Sustainable Wastewater Treatment Alternative Selection for Small Canadian Communities Using Collaborative Decision-Making Approach

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Abstract. Budget limitations, limited access to innovative wastewater treatment (WWT) solutions, and a lack of technical assets for small communities make selecting appropriate technologies for WWT a challenge. In this study, the best–worst approach (BWM) integrated with Multi-Objective Linear Programming (MOLP) using Sequential Interactive Modelling for Urban Systems (SIMUS) software approaches to determine the optimal solution. For a theoretical small group in Canada, seven widely used WWT technology alternatives were evaluated. The assessment was based on a systematic evaluation of technical, economic, social, and environmental parameters, with multiple sub-indices being composed of each parameter. Due to the above-mentioned constraints in the selection of the WWT process for small Canadian communities, this study examines how existing primary stakeholders can contribute to select the best alternatives from seven conventional WWT techniques. Besides, it revealed freedom for criteria selection by stakeholders to influence decision-making and provide more accurate results. This study can be further implemented and utilized for further advancement related to the WWT selection process.

Keywords: Wastewater treatment · Best-worst method · Multi-objective linear programming · SIMUS

1 Introduction

The selection of suitable technologies for wastewater treatment (WWT) is indeed a challenge to allow environmental sustainability for policymakers. Due to budget constraints, insufficient accessibility to new WWT solutions and a lack of technological resources, the procurement of suitable urban wastewater treatment equipment has long been a concern for small communities (Kalbar et al. 2012). 80% of the total communities in Canada are rural villages with a population of below five thousand, and all of them have an immediate desire to upgrade their WWT municipal facilities to comply with extremely strict sewage legislations. Theories such as fiscal, technical, and social criteria need to be weighed to ensure that society achieves the greatest value from WWT programs at a competitive cost to choose the best WWT technology from a range of alternatives (Kh et al. 2019). Finding a consensus solution in the inclusion of multiple decision-makers,

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indeed a challenge to determine. Following this involvement of various stakeholders from the diverse environment, this project focuses on a collaborative decision-making framework to find the best WWT alternative that evaluates the best suitable output with considers each stakeholder's preferences and priorities. The following question rises and those will be discussed further in this work,

(1) Which criteria is more important to focus on further implementation of WWT techniques?
(2) Which alternative is most suitable from various perspectives?
(3) How multiple stakeholders will influence the decision-making process?
(4) Is the freedom of selecting criteria for decision-makers based on their expertise affect the decision-making process?

Succeeding that, this project focuses on BWM integrated with Multi-objective linear programming (MOLP) using Sequential Interactive Modelling for Urban Systems (SIMUS) software to find the optimum solution as a result. In this work, two different scenarios are considered, and then results were compared for those, namely (1) All decision-makers will consider All Criteria and (2) Decision-makers consider Criteria based on their area of expertise. This paper presents a framework of decision-support for the Selection of technologies for wastewater treatment.

2 Literature Review

This project work proposes a tool that combines two MCDM methods, that is BWM-MOLP to find out which WWT alternatives are best suitable for small communities in Canada based on identified criteria. The following section provides a detailed study of each MCDM methodology and motivation for selecting it for this project, followed by other researches related to this topic. After that, provided a foundation for selected criteria, alternatives, and stakeholders based on other pieces of literature.

2.1 Research Related to Selection of WWT Alternatives

Since many alternatives are available and many requirements are involved in the decision-making process, choosing the most suitable WWT technology is typically unpredictable and challenging (Molinos-Senante et al. 2014). As a result, authorities in wastewater management face the greatest challenge in choosing the most suitable or acceptable WWT technology (Kalbar et al. 2012). Multicriteria decision-making (MCDM) techniques can help with this issue because they take a systematic and organized approach to modeling complex decision-making situations (Phillips 2006). The current study refers to Molinos-Senante et al. (2014) developed 17 criteria for the evaluation of the feasibility of WWT developments for smaller towns, based on a thorough research study and detailed expert consultation. For the parameters examined in this analysis, these measures provide an updated suggestion to the creation of sub-indicates. Concerning all these measures, because a huge area in Canada has a lengthy and close to zero winter season, cold climate adaptability has also been considered a significant sub-index under the technical performance criterion (Kh et al. 2019). So, this project work implements this data to collaborative decision-making approach where stakeholders can contribute their own considered criteria and based on that they can produce their preferred matrix, which later referred to for decision-making.

