh et al. (1988).

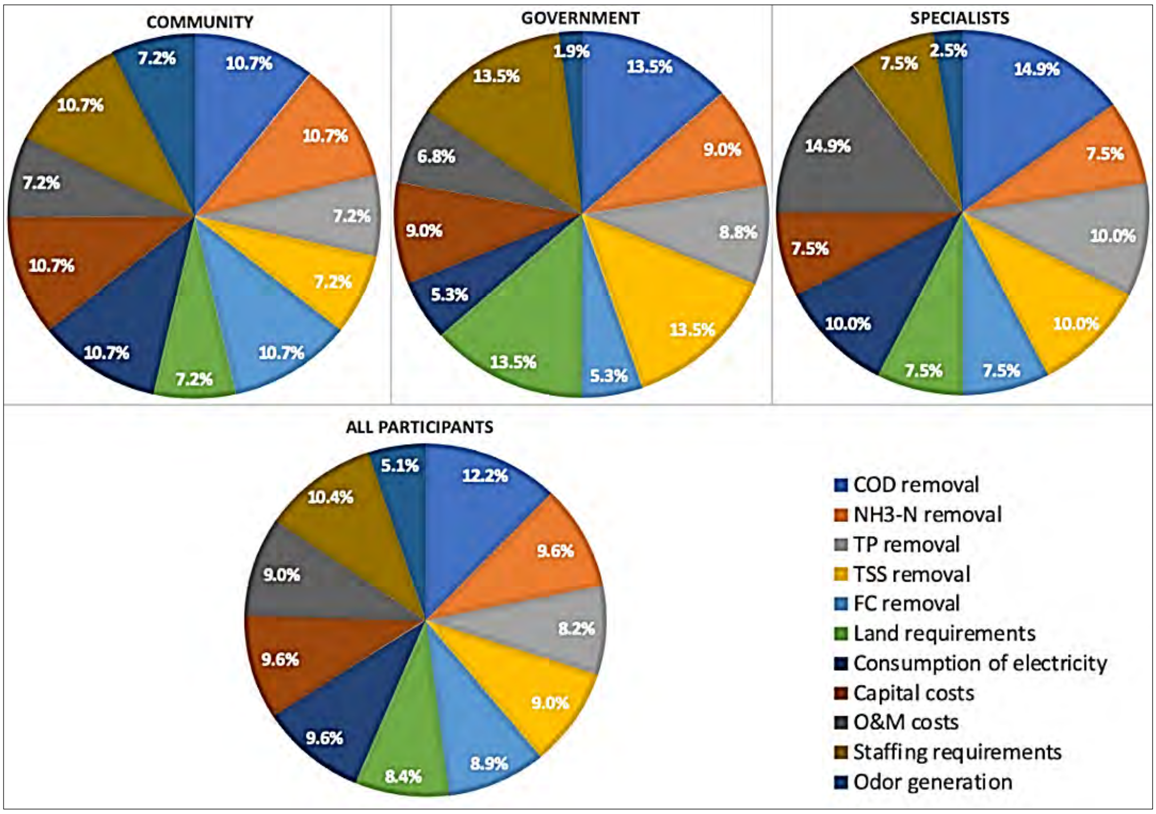


Fig. 3. Group's weights (ω_k) from the ValueCharts application

Table 8. Overall multi-attribute values given by all participants

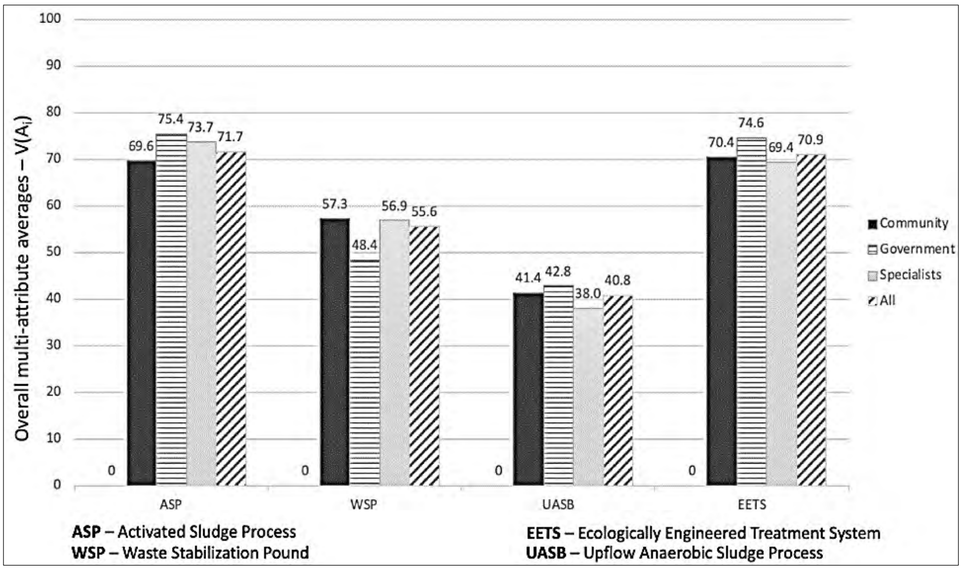
	Overall multi-attribute values $\mathbf{V}(A_i)$			
Groups	***ASP***	***WSP***	***UASB***	***EETS***
Community				
Community Member_1	**77**	67	49	72
Community Member_2	75	69	42	**85**
Community Member_3	73	72	46	**83**
Community Member_4	**65**	52	27	63
Community Member_5	**75**	51	29	74
Community Member_6	65	48	29	**68**
Community Member_7	**83**	74	60	82
Community Member_8	**67**	56	44	64
Community Member_9	**83**	48	33	82
Community Member_10	**70**	63	55	63
Community Member_11	72	33	21	**75**
Community Member_12	64	46	33	**73**
Community Member_13	58	**74**	72	57
Community Member_14	**74**	55	33	73
Community Member_15	55	41	22	**61**
Community Member_16	58	**67**	**67**	52
Government				
Government Member_1	**82**	38	37	72
Government Member_2	74	32	34	**81**
Government Member_3	65	56	41	**66**
Government Member_4	**78**	48	31	**78**
Government Member_5	**78**	68	71	76
Specialist				
Specialist Member_1	**74**	39	26	65
Specialist Member_2	**76**	51	32	69
Specialist Member_3	**81**	70	46	69
Specialist Member_4	**78**	68	52	73
Specialist Member_5	65	48	37	**67**
Specialist Member_6	72	**73**	47	66
Specialist Member_7	70	49	26	**77**

