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POLYTECHNIQUE MONTRÉAL

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A new multicriteria decision support framework on hybrid wastewater systems: application to a municipality in Quebec, Canada

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Mémoire présenté en vue de l'obtention du diplôme de *Maîtrise ès sciences appliquées*

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Ce mémoire intitulé :

A new multicriteria decision support framework on hybrid wastewater systems: application to a municipality in Quebec, Canada

présenté par **Pouria SOLEIMANI**

en vue de l'obtention du diplôme de *Maîtrise ès sciences appliquées*

a été dûment accepté par le jury d'examen constitué de :

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RÉSUMÉ

Les systèmes d'assainissement offrent des avantages importants aux communautés urbaines en protégeant la santé publique et en protégeant l'environnement. Cependant, l'urbanisation rapide, la croissance démographique et le changement climatique posent des défis aux décideurs en termes de gestion efficace et de planification stratégique de ces systèmes. Les systèmes centralisés dominent dans les zones urbaines pour la collecte et le traitement des eaux usées et que ces systèmes atteignent leur limite dans plusieurs municipalités québécoises. À l'autre extrémité du spectre, des systèmes complètement décentralisés sont implantés en régions moins densément urbanisés, posant aussi des défis sanitaires et environnementaux. Des options hybrides qui intègrent des fonctionnalités de systèmes centralisés et décentralisés sont proposées pour améliorer la durabilité et l'efficacité de la gestion des eaux usées. Cependant, les outils d'aide à la décision manquent pour guider ces choix d'investissements majeurs dans les municipalités. Dans cette étude, nous avons développé un cadre d'analyse décisionnelle pour une ville de taille moyenne dans la province de Québec, Canada, basé sur l'analyse décisionnelle multicritère (ADMC). L'ADMC permet de représenter un ensemble de critères de décision, formulés sous forme d'objectifs et organisés en une hiérarchie d'objectifs fondamentaux et de sous-objectifs, et de leur accorder un poids reflétant l'importance de chaque objectif dans la prise de décision. L'application d'un tel cadre d'analyse pour évaluer différentes alternatives permet d'obtenir un score de performance correspondant à une somme pondérée des performances de chaque alternative selon les différents objectifs de la hiérarchie. Nous avons développé six alternatives de gestion des eaux usées, incluant des systèmes centralisés, hybrides et décentralisés, en mettant en œuvre la méthode de la table de génération de stratégies. Nous avons ensuite évalué les six alternatives en fonction d'une hiérarchie d'objectifs, développée en co-création avec des experts et professionnels du milieu utilisateur. Nous avons activement impliqué ces parties prenantes en organisant deux ateliers en ligne afin d'obtenir leurs points de vue et leurs préférences, à la fois pour le développement de la hiérarchie des objectifs (reflétant les critères de décisions) et pour l'obtention de la pondération des objectifs. Le premier atelier a permis d'identifier cinq objectifs principaux pour les systèmes d’assainissement : une fonctionnalité technique élevée, des performances de traitement élevées, une protection environnementale élevée, une acceptabilité sociale élevée et des coûts faibles. Le deuxième atelier a montré que la fonctionnalité technique et les performances de traitement des systèmes étaient les objectifs principaux les plus importants pour les parties prenantes consultées, tandis que la

protection de l'environnement était considérée la moins importante dans l’ensemble. Après le développement du cadre d’ADMC, celui-ci a été appliqué à deux des six alternatives développées afin de comparer leur performance selon les objectifs identifiés et leurs pondérations obtenues des parties prenantes. Le score global final d'une alternative entièrement centralisée et d'une alternative hybride (combinaison d'un système centralisé et d'un système à petite échelle communautaire) a montré que l'alternative hybride a obtenu une valeur globale supérieure de 15.9 %. Le cadre développé offre un potentiel prometteur pour une application dans d'autres villes du Québec et du Canada, facilitant un processus de prise de décision plus éclairé concernant la gestion des systèmes de traitement des eaux usées.

ABSTRACT

Wastewater systems provide important benefits to urban communities by promoting sanitation and protecting the environment. However, rapid urbanization, population growth and climate change raise challenges for decision makers in terms of effective management and strategic planning. Large centralized systems dominate in urban areas for the collection and treatment of wastewater and they have reached their maximum capacities in many Quebec municipalities. At the other end of the spectrum, completely decentralized systems are implemented in less densely urbanized regions, also posing health and environmental challenges. Hybrid options that incorporate centralized and decentralized system functionality are offered to improve the sustainability and efficiency of wastewater management. However, decision support tools are lacking to guide these major investment choices in municipalities. In this study, we developed a decision analysis framework for a medium size city in the province of Quebec, Canada, based on the multi criteria decision analysis (MCDA). MCDA makes it possible to represent a set of decision criteria, formulated in the form of objectives and organized in a hierarchy of fundamental objectives and sub-objectives, and to assign them a weight reflecting the importance of each objective in decision-making. The application of such an analysis framework to evaluate different alternatives makes it possible to obtain a performance score corresponding to a weighted sum of the performances of each alternative according to the different objectives of the hierarchy.We developed six different wastewater management alternatives including centralized, hybrid and decentralized systems by implementing the generation table method. We further evaluated the six alternatives with respect to a hierarchy of objectives. We actively involved the stakeholders by conducting two online workshops to obtain their insights and preferences for both the development of the objective's hierarchy and the elicitation of the objective weights. The first workshop allowed to identify five main objectives: high technical functionality, high treatment performances, high environmental protection, high social acceptability and low costs. The second workshop demonstrated that high system technical functionality and treatment performances were the most important main objectives while environmental protection was the least important. The final overall value of a fully centralized alternative and a hybrid alternative showed that hybrid alternative obtained 15.9% higher overall value. The developed framework holds promising potential for application in other cities, facilitating a more informed decision-making process concerning the management of wastewater treatment systems.