2.2 Decision-Making Method Used

Multiple decision-making methods are available, but there are some specific advantages over other strategies using the BWM framework developed by Rezaei (2016). As it is a simple procedure that requires fewer data along with higher reliability than other traditional decision-making methods as per its consistency in results. To enhance the service quality of patients in the ICU, including various stakeholders, a collaborative decision-making process is developed. Authors used BWM-MAMCA-MOLP method to obtain a consensus solution as an output that is more consistent (Sivakumar et al. 2021). The distinctions in the decision-making methodology lie between the present research and other findings in similar fields. This study combines the SIMUS method based on linear programming developed by Munier et al. (2019) to rank alternatives and the BWM method to determine the appropriate weights of criteria for given parameter.

2.3 Identified WWT Criteria, Alternatives, and Stakeholders

2.3.1 Criteria

All considered Criteria from various along with explanation are described in Table 1.

2.3.2 Alternatives

A hypothetical small WWT plant with a treatment capacity of 3000 population equivalent was assumed for the referred study to find an ideal WWT alternative for small communities in Canada (Kh et al. 2019). Table 2 represents identified alternatives along with its explanation.

2.3.3 Stakeholders

Four stakeholders are characterized based on considering Primary stakeholders for this study to find the most suitable alternative among 7 alternatives ("SUMMARY STAKEHOLDER ANALYSIS Water Supply and Sanitation Services ADB TA 7240-UZB," 2009).

(1) Local leaders and sub-project monitoring groups **(STKH1)**

There is a strong interest in improving the country's water supply and sanitation systems and in poverty reduction. Accountable for development cooperation, direction, program evaluation, and ensuring that all aspects relating to the achievement of program goals and the maintenance of enhanced services at the appropriate standards.

(2) Local contractors/plumbers **(STKH2)**

Quite strong interest in expanded possibilities for work related to the meter installation and domestic water pipeline repairs.

(3) Local trainers/disseminators **(STKH3)**

Individuals promote the implementation of communication, engagement,

Factors related to knowledge and education and track shifts in stakeholder perceptions and behaviors as well.

(4) Customers and consumers (households, schools, hospitals, enterprises, etc.) **(STKH4)**

Strong interest among public institutions in receiving adequate water supply and sanitation services to enhance the standard of service to school students and hospital patients; and Extremely significant interest in obtaining increased and enhanced supply of piped water to their homes.

3 Proposed Framework

3.1 Best-Worst Method (BWM)

Step 1: Identify a set of Criteria and Alternatives for WWT

Initially, all suitable criteria were identified to find optimal WWT alternatives.

Step 2: Identifying a set of stakeholders related to WWT

Suitable stakeholders were considered for this project work to fulfill the requirements of the proposed framework to apply this methodology.

Step 3: Identify the best and worst criteria

Stakeholders were interrogated to select the best and worst criteria among all listed criteria.

Step 4: Matrix formation for the preference of best criteria over other

On a 9-point score, stakeholders were asked to evaluate their preference for their best criterion over the other criteria, with 1 representing equal preference and 9 indicating the highest preference. Obtained resulting vector would be as follows,

$$A_B = (a_{B1}, a_{B2}, a_{B3}, \ldots .a_{Bn}) \quad (1)$$

where A_B is a pairwise comparison of the appropriate criteria, a_{Bj} suggests that the preference of B (best) over criterion j (all other criteria), and $a_{BB} = 1$.

Step 5: Matrix formation for the preference other over worst criteria

On a 9-point score, stakeholders were asked to evaluate their preference for all other criteria over the worst criteria, with 1 representing equal preference and 9 indicating the highest preference. Obtained resulting vector would be as follows,

$$A_w = (a_{w1}, a_{w2}, a_{w3}, \ldots .a_{wn})^T \quad (2)$$

where A_w is a pairwise comparison of worst criteria, a a_{jw} suggests the preference of j (all other criteria) over W (worst criterion), and a_{ww} =1.