The highlighted weights (ω_k) of each k^{th} indicator as seen in Fig. 4 were obtained with the application of the Eq. (3), as depicted in section 2.5. Moreover, the application of the ValueCharts tool by all applicants has resulted in the summarized total scores (averages given by each group of stakeholders) of each alternative, as shown in Fig. 4. Each vertical bar and respective values correspond to the $\mathbf{V}(\boldsymbol{A_i})$ averages of a particular group of participants, which was obtained from the results of the equations as depicted in section 2.5. Fig. 4 indicates that the outcomes of the ValueCharts tool present similar bias when comparing all groups and their averages. For instance, the standard deviations go from 2.01 (UASB) to 4.14 (WSP) between the $\mathbf{V}(\boldsymbol{A_i})$ averages for each WWTS alternative. As also shown in Fig. 4, the ASP has received the highest average scores, while the UASB the lowest. A possible explanation for this might be that, particularly, the most weighted indicators by the participants are those inserted within the environmental group of indicators. Indeed, the ASP has shown efficient COD and nutrients removal performances (for details see Table 7). Nevertheless, the UASB has presented the lowest efficiencies of the same parameters. Another important aspect is that EETS was the second highest scoring WWTS alternative. Certainly, because of its similar characteristics to the ASP in terms of environmental performances. Notwithstanding, the EETS has received a slightly less total score than the ASP given the fact that the performances are related to 'phosphorus removal' and 'O&M' indicators.