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LIST OF ABBREVIATIONS

AHP	Analytical hierarchy process
BOD	Biological oxygen demand
LCA	Life cycle analysis
MAVT	Multi attribute value theory
MCDA	Multi criteria decision analysis
TSS	Total suspended solids
UWWTP	Urban wastewater treatment plant
WWT	Wastewater treatment
WRRF	Water resource recovery facility

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CHAPTER 1 INTRODUCTION

1.1 Context of the study

Wherever humans live, a persistent need for safe drinking water exists and human waste is continuously generated. Therefore, the development of human civilization has depended on the availability of drinking water and the management of human waste (Daims et al., 2006). Typically urban wastewater is a mix of discharges from homes, commercials, industries, and agricultures sectors and it contains various contaminants and pollutants such as microorganisms, nutrients, organic and inorganic matter and heavy metals (Metcalf & Eddy-AECOM, 2013). The lack of wastewater treatment systems can lead to pollution and threaten human and environmental health (Molinos-Senante et al., 2014). Hence, good management of water and wastewater increases the economic and health conditions of every country and region (Deepa & Krishnaveni, 2012). However, wastewater management is still a crucial issue in many countries even though considerable efforts have been conducted globally in recent decades to establish or improve wastewater management systems (Molinos-Senante et al., 2014). Programs to improve the sanitation systems such as Millennium Development Goal (MDG) were successful to provide sanitation systems around the globe to 2.1 billion people until 2015, however, around 2.4 billion people remained without access to upgraded sanitation systems in 2015 (Cossio et al., 2020). Later, the concept of sustainable development goals was developed and the sanitation target of these goals aims at ensuring safe sanitation facilities for everyone worldwide by 2030 (Mara & Evans, 2018).

Preventing water contamination and preserving its quality are key components of sustainable water management (Mahjouri et al., 2017). In this context, urban wastewater treatment plants (UWWTPs) are critical infrastructure components that have two main objectives. The first objective is to preserve and improve human health by breaking the illness cycle, caused primarily by fecal (microbial) contamination of water resources from human waste (although chemical and emergent contaminants are increasingly considered in wastewater management). The second objective is related to improving the ecosystem quality and protecting water by avoiding the discharge of untreated wastewater in the environment with high levels of pollutants (Capodaglio et al., 2017).

Even though in developed countries like Canada almost all the produced wastewater (95%) is treated, most treatment systems are old and costly because of growing need for rehabilitation (Molinos-Senante et al., 2014 ; Poustie et al., 2015). Therefore, additional investments in the construction or upgrade of wastewater treatment plants are needed, and governments are under pressure to provide enhanced and expanded water and wastewater services (Molinos-Senante et al., 2014 ; Poustie et al., 2015).

Wastewater treatment infrastructures have an expected lifespan of 25-100 years. Over this lifespan, they face unexpected changes that effect their operational performances because of different challenges including urbanization, water consumption habits and climate change (Spiller et al., 2015). Also, the need for sustainable wastewater management is becoming increasingly important as the environment is continually subjected to highly stressful events caused by insufficient or non-existent wastewater management that cause health and environmental problems (Libralato et al., 2012).

Under climate change and accelerated urban growth leading to urban sprawl, growing incentives for stricter water quality requirements and resource recovery from wastewater make it challenging to plan and design wastewater systems that are economically and technically efficient while meeting the environmental standards and social components of sustainability (Castillo et al., 2016 ; Molinos-Senante et al., 2015).

Across the full spectrum of scales for wastewater management system strategies, different options can be categorized into three groups, i.e., centralized, hybrid and decentralized systems (Larsen et al., 2013).

Centralized wastewater management is the largest scale of wastewater management and is prevalent in urban areas. Such systems typically include a sewer system network for collecting wastewater from residential and commercial buildings and sometimes stormwater and transporting it to a wastewater treatment facility (Figure 1.1). The sewer network consists of two sub-systems, including the collection sub-system and transport sub-system. The wastewater treatment plant also has two sub-systems. One sub-system is intended to remove contaminants from the wastewater, and it includes physical, chemical and biological processes. The other sub-system converts the solids removed from the wastewater in the first stage (waste sludge) into a usable or compost form. Usually, the treated wastewater effluent from the wastewater treatment plant is released into the nearest water stream (Wilderer & Schreff, 2000).