Table 1. Identified criteria

Criterion	Sub-index	Description	Explanation	References
C1 (Economic)	EC1	Investment cost	Relates to the money outlay required for the construction, along with several costly components, including construction, machinery and equipment, infrastructure, and pipework	(Lennartsson et al. 2009; Murray et al. 2009; Bottero et al. 2011)
	EC2	OandM costs	Relates to cost of power, workers, materials, waste management, and maintenance management	
	EC3	Land area required	Refers land cost investment for a particular location or site	
C2 (Technical)	TP1	Organic matter removal	Consideration of the proportion of these contaminants removed from the influent	(Murray et al. 2009; Bottero et al. 2011; Bracken et al. 2015)
	TP2	Suspended solids removal	Consideration of the proportion of these contaminants removed from the influent	
	TP3	Nitrogen removal	Consideration of the proportion of these nutrients removed from the influent	

(*continued*)

Table 1. (*continued*)

Criterion	Sub-index	Description	Explanation	References
	TP4	Phosphorus removal	Consideration of the proportion of these nutrients removed from the influent	
	TP5	Cold climate adaptability	The addresses majority portion of Canada has a long winter season	
	TP6	Reliability	Indicates the possibility of mechanical failures as well as their effect on effluent quality	
	TP7	Ease to operation	Reflects how ease and smooth operation works along with less complexity	
C3 (Environmental impact)	E11	Sewage sludge generation	Sewage sludge is an inevitable by-product of Wastewater treatment. However, it has been used as a soil fertilizer, manufacturing, reuse, and disposal are some of the most challenging concerns that WWT sectors must deal with	(Bottero et al. 2011; Kalbar et al. 2012; Molinos-Senante et al. 2014, 2015)
	E12	Energy consumption	Indicates portions of energy consumption during operations	

(*continued*)

Table 1. (*continued*)

Criterion	Sub-index	Description	Explanation	References
	E13	Water reuse potential	Since the effluent is released to non-sensitive areas without being recycled, it is indeed worth considering the ability of WWT technologies to generate effluent of adequate quality to be repurposed	
	E14	Resource recovery potential	Energy and/or phosphorus can be extracted from wastewater using Sewage treatment technologies. Organic material in wastewater should be treated as a source of energy rather than a pool of energy	
C4 (Social impact)	SI1	Odors	WWTPs can emit unpleasant odors, which need to be addressed	(Lennartsson et al. 2009; Molinos-Senante et al. 2014; Murray et al. 2009)
	SI2	Noise	The amount of Noise pollution to close areas needs to be considered	
	SI3	Visual impact	Local environment influences and disturbance because of WWT operations	
	SI4	Public acceptance	Considers local public's opinion and perceptions	

Table 2. Identified alternatives

Notation	Alternative	Explanation	References
CW	Constructed wetland	It is a wastewater treatment system that allows the use of the natural functions of wetland plants, soils, and microbial species	(Ghodeif, 2013; Wilas et al. 2016)
SP	Stabilization pond	It is the man-made pond where wastewater is treated using naturally produced methods. The depth is normally shallow to allow light to filter and sustain the photosynthesizing operation of the algae found within	(Wilas et al. 2016)
EA	Extended aeration	It is the redesign of the conventional sludge procedure that is selected for smaller applications where technical flexibility compensates for lower operational effectiveness	(Matsui 1996; Metcalf and Eddy 2004)
MBR	Membrane bioreactor	The use of a membrane procedure in connection with a traditionally attached growth bioreactor	(Wilas et al. 2016; Li and Yang 2018)
RBC	Rotating biological contactor	It represents a set of closely spaced adjacent discs mounted on a revolving shaft suspended above the wastewater's layer	(Ravi et al. 2015)
TF	Trickling filter	It is a biological wastewater treatment system in which sewage streams inward, creating a biofilm that covers the media surface	(Bressani-Ribeiro et al. 2018)
SBR	Sequencing batch reactor	It is based on the sludge activation process where many of the procedures, including loading, reacting, settling, and drawing, take place in the same reactor	(Ghodeif 2013; Li and Yang 2018)

Step 6: Formulate the weight of criteria

The optimal weights of the criteria ($w_1^*, w_2^*, \ldots\ldots, w_n^*$) were then determined to fulfill the following mentioned requirements and conditions. The estimated solution for each pair of w_B/w_j and w_j/w_w, can be $w_B/w_j = a_{Bj}$ and $w_j/w_w = a_{jW}$. Maximum among pair of $\{|w_B - a_{Bj}w_j|, |wj - a_{jW}\ w_W|\}$ must be minimized to obtain optimal results. Formulation of provided problem:

$$\begin{gathered} min, max_j\{|w_B - a_{Bj}|, |w_j - a_{jw}w_w|\} \\ \sum_j w_j = 1 \\ \text{Where, } w_j \geq 0, \text{ for all j} \end{gathered} \tag{3}$$

Formulating the above equation to linear programming,

$$\begin{gathered} \min\ \xi^L \\ \text{Subject to} \\ |w_B - a_{Bj}w_j| \leq \xi^L \text{ for all j} \\ |w_j - a_{jw}w_w| \leq \xi^L \text{ for all j} \\ \sum_j w_j = 1 \\ \text{Where, } w_j \geq 0, \text{ for all j} \end{gathered} \tag{4}$$

ξ^L depicts consistency in data, which is more ideal when it is close to zero. So, it is one of the verifications of the process, which shows how reliable and consistent data processed.