Additionally, as seen in Fig. 4, the UASB has received the lowest (38.0) total scores on average by the specialists' group. Indeed, the most weighted indicators by the specialist group are those also inserted within the environmental group. In this view, while the ASP has shown high COD removal performances, as well as in terms of nutrients removals, the UASB has presented acceptable or insufficient efficient based on the preferences of the same parameters, which indicate why the anaerobic systems has not received relevant scores in the evaluation analysis.

In summary, the outcomes from Fig. 4 show that there is a tendency of choosing aerated systems (i.e. the ASP and EETS), with Overall multi attributes orbiting 72. Additionally, all groups were consistent in not selecting the anaerobic treatment (UASB). The total scores of this cited system have been stationary between 38 and 43. These results indicate the obvious advantage in pointing out the quality of water bodies by examining all participants' judgments. In other words, it corroborates the propensity to succeed WWTS alternatives that bear more efficient process in terms of environmental characteristics removals. As shown in Fig. 3, the weights related to environmental indicators have reached an average of approximately 50% (from COD removal to land requirements) of the preferences given by the users, while economics and social aspects have divided another half of the priorities.

In this view, the ASP and EETS are the alternatives that show higher efficiencies in terms of environmental indicators. Therefore, the have presented higher scores from the application of the ValueCharts evaluation modelling. For instance, the ASP was the most scored alternative from the application of the SDM instrument. Indeed, taking in consideration all applicants' preferences from the comparison process (ValueCharts tool), the results have shown important bias for systems that have had better environmental performances in terms of removal characteristics, mainly by the participants' predilections for the indicator related to organic matter removal.



* *In bold and red* $\mathbf{V}(\boldsymbol{A_i})$*: highest overall multi-attribute given by each participant*

Fig. 4. $\mathrm{V}(A_i)$ groups' averages

Additionally, it is highly likely that the community group is more concerned with the WWTS in terms of quality of life in nearby areas and a possibility to pay more taxes from the power demand pass-through. Therefore, highlighting the preferences experiment of the community group within the decision, it might suggest that most suitable WWTS alternatives should consider some aspects occasionally neglected. In particular, those connected to the well-being of the nearby communities, i.e. – odor potential and pass-through taxes. Moreover, Table 9 summarizes the outcomes from the application of the statistical analysis of the population sample. The results of the statistical analysis and hence application of the Eq. (1) indicate that based on 95% of confidence and in the size of the sample, the difference between the average scores can be ignored. In other words, the value of E is approximately 4.9%, lower than 5%, which indicates that the two highest scoring alternatives may be considered winners in the evaluation application.

Table 9. Statistical analysis of the population sample

n	N	σ	$Z_{\alpha/2}$	E
16	2,000	0.10	1.96	~0.049

Finally, in spite of most scored WWTS alternatives by the application of the process were the ASP and EETS, the preferences of different groups and hence the scored results have expressed additional important findings. Indeed, the relevant analysis of the outcomes is not only to access a unique preferred alternative. Rather, the whole assessment allows the decision-makers to focus on to distinguish preferences from a different point of view. Additionally, to extract the main predilection of all participants and groups of users separately, and hence discuss them cyclically in order to obtain one, or even more, acceptable solutions.

4. Conclusions

The Structured Decision Making (SDM) instrument, through the use of a developed pre-selecting WWTS alternatives and ValueCharts tools were successfully applied within an evaluation decision making analysis into a peri-urban community in Brazil.

Between the evaluated alternatives the Activated Sludge Process has represented the most suitable balance of preferences between the selected indicators, mostly due to its environmental removal performances.

Although, the outcomes have shown that social indicators possess significant matter by the users' preferences, hence indicating that the second most scored (i.e. the Ecological Engineered Treatment System) also might be suitable for the scenario elected.

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