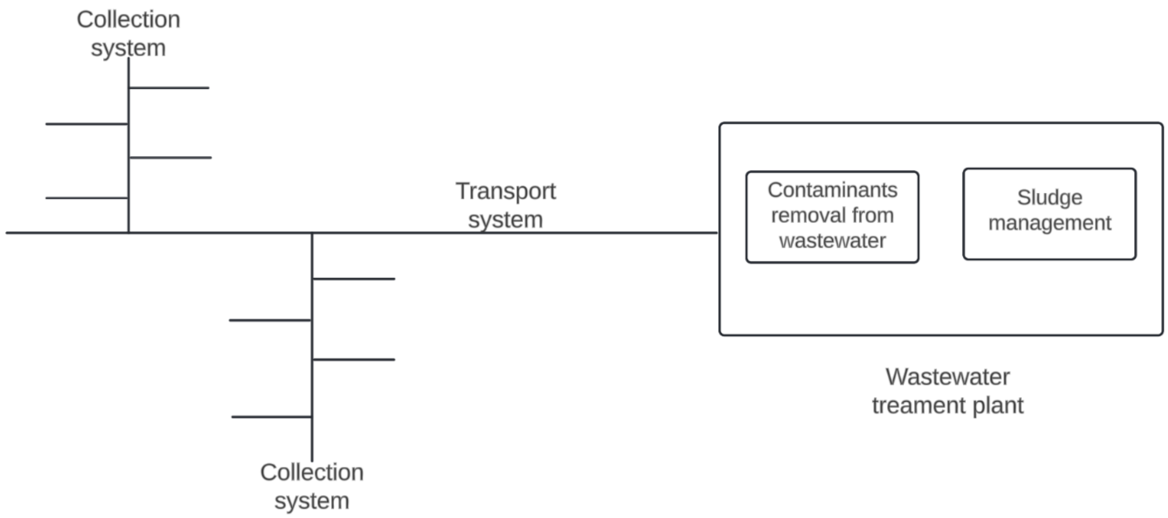


Figure 1.1 Illustration of a centralized sewer network and wastewater treatment plant ;taken and adapted from (Wilderer & Schreff, 2000)

Fully decentralized systems are the smallest scale of wastewater management strategies and are implemented at the residential scale, like septic systems: they are designed to treat small wastewater flows such as from isolated buildings and individual dwellings, and are typically found in low densely regions (Kösters et al., 2020 ; Larsen et al., 2013 ; Libralato et al., 2012). Decentralized wastewater management allows the possibility to reuse the effluent for different purposes and recovery of nutrients (Larsen et al., 2013).

Both extremes of the spectrum present challenges in terms of resilience and sustainability. For instance, centralized systems have been criticized for their low nutrient recovery and high costs when used in low-density developments (Zheng et al., 2016). Decentralized systems also suffer from lack of implementation regulation and monitoring and in some cases, energy flow is higher than in comparison to bigger treatment plants (Larsen et al., 2013 ; MELLC, 2015). Therefore, hybrid wastewater systems, i.e., that integrate features from both centralized and decentralized facilities, are proposed to improve the sustainability and efficiency of wastewater management (Larsen et al., 2013).

Selecting the most suitable wastewater management system that effectively satisfies sustainability objectives encompassing society, economy, and the environment can be a complex task, owing to the presence of multiple alternatives and the inclusion of various decision criteria. Therefore, acknowledging the trade-offs among different objectives becomes imperative in the decision-making process. (Molinos-Senante et al., 2015 ; Zheng et al., 2016). Moreover, the municipalities in Quebec lack decision support tools to take informed decisions around upgrading or building new wastewater treatment systems, taking into consideration a broad range of possible strategies and relevant social, environmental and economic objectives. The case study of this project is a medium-size municipality in southern Quebec. The municipality is planning to have a new development area and wants to make decision on the wastewater management of this area.

Frameworks exist to assess different wastewater management systems considering different evaluation objectives, e.g., (Aubert et al., 2022). However, they were applied to a case study in Switzerland. Research that considers the condition of cities and regulations in Quebec and in general Canada is missing. Furthermore, considering the contribution of stakeholders in the domain of wastewater management in Quebec is of high importance when developing a framework that assesses the performance of untraditional wastewater management systems which have not been studied so far.

1.2 Research objectives and contribution

The main objective of this research was to develop a decision support framework for the evaluation of wastewater management systems in terms of sustainability for municipalities in the province of Quebec, Canada. We used multi criteria decision analysis (MCDA) to build the framework. To achieve the main objective, the following sub-objectives were completed:

- Develop a hierarchy of objectives for the evaluation of the wastewater management alternatives;
- Develop wastewater management alternatives across the full spectrum of scales, from centralized to decentralized systems, including hybrid systems;
- Determine the performance of the alternatives for each of the objectives included in the MCDA framework (hierarchy);
- Determine the importance (weight) of each of the objectives in the objective hierarchy;
- Apply the framework to the study site to evaluate and compare the overall performance (score) of two of the developed alternatives.

This research aims to develop an analytical framework to provide Canadian municipalities with a comprehensive tool for considering a broad range of wastewater system configurations, while accounting for a diversity of criteria, local priorities, and perceptions in the complex decision-making process. The framework's adaptability also means that it can be further customized and applied to cities facing similar development challenges in Quebec and across Canada.

1.3 Structure of the document

Chapter 2 of this thesis provides a literature review encompassing wastewater treatment processes and management strategies. Subsequently, it elucidates the challenges that exert pressure on wastewater management, followed by an exploration of approaches to determine the appropriate wastewater systems. In Chapter 3, the research methodology employed in this study is elaborated in detail. Chapter 4 presents the results derived from various stages of the study, accompanied by a discussion of the findings. Chapter 5 examines the limitations encountered during the project and proposes potential avenues for future research. Finally, chapter 6 serves as a comprehensive conclusion.

CHAPTER 2 LITERATURE REVIEW

2.1 Wastewater treatment: a historical need

In the middle of the 20th century, scientists realized that the main reason for the spread of serious illnesses such as cholera and diarrhea among the population was the contact of humans with their own excreta. The contact caused the transmission of dangerous microbes contained in the excreta that lead to fatal diseases (Wilderer & Schreff, 2000).