3.2 Multi-Objective Linear Programming (MOLP)

Step 7: Construct Initial Decision Matrix as Input

In the first stage, SIMUS requires few inputs from the decision-maker must note the project title, the directory where the project will be saved, and the number of criteria and alternatives that will be included in this program. And weight obtained from the BWM method will be assigned to the weight field.

Step 8: Allocating operator, objective function, and normalization method

Based on the nature of the criteria, STKH needs to allocate operators (less than or equal to, greater than or equal to, or equal to) to each criterion.

Step 9: Solving the Multi-Objective Linear Programming (MOLP)

At the very first step, SIMUS removes the first criterion from the decision matrix and uses it as an objective function. Then, based on the remaining set of criteria, all alternatives are evaluated to comply with that objective function. The solver algorithm is being used for this, to determine whether or not a feasible solution to the problem exists.

Step 10: Determination Ranking of Efficient Result Matrix (ERM)

Afterward, SIMUS performs two operations, which both depend on the ERM. It examines the ERM vertically which is column by column and evaluates the sum of its values (positive and negative). After that, it applies a coefficient based on the number of times each alternative contributes to a solution to this result. It then generates a ranking of projects or alternatives known as 'Ranking ERM'.

Step 11: Determination Ranking of Project Dominance matrix (PDM)

In this procedure, SIMUS analyses the ERM horizontally which is calculating how many times a project or alternative outranks others in all criteria. Which is creating a new matrix called the "Project Dominant Matrix" (PDM), and generating a ranking of projects or alternatives based on the difference in the number of times each project or alternative outranks and is outranked by others. This discrepancy generates values that can be used in a ranking algorithm known as 'Ranking PDM.'

Step 12: Result analysis and final selection of best alternative

Need for the second matrix which will help Decision maker (DM) in the following 3 cases,

(1) If both rankings match, as they often do – although that is not needed – it strengthens the ERM result.
(2) Whether there are discrepancies between the two rankings, these will assist the DM in making a decision when two or more values in the ERM are too similar for the STKH to be certain which one to choose, thus breaking a tie.
(3) Both rankings are rarely completely different, and if they are, PDM informs the STKH of the need for information revisions.

4 Implementation of Proposed Framework

4.1 Scenario 1: All Decision-Makers Will Consider All Criteria

Step 1–2: Identify a set of criteria, alternatives and stakeholders for WWT.

As discussed in the literature review section, the data presented in Table 3 is utilized for futher study (Molinos-Senante et al. 2014).

Step 3–5: Identify the best and worst criteria and matrix formation

Here, we have more than 9 criteria (i.e., 18), so we have to divide those into clusters of C1 (Economic), C2 (Technical), C3 (Environmental impact), C4 (Social impact) to apply BWM methodology. First of all, making pair-wise comparisons for all four criteria, and determination of Best and Worst Criteria for Clusters. Then, matrix determination using preference values for best over others and worst over others. Similarly repeated same process for C1, C2, C3, C4.

Step 6: Formulate the weight of criteria

At last, all matrix with being aggregated to find optimal weights for each criterion. Table 4 shows the aggregated weights for each criterion. In this study, all preference values are taken hypothetically, and the solution will be better and modified after actual values from decision-makers. Moreover, obtained **Ksi*** values are as close as possible to 0, which depicts accurate results and assumptions.

Step 7: Construct Initial Decision Matrix as Input

First of all, SIMUS demands the Title of the project, number of alternatives, and number of criteria. According to this data, there are 18 criteria and 7 alternatives in this work. And then it will generate an 18 $\times$ 7 matrix.

Table 3. Criteria and sub-indices to assess the overall performance (modified after Molinos-Senante et al. 2014)

Criterion	Sub-Index	Description	Units	CW	SP	EA	MBR	RBC	TF	SBR
C1 (Economic)	EC1	Investment Cost	€a/p.e	219	199	239	355	355	347	391
	EC2	OandM costs	€/m^3	0.119	0.17	0.203	0.3	0.1	0.18	0.18
	EC3	Land area required	m^2/p.e	4.5	4	0.52	0.25	0.4	0.35	0.35
C2 (Technical)	TP1	Organic matter removal	–	0.7	0.75	0.85	0.89	0.8	0.85	0.8
	TP2	Suspended solids removal	–	0.8	0.7	0.9	0.99	0.8	0.7	0.9
	TP3	Nitrogen removal	–	0.5	0.3	0.7	0.7	0.5	0.45	0.65
	TP4	Phosphorus removal	–	0.4	0.55	0.45	0.5	0.2	0.45	0.45
	TP5	Cold climate adaptability	–	0.1	0.1	0.5	0.5	0.9	0.9	0.5
	TP6	Reliability	–	0.5	0.5	0.7	0.5	0.7	0.3	0.7
	TP7	Ease to operation	–	0.7	0.7	0.3	0.1	0.3	0.3	0.5
C3 (Environmental impact)	E11	Sewage sludge generation	Kg/m^3	0.06	0.06	0.5	0.7	0.3	0.3	0.41
	E12	Energy consumption	kWh/m^3	0.06	0.06	0.5	0.7	0.3	0.3	0.41
	E13	Water reuse potential	–	1.73	0.85	1.22	0.85	0.8	0.85	0.85
	E14	Resource recovery potential	–	0.3	0.3	0.5	0.7	0.5	0.5	0.7
C4 (Social impact)	SI1	Odors	–	0.7	0.7	0.3	0.3	0.5	0.5	0.3
	SI2	Noise	–	0.3	0.3	0.7	0.7	0.5	0.5	0.7
	SI3	Visual impact	–	0.1	0.1	0.7	0.7	0.7	0.9	0.5
	SI4	Public acceptance	–	0.7	0.7	0.5	0.5	0.5	0.3	0.5

(Note: CW = constructed wetland, SP = stabilization pond, EA = extended aeration lagoon, MBR = membrane bioreactor, RBC = rotating biological contactor, TF = trickling filter, SBR = sequencing batch reactor, OandM = operation and maintenance, p.e. = population equivalent. The monetary cost is measured in Euro (€). Converting the monetary cost into Canadian dollars would not affect the final ranking results.)

Table 4. Aggregated weights for each criterion

		STKH1	STKH2	STKH3	STKH4	Average
C1	EC1	0.4456	0.1308	0.0073	0.0067	0.1476
	EC2	0.1421	0.0275	0.0696	0.0658	0.0763
	EC3	0.0452	0.1721	0.0110	0.0141	0.0606
C2	TP1	0.0070	0.0297	0.0333	0.0325	0.0256
	TP2	0.0058	0.1040	0.0115	0.0072	0.0321
	TP3	0.0058	0.0416	0.0045	0.0081	0.0150
	TP4	0.0087	0.0693	0.0192	0.0325	0.0324
	TP5	0.0116	0.0223	0.0096	0.0427	0.0215
	TP6	0.0174	0.0416	0.0144	0.0081	0.0204
	TP7	0.0070	0.1263	0.0064	0.0034	0.0358
C3	EI1	0.0135	0.0262	0.3142	0.0324	0.0966
	EI2	0.0783	0.0126	0.0615	0.0486	0.0503
	EI3	0.0185	0.1039	0.0376	0.0243	0.0461
	EI4	0.0162	0.0225	0.0922	0.0486	0.0449
C4	SI1	0.0163	0.0114	0.1927	0.0792	0.0749
	SI2	0.0796	0.0042	0.0402	0.3169	0.1102
	SI3	0.0181	0.0426	0.0212	0.1585	0.0601
	SI4	0.0633	0.0114	0.0536	0.0704	0.0497

Step 8: Allocating operator, objective function, and normalization method

Then, according to the nature of the criteria operators will be allocated and the RHS limit will be assigned as well (Fig. 1). Besides that, all weight will be assigned which is determined in step 6.

Step 9: Solving the Multi-Objective Linear Programming (MOLP)

After selecting the normalization method as the Euclidean formula method in the earlier step, and click the automatic analysis button, all criteria will be considered the objective function and at that time rest all criteria will be considered as constraints and operations will be performed to find a feasible solution for each equation.