The discharge of untreated wastewater into the river and water streams cause severe problems. An abundance of harmful microorganisms can pose significant health hazards to the individuals residing in areas located downstream. Fish downstream of the wastewater discharge can be killed due to the bacterial activity. Moreover, excess levels of nutrients can cause water eutrophication and prevent the usage of the water stream as a source for the supply of water (Wilderer & Schreff, 2000).

Historically, the principal objective of wastewater infrastructure was to promote sanitation for humans and protect the ecology through wastewater collection and treatment and safe discharge of wastewater according to the regulations (Kanchanamala Delanka-Pedige et al., 2021). Urban wastewater systems provide crucial benefits to societies. Throughout the last 150 years, the development of wastewater collection and treatment systems has improved public health and reduction of pollutants in the environment (Hughes et al., 2021). From the early 19th century to the 1970s, wastewater treatment focused essentially on the elimination of colloidal and suspended material, hazardous microorganisms and organic materials. After 1970 and until 1980, wastewater treatment was focused on solving the environmental concerns and aesthetic issues by including higher levels of treatment of wastewater to achieve lower biological oxygen demand (BOD) and total suspended solids (TSS) in effluents discharged to water bodies, and by considering nitrogen and phosphorus removal in the treatment process. After this time, the focus has been on the removal of contaminants that can have long-lasting hazardous impacts on human health and on the environment, such as pesticides and industrial chemical and medical compounds (Metcalf & Eddy-AECOM, 2013).

2.2 Wastewater treatment processes: an overview

Wastewater treatment is often achieved by a combination of biological, physical, and chemical processes. In biological treatment processes, microorganisms in the wastewater help the elimination of contaminants from the wastewater. In physical treatment processes, contaminants and pollutants are removed by installing a solid media or by filtration. Chemical treatment consists in adding certain chemicals to precipitate or adsorb a range of selected contaminants or pollutants onto a media. Each of these processes purify the wastewater up to a certain level of treatment. Based on the source of the wastewater, the presence of contaminants and pollutants, and the intended usage after treatment, different degrees of wastewater treatment can be implemented including preliminary, primary, secondary, advanced secondary, tertiary treatment, nutrient removal, and disinfection (Health Canada, 2010 ; Mavinic et al., 2018). Hereafter, a brief explanation of each treatment level is provided:

Preliminary treatment: This is the first step in wastewater treatment when coarse suspended materials or solids and grits such as sticks or gravel are removed using bar screens to prevent mechanical damage or blockage of the system (Health Canada, 2010 ; Mavinic et al., 2018).

Primary treatment: This treatment level eliminates organic and inorganic particles by using sedimentation or flotation. At this step, large fractions of the total BOD, TSS, lipids and oils in the raw wastewater are removed. The average removal rates of BOD5 and TSS are 30% and 60%, respectively (Health Canada, 2010 ; Mavinic et al., 2018).

Secondary treatment: It is particularly intended for eliminating biodegradable organic particles, dissolved or in suspension. A variety of biological processes are used in secondary treatment, using aerobic and anaerobic bacteria. Aerobic bacteria are more frequently used in secondary treatment because the treatment is faster compared to anaerobic bacteria (Health Canada, 2010). Secondary treatment can reduce the BOD5 and TSS concentrations to less than 25-30 mg/L. However, even after this level, organic pollutants, nutrients, and residual particles that are resistant to microbial degradation may persist in wastewater effluent (Mavinic et al., 2018 ; Quebec, 2009).

Advanced secondary treatment: The same secondary treatment processes are used with the addition of filtration for higher removal of BOD and colloidal solids. The concentration of BOD5 and TSS at the effluent from this level is intended to be less than 10-15 mg/L (Health Canada, 2010 ; Mavinic et al., 2018 ; Quebec, 2009).

Tertiary treatment: It is the further treatment required to remove the remaining suspended and colloidal particles after secondary or advanced secondary treatment, consisting of either biological or chemical processes. The concentration of the BOD5 and TSS in the effluent is around 5 mg/L (Health Canada, 2010 ; Mavinic et al., 2018).

Nutrient removal: It is a treatment that specifically intends to eliminate the nutrients such as nitrogen and phosphorus from the wastewater. Different types of treatment methods can be used including nitrification, denitrification for nitrogen removal, and chemical and biological methods for phosphorus removal. These treatment methods can be integrated with any of the primary, secondary, advanced secondary and tertiary treatments (Health Canada, 2010 ; Mavinic et al., 2018).

Disinfection: This treatment method focuses on the deactivation of microorganisms that exist in the wastewater and are hazardous to humans. Disinfection methods include chlorine, ozonation and ultraviolet (UV) irradiation (Health Canada, 2010 ; Mavinic et al., 2018).

2.3 Wastewater management strategies

Traditionally, wastewater treatment in many cities in the world relies on centralized systems. These systems include a sewer network that collects the generated wastewater from the houses, industry and sometimes stormwater and transports it to a centralized wastewater treatment facility to treat the wastewater before discharging it to a nearby water stream (Wilderer & Schreff, 2000) (Figure 2.1). Two different types of sewer network exist. First type includes two separate network. separate sewer network that collects wastewater and another one for the collection of the stormwater. The second type of sewer network collects and carries both of the wastewater and runoff in same system (Brière, 2014).