Step 10: Determination Ranking of Efficient Result Matrix (ERM)

In this step, the efficient result matrix were generated. Figure 2 highlights the efficient result matrix for Scenario 1.

Step 11: Determination Ranking of Project Dominance matrix (PDM)

In this stage, the project dominance matrix are determined. Figure 3 shows for the Scenario 1.

ALTERNATIVES >								Action	Operator LHS	RHS Limits	Weight
219	199	239	355	355	347	391	1	MIN	>=	199	0.148
0.119	0.179	0.203	0.303	0.173	0.18	0.185	2	MIN	>=	0.119	0.076
4.5	4	0.52	0.25	0.4	0.35	0.35	3	MIN	>=	0.25	0.061
0.7	0.75	0.85	0.89	0.8	0.85	0.8	4	MAX	<=	0.89	0.026
0.8	0.7	0.9	0.99	0.85	0.7	0.9	5	MAX	<=	0.99	0.032
0.5	0.3	0.7	0.7	0.5	0.45	0.65	6	MAX	<=	0.7	0.015
0.4	0.55	0.45	0.5	0.2	0.45	0.45	7	MAX	<=	0.55	0.032
0.1	0.1	0.5	0.5	0.9	0.9	0.5	8	MAX	<=	0.9	0.022
0.5	0.5	0.7	0.5	0.7	0.3	0.7	9	MAX	<=	0.7	0.02
0.7	0.7	0.3	0.1	0.3	0.3	0.5	10	MAX	<=	0.7	0.036
0.06	0.06	0.5	0.7	0.3	0.3	0.41	11	MIN	>=	0.06	0.097
0.06	0.06	0.5	0.7	0.3	0.3	0.41	12	MIN	>=	0.06	0.05
1.73	0.85	1.22	0.85	0.85	0.85	0.85	13	MAX	<=	1.73	0.046
0.3	0.3	0.5	0.7	0.5	0.5	0.7	14	MAX	<=	0.7	0.045
0.7	0.7	0.3	0.3	0.5	0.5	0.3	15	MIN	>=	0.3	0.075
0.3	0.3	0.7	0.7	0.5	0.5	0.7	16	MIN	>=	0.3	0.11
0.1	0.1	0.7	0.7	0.7	0.9	0.5	17	MIN	>=	0.1	0.06
0.7	0.7	0.5	0.5	0.5	0.3	0.5	18	MAX	<=	0.7	0.05

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Fig. 1. Initial decision matrix with operators for Scenario 1

Efficient Results Matrix (ERM) Normalized

	Project 1	Project 2	Project 3	Project 4	Project 5	Project 6	Project 7
Criterion 1		0.83	0.11	0.05			
Criterion 2	0.73		0.27				
Criterion 3				0.08		0.92	
Criterion 4		0.26				0.74	
Criterion 5			0.75			0.25	
Criterion 6			0.75			0.25	
Criterion 7		0.26				0.74	
Criterion 8					0.75	0.25	
Criterion 9					1.00		
Criterion 10	1.00						
Criterion 11	0.94			0.06			
Criterion 12		0.89				0.11	
Criterion 13	0.26					0.74	
Criterion 14						0.67	0.33
Criterion 15	0.11			0.89			
Criterion 16		0.84		0.12		0.04	
Criterion 17		0.86		0.14			
Criterion 18	0.17	0.47		0.19	0.17		
Sum of Column (SC)	3.21	4.40	1.88	1.53	1.92	4.72	0.33
Participation Factor (PF)	6	7	4	7	3	10	1
Norm. Participation Factor (NPF)	0.33	0.39	0.22	0.39	0.17	0.56	0.06
Final Result (SC x NPF)	1.07	1.71	0.42	0.60	0.32	2.62	0.02

Fig. 2. Efficient result matrix for scenario 1

Project Dominance Matrix (PDM)

Dominant proj.	Project 1	Project 2	Project 3	Project 4	Project 5	Project 6	Project 7	Row sum of dominant projects	Net dominance
	Subordinated projects - alternatives - options								
Project 1		3.0	2.9	2.9	3.0	3.0	3.2	18.1	4.5
Project 2	4.2		4.3	3.9	4.2	3.7	4.4	24.8	12.8
Project 3	1.6	1.8		1.8	1.9	1.4	1.9	10.4	-4.8
Project 4	1.2	1.0	1.5		1.4	1.4	1.5	8.0	-7.3
Project 5	1.8	1.8	1.9	1.8		1.7	1.9	10.8	-4.5
Project 6	4.5	4.0	4.2	4.6	4.5		4.4	26.2	15.0
Project 7	0.3	0.3	0.3	0.3	0.3			1.7	-15.7
Column sum of subordinated projects	13.6	12.0	15.2	15.3	15.3	11.2	17.3		

Fig. 3. Project dominance matrix for scenario 1

Step 12: Result analysis and final selection of best alternative

As mentioned in Sect. 3, if any difference between ERM and PDM happens, dominance found in PDM will be utilized to break a tie. There is just one change in the ranking by 4^{th} and 6^{th} position between MBR and RBC. Notice that, the value of RBC in PDM is −4.5, which is indeed higher than MBR with –7.3. So, the final ranking would be as follows,

$$\mathbf{TF > SP > CW > RBC > EA > MBR > SBR}$$

4.2 Scenario 2: Decision-Makers Consider Criteria Based on Their Area of Expertise

Step 1–2: Identify a set of criteria, alternatives and stakeholders for WWT

In this case, Stakeholders will only consider criteria based on their field of knowledge or they perceive that it might be useful to consider. So, here STKH has the freedom to select criteria based on their preferences. And alternatives will remain the same as earlier. Based on that, hypothetically, some criteria were removed based on some stakeholder's background and are shown in Table 5.

Table 5. Criteria selected by each STKH

STKH1			STKH2			STKH3			STKH4		
C1	C2	C3	C2	C3	C4	C1	C2	C3	C2	C3	C4
EC1	TP1	EI2	TP1	EI1	SI3	EC2	TP1	EI1	TP1	EI2	SI2
EC2	TP4	EI3	TP3	EI3	SI4	EC3	TP2	EI2	TP4	EI3	SI3
	TP5	EI4	TP4	EI4			TP4	EI4	TP5	EI4	SI4
	TP6		TP7				TP6				

Steps 3, 4, 5, and 6 will be performed in the same way compared to case 1

Following BWM method, Table 6 presents the obtained weight for each decision-maker.

Table 6. Weights for each decision-maker

STKH1	**EC1**	**EC2**	**TP1**	**TP4**	**TP5**	**TP6**	**EI2**	**EI3**	**EI4**
	0.2469	0.1235	0.0309	0.0926	0.1235	0.0617	0.0741	0.0617	0.1852
STKH2	**TP1**	**TP3**	**TP4**	**TP7**	**EI1**	**EI3**	**EI4**	**SI3**	**SI4**
	0.0763	0.0545	0.1908	0.2726	0.0636	0.0477	0.1908	0.0763	0.0273
STKH3	**EC2**	**EC3**	**TP1**	**TP2**	**TP4**	**TP6**	**EI1**	**EI2**	**EI4**
	0.1331	0.0280	0.1331	0.0998	0.0798	0.1331	0.2696	0.0665	0.0570
STKH4	**TP1**	**TP4**	**TP5**	**EI2**	**EI3**	**EI4**	**SI2**	**SI3**	**SI4**
	0.0813	0.1016	0.2033	0.1016	0.0339	0.1016	0.2372	0.0581	0.0813

Step 7–12: Result analysis and final selection of best alternative

As mentioned in Sect. 3, if any difference between ERM and PDM happens, dominance found in PDM will be utilized to break a tie. So, the final ranking would be as follows,

MBR > SP > EA > CW > RBC > TF > SBR

5 Discussion

5.1 Result Comparison

Table 7. Scenario comparison

SCENARIO: 1				SCENARIO: 2			
ERM		PDM		ERM		PDM	
TF	2.62	TF	15.0	MBR	9.37	MBR	37.8
SP	1.71	SP	12.8	SP	4.12	SP	28.9
CW	1.07	CW	4.5	RBC	2.44	EA	7.8
MBR	0.60	RBC	– 4.5	CW	2.37	CW	– 4.6
EA	0.42	EA	– 4.8	EA	2.08	RBC	– 5.3
RBC	0.32	MBR	– 7.3	TF	0.21	TF	– 28.5
SBR	0.02	SBR	– 15.7	SBR	0.00	SBR	– 36.0

The proposed structure is implemented successfully in both scenarios to obtain the best WWT alternative as a result for small Canadian communities (Table 7). The key difference between these two scenarios is the selection of the number of criteria in the decision-making process. The list of criteria and weights provided by stakeholders influences the ranking of alternatives; however, the main explanation for the transition in alternative ranking is due to the parameters chosen by the stakeholders. For instance, TF was highly ranked with the highest dominance alternative compared to the rest in scenario 1; in contrast, MBR was in first place in scenario 2. Both the scenarios report SBR as the lowest important alternative; whereas SBR secures second place in both the scenarios. Finally, it proves that freedom for criteria selection drives the ranking process and provides new direction to the decision-making process.