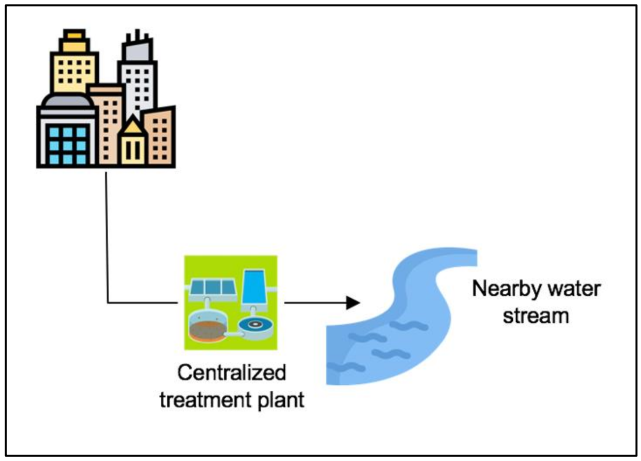


Figure 2.1 Visual representation of centralized wastewater treatment system

These systems have been widely implemented in dense urban areas and have shown their effectiveness for treating the wastewater (Wilderer & Schreff, 2000). In such centralized systems, around 80-90 % of the capital expenses are associated with the sewer collection system, with significant economies of scale associated with areas of high density, which increase their per-capita cost efficiency (Libralato et al., 2012). Centralized wastewater systems are considered to function generally well, but they are often criticized for their excessive use of water for toilet flushing, limited nutrient recovery, high costs, and lack of system flexibility (Zheng et al., 2016). Moreover, building a new centralized treatment system or extending the existing sewer network for lower density areas is often not economically efficient and can put a high monetary burden on the city and society (Larsen et al., 2013).

The conventional approach to urban wastewater treatment, involving the collection and conveyance of wastewater from residential areas to a remote centralized treatment facility, is increasingly questioned for its sustainability implications and its limited effectiveness in addressing concerns regarding ecological health, human well-being, and water resource management (Poustie et al., 2015). In order to tackle the sustainability issue, there is currently a significant shift towards a more sustainable approach to wastewater management with a focus on protecting the resources, recycling, and reusing of water and nutrients (Schmack et al., 2019).

Another approach for management of wastewater is decentralized systems. These systems were implemented in certain rural and urban areas where low density or long distances to the centralized treatment plant posed limitations on the utilization of a centralized system (Larsen et al., 2013).

Decentralized systems collect small flow of wastewater from individual buildings and houses and treat the wastewater near to the source of wastewater generation. The treated effluent can then either be infiltrated into the soil, discharged to a nearby water course, or reused (Larsen et al., 2013) . Decentralization in wastewater management can take different forms. Starting from the smallest scale of treatment, individual on-site treatment, like septic systems, treats the wastewater for an individual house or building (Libralato et al., 2012) (Figure 2.2).

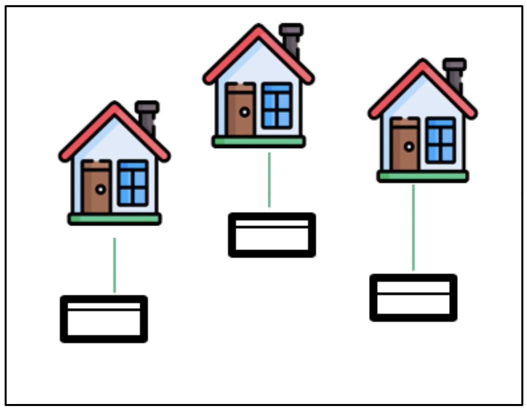


Figure 2.2 Scheme of on-site wastewater treatment

The second level is allocated to a wastewater treatment system for a cluster of 4-12 isolated houses or buildings (Libralato et al., 2012). The treatment system collects the produced wastewater from the number of houses or buildings and treats it near them (Figure 2.3).

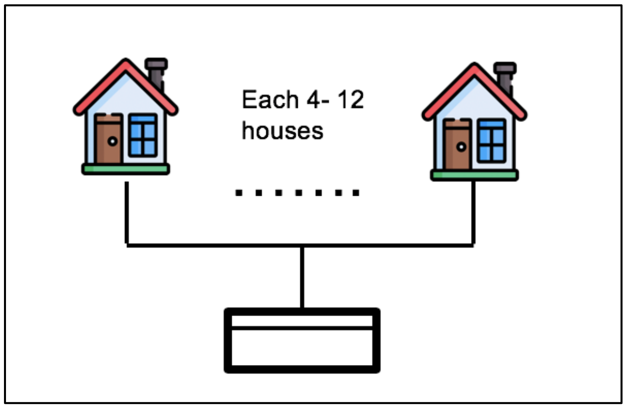


Figure 2.3 Scheme of the wastewater treatment for a cluster of 4-12 houses

The third level of decentralization is assigned to a bigger scale that can include the treatment of produced wastewater from communities such as schools, hospitals and shopping centers (Libralato et al., 2012). In decentralized systems, source separation and resource recovery is relatively simpler than in the centralized treatment systems (Larsen et al., 2013). Therefore, it can lead to higher level of sustainability by reusing the nutrient and treated effluent. Moreover, these systems minimize some of the difficulties associated with the collection of the wastewater and transportation to the centralized systems as they use smaller and shorter pipes (Libralato et al., 2012). However, decentralized wastewater systems suffer from a lack of regulations and legislation to assist proper implementation and monitoring methods. Inappropriate monitoring and implementation can lead to the contamination of the groundwater that consequently can impact the health conditions of near-by residents who rely on wells for their water supply (MELLC, 2015). Moreover, due to the system inefficiencies associated to the operational phase of small-scale treatment systems, energy flow is mostly greater for the treatment of wastewater according to bigger treatment systems (Larsen et al., 2013).