5.2 Sensitivity Analysis

SIMUS performs sensitivity analysis using marginal values for each parameter. The computation of shadow prices is done automatically, which provides information that due to unit variation of any criterion how much objectives depict changes in its value. Figures 4 and 5 were generated in results that show graphic discrimination per criterion in both the scenarios. Munier et al. (2019) mentioned that larger discrimination is better. In other word, both graphs provides information regarding importance of criteria, which later useful to priotizing criteria.

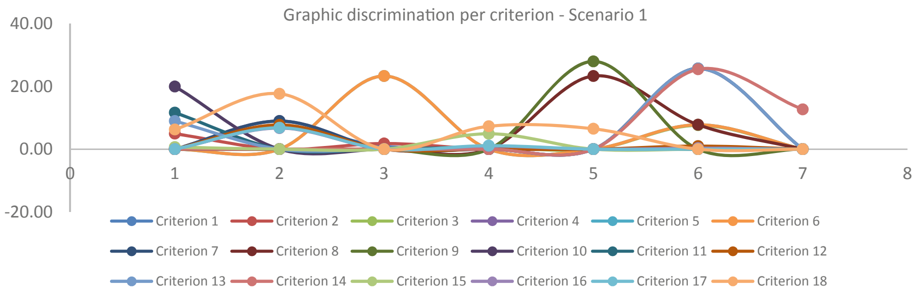

Fig. 4. Sensitivity graph for scenario 1

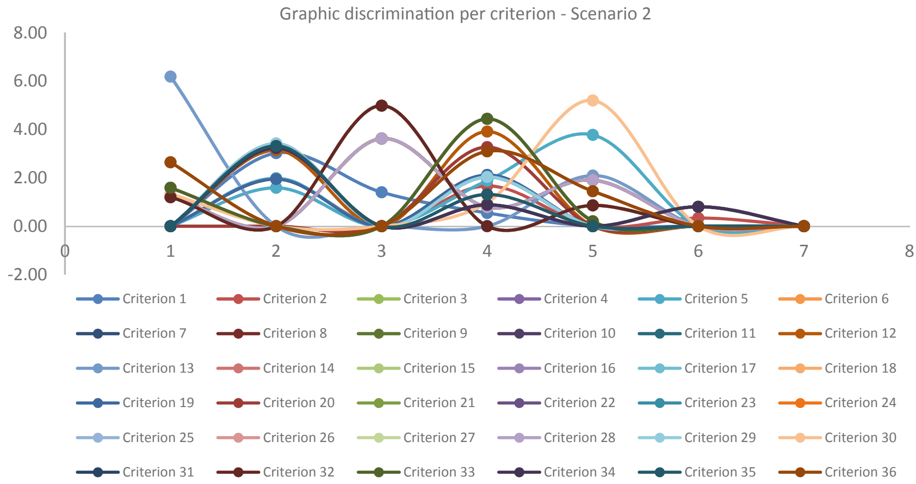

Fig. 5. Sensitivity graph for scenario 2

6 Conclusions

Determination of the best WWT alternative is a challenging and multiple-objective decision-making process that involves uncertainty that originates from ambiguous thoughts of stakeholders concerning the weighting of evaluation parameters. An integrated BWM-SIMUS approach was proposed to compare WWT alternatives by their performances for selected criteria. As BWM was selected for its more reliable and consistent results to obtain aggregated weights from stakeholders, and SIMUS was utilized to rank alternatives by considering every criterion as an objective function to obtain consensus results. The current study proves that stakeholder's liberty to identify criteria by their field of expertise can influence the decision-making process and it could shape results more precisely, as in that case stakeholders must have provided preferences on the field they have worked for a long time or they are familiar with that. However, this framework was applied to primary stakeholders only at this time, which can be applied further by considering secondary stakeholders as well to check its consistency in results. Moreover, this study can be further implemented with actual data obtained from all stakeholders and experts to determine to validate results.

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