Therefore, both centralized and decentralized systems, despite providing their sets of benefits, have some weak points that can create concerns according to their future sustainability in terms of social, economic and environmental aspects (Sapkota et al., 2015). Moreover, at a time when sewage systems urgently need to be improved and built to protect the environment and human health in line with stricter discharge standards, significant investment will be necessary to this sector, providing an opportunity to implement innovative approaches. To overcome the challenges in terms of resilience and sustainability of centralized and decentralized treatment systems, hybrid systems are being developed that combine some characteristics of the centralized and decentralized system to enhance the benefits of wastewater management (Larsen et al., 2013). In this regard, integrated urban water management, with theobjective to sustainably manage urban water supply, wastewater and stormwater to achieve economic, social, and environmental goals, also promotes the integration of hybrid systems into the wastewater management sector (Lu et al., 2019 ; Schmack et al., 2019). However, hybridization is still a novel concept and the utilization of these systems are limited worldwide (Hoffmann et al., 2020).

2.4 External pressures on wastewater management

Challenges such as accelerated urbanization and rapid population growth, , climate change, collection system issues, and long-term water shortage make it difficult to plan and design sustainable wastewater systems that are economically and technically efficient while meeting environmental standards and the social components of sustainability (Castillo et al., 2016 ; Molinos-Senante et al., 2015). Table 2.1 summarizes the impact of such pressures on wastewater management systems.

Table 2.1 Overview of the impacts of external challenges on wastewater management

External challenges		**Impact on wastewater management**	**Reference**
Urbanization		Creation of urban sprawl that makes it challenging to transport all the generated wastewater toward the centralized treatment system.	(Larsen et al., 2013)
Climate change	Modified precipitation trends	Flood will result in an increased frequency of untreated sewer discharge in the environment.	(Abdulla & Farahat, 2020)
		Decrease in water consumption due to drought condition adversely impact the efficiency of WRRF	(Abdulla & Farahat, 2020)

Table 2.1 Overview of the impacts of external challenges on wastewater management (cont'd)

		Heavier rainfall leads to soil saturation and have impact on the functionality of septic systems	(Vorhees et al., 2022)
	Modified temperature	Change in temperature causes unwanted changes in the natural-based and non-mechanized treatment processes.	(Abdulla & Farahat, 2020)
	Sea level rise	it can have impact on the large treatment plants located near the water streams	(Larsen et al., 2013)
Water shortage		It can cause severe problems in the sewer collection network such as accumulation of grease and solids and accelerated corrosion rates due to the low water generation	(Larsen et al., 2013)
		It can increase the need for use of reclaimed water	(Larsen et al., 2013)

2.5 Sustainability of wastewater management systems

Infrastructure for managing wastewater has the potential to provide multiple benefits, and therefore can be viewed as a multi-functional system (Cossio et al., 2020 ; Haag et al., 2019). Evaluating the sustainability of various wastewater treatment (WWT) technologies would offer valuable insights to assist in making informed decisions. However, the absence of agreement regarding the meaning of sustainability, both in a broader sense and specifically in the context of wastewater treatment (WWT), is a notable issue (Molinos-Senante et al., 2015). For instance, a sustainable system was defined as a system that poses no risk to the quantity and quality of resources while having the least amount of costs in terms of physical, social, economic and environmental (Balkema et al., 2002). Although a consensus has not yet been reached, the sustainability of wastewater treatment infrastructures conventionally encompasses three dimensions: environmental, social, and economic aspects(Cossio et al., 2020 ; Haag et al., 2019). Hellström et al. (2000) mentioned that the wastewater systems should adhere to standards grouped into five classes, including: health and sanitation, socio-cultural factors, environmental considerations, economic concerns, and technical aspects. Various objectives (decision criteria) should be used to assess the defined aspects in the study the performance of the systems according to these five classes (Mahjouri et al., 2017).

Although some international frameworks have been developed to assess the sustainability of urban water systems (UWSs) and defining policies and implementing measures that facilitate the transition towards water-wise cities in broad terms, such as the City Blueprint (Koop & van Leeuwen, 2015) and Water Sensitive Cities index (Rogers et al., 2020) in cities worldwide , they do not allow considering a wide range of wastewater management strategies and assess them with quantitative objectives. Such comparative and quantitative evaluation is an important challenge for municipalities when facing decisions on upgrading or implementing new treatment systems, namely in Quebec and Canada. This deficit of decision support tools leaves decision makers without a comprehensive understanding of the possible options and the potential trade-offs involved in wastewater management, which can lead to suboptimal decisions that negatively impact both the environment and the community.

2.6 Approaches to choose the most suitable system

There are multiple methods, both practical and theoretical, that can be used to conduct a comprehensive evaluation of the effectiveness of urban water systems. Studies have considered two principal approaches for evaluating the effectiveness of systems. The first approach involves developing a single indicator that encompasses multiple decision criteria, while the second approach focuses on establishing a set of multidisciplinary indicators (Molinos-Senante et al., 2014 ; Poustie et al., 2015).

Examples of the first approach are life cycle analysis (LCA) and cost-benefit analysis. LCA is an inclusive method that evaluates the environmental impacts of a system into soil, water and air throughout the entire lifespan, from production to disposal (Renou et al., 2008). Cost-benefit analysis is a method to compare the monetized costs and benefits of the system (Molinos-Senante et al., 2014). The weakness of these approaches is that they consider only one aspect of sustainability and do not provide a comprehensive set of indicators for assessment of the system.

The second approach includes various objectives including environmental, economic, social and system functionality to evaluate the performance of a system (Molinos-Senante et al., 2014). An example of such an approach is Multi-Criteria Decision Analysis (MCDA). The field of MCDA involves various techniques and methods that take into account several criteria when making decisions, with the specific aim of enhancing the accountability and analytical accuracy of these decisions. The rational and systematic structure in MCDA allows modelling complicated decision-making challenges and integrating stakeholders' opinions on different decision criteria (framed as performance objectives) and their importance (represented by objective weights) (Molinos-Senante et al., 2015 ; Poustie et al., 2015). MCDA includes a variety of theories, methods and approaches such as multi-attribute value theory (MAVT) and value-focused thinking, analytical hierarchy process (AHP) and technique for order preference by similarity to ideal solution (TOPSIS).

MCDA has found applications in diverse domains of urban water management, encompassing water, wastewater, and stormwater management Table 2.2 presents a selection of examples from the literature that illustrate the applications of (MCDA).

Table 2.2 Summary of MCDA applications in urban water decision-making processes

Reference	Decision context	MCDA	Objectives categories	Stakeholder participation
Zheng et al., 2016	Wastewater management scale	MAVT	Social, economic, environmental	Yes
Molinos-Senante et al., 2015	Wastewater treatment technology	Generalized AHP	Social, economic, environmental	No
Poustie et al., 2015	Water, wastewater and stormwater management scale	Expert elicitation	Technical, economic, environmental, resilience	No

Table 2.2 Summary of MCDA applications in urban water decision-making processes (cont'd)

Mahjouri et al., 2017	Wastewater treatment technology	Fuzzy Delphi and Analytic Hierarchy Process (FAHP)	Reliability, system complexity, system efficiency, economic, environmental, sustainability	No
Kamble et al., 2017	Wastewater treatment technology	Fuzzy MCDA	Social, economic, environmental, technical	No
Kim et al., 2013	Location of treated wastewater reuse	fuzzy TOPSIS	Social, economic, environmental, technical	No
Lienert et al., 2022	Flood forecasting	MAVT	High information accuracy and clarity, Good information access, low costs, high sustainability	Yes
Aubert et al., 2022	Wastewater management scale	MAVT	Economic, environmental, social	Yes
Zeng et al., 2007	Wastewater treatment technology	AHP	Economic, technical, administrative	No

Notably, within the context of wastewater management, MCDA has proven instrumental in addressing decision-making challenges pertaining to the determination of wastewater management scale, selection of wastewater treatment technologies, and identification of suitable locations for effluent reuse.

Three categories of economic, environment, and social aspects have consistently emerged as the most commonly studied categories of objectives (Table 2.2). This observation highlights the substantial attention and focus devoted by researchers to these particular areas, underscoring their significance in the field of study. In the examined studies that employed weight assignment to objectives, it was found that environmental objectives were assigned the highest importance in the study conducted by Zheng et al. (2016), while economic objectives were assigned the lowest importance. Similarly, Aubert et al., (2022) found that objectives related to environmental protection were assigned the highest importance in the weight elicitation process, whereas social objectives were deemed the least significant for the evaluation of alternatives.

The inclusion of more informed individuals such as the public and stakeholders in the decision-making process has been shown to improve decision outcomes. Additionally, citizen engagement has been demonstrated to increase public acceptance of the decision (Aubert et al., 2022). Three studies of Zheng et al. (2016), Aubert et al. (2022) and Lienert et al. (2022) demonstrate a higher level of inclusion of stakeholders in the decision-making process compared to other studies.

To our knowledge, no decision-making framework for wastewater management in Canada exists, particularly for Quebec. Such a framework is essential for municipalities to consider all possible wastewater systems and relevant evaluation objectives, ensuring that they choose the appropriate wastewater management system. The aim of this research project, therefore, is to fill this gap by developing a decision framework applicable in the domain of wastewater management. To achieve this, the project will utilize MCDA. By developing such a framework, the research project seeks to make a significant contribution to the field of wastewater management, enabling decision makers to make more effective and efficient decisions that account for the diverse range of factors that influence this complex process.

We use Value-Focused Thinking and Multi-Attribute Value Theory (MAVT). Value-focused thinking is a problem-analysis approach that starts from the notion of values (objectives) in the decision-making process (Keeney, 1996). Thus, rather than starting from the alternatives that are solely developed to reach the values, we focus on the values first. Defining values is basic step of decision-making. We conduct the MCDA based on the objectives that stakeholders consider as being most relevant In a decision-making process, alternatives are considered as means to reach the values (objectives)(Keeney, 1996 ; Lienert et al., 2022). Thereafter, alternatives will be assessed according on how effectively they achieve the various objectives and the stakeholders' preferences towards accomplishing these objectives. Moreover, this insight provides the possibility that if an alternative does not perform well on an important objective for the stakeholders, decision makers can concentrate on determining how to improve this alternative in such a manner that it better satisfies the specific objective (Aubert et al., 2022).

CHAPTER 3 METHODOLOGY

To facilitate the development of a decision framework that promotes better understanding, clarity, and ease in the decision-making process, we applied the concept of Multi-Criteria Decision Analysis (MCDA). Pertinent steps of MCDA were sequentially undertaken based on earlier studies (Eisenführ et al., 2010 ; Gregory, 2012 ; Lienert et al., 2015) (Figure 3.1). The case study is first defined, with the identification of the stakeholders involved in the project. Then, the procedures used to develop the hierarchy of objectives and the wastewater management alternatives are provided. The approaches used to assess the performance of the alternatives in relation to each objective and determine the stakeholders preferences are described. Finally, the calculation method of the overall value of the alternatives is explained.

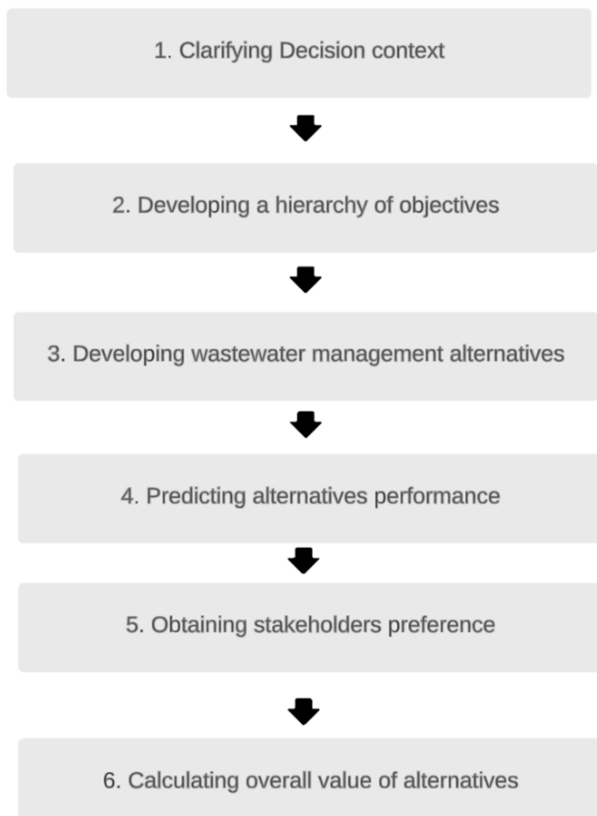


Figure 3.1 Methodical decision-making procedure

3.1 Clarifying decision context

3.1.1 Case study

As a case study, we focused on a medium-sized municipality located in southern Quebec, with an approximate population of 40 000 people and total area of between 60 and 80 km^2. The case study municipality (confidential) is currently examining a critical decision regarding the development of wastewater treatment systems for the municipality's new development area that will be under construction with an estimated area of 0.7 km^2. For the purposes of this study, we assumed that the entire development area will consist exclusively of residential buildings. As municipalities dealing with new development projects grow and expand (like the case of this study site), there is an increasing need to upgrade or build of new wastewater management systems. However, these systems can represent a significant economic burden on municipalities. Hence, it is crucial to consider the economic feasibility of different wastewater management systems while ensuring sustainability. The research will investigate various options, including centralized, decentralized and hybrid systems, to determine the most sustainable and cost-effective approach to managing wastewater in urban and peri-urban areas.

3.1.2 Identifying potential stakeholders

The involvement of stakeholders is a crucial factor in enhancing the credibility and validity of the decision-making procedure, as well as in gaining public acceptance of the decisions made in different steps of the project. By engaging stakeholders in the project, we ensure that the decisions are aligned with the interests and concerns of relevant parties, and that their insights and feedback are taken into account in the development process (Aubert et al., 2020).

We aimed to ensure a comprehensive and inclusive decision-making process by engaging a diverse range of stakeholders who either have direct impacts on wastewater management systems, have been affected by them, or possess expertise in the field. To achieve this, we contacted 14 individuals and six stakeholders from municipalities of similar scale to our case study, from the watershed management sector, Ministère de l’Environnement, de la Lutte contre les changements climatiques, de la Faune et des Parcs , and renowned wastewater management experts to request their participation in our study (Table 3.1). We contacted them via e-mail, in which a brief overview of the project (objectives and context of the study, methodology) and the planned activities were provided. An individual consent form was sent to each participant.

We also benefitted from the assistance of a respected professor in the field from Polytechnique Montreal to identify and contact these stakeholders for their valuable contributions to the research project and related activities.

Table 3.1 Selected stakeholders. WT: water treatment, WWT: wastewater treatment. Adapted from (Zheng et al., 2016)

Reference	**Responsibility**	**Decision level**
SH1	Municipal WWT project manager	Local
SH2	Municipal administration for WT	Local
SH3	Municipal engineering deputy director	Local
SH4	Provincial ministry for of the Environment and Climate Change	Provincial
SH5	Executive director of a watershed council	Provincial
SH6	WWT engineer	National

3.2 Developing a hierarchy of objectives

In Multi-Criteria Decision Analysis (MCDA), developing objectives and an organized objective hierarchy is crucial in areas such wastewater management, where few objectives are typically taken into account and are instead enforced by standards (Haag et al., 2019 ; Marttunen et al., 2019). In this context, having knowledge about the objectives that represent a wide variety of concerns related to the decision context can be vital as the objectives specify the scope of the assessment, analysis, and discussion of alternatives, and different sets of objectives may result in different conclusions.

3.2.1 Developing objectives based on the literature

We did a comprehensive literature review on past studies that address evaluations and decision-making process within the context of managing wastewater in urban areas to obtain the objectives that are important to consider for the evaluation of wastewater management systems. A synthesis of this review is presented in Table 3.2.

Table 3.2 Comprehensive objectives for the evaluation of wastewater management systems from extensive literature review, including main objectives, objectives, attributes used to measure the performance, description and references

Main objectives	Objectives	Attributes [units]	Description of the objectives	References
1. High system technical functionality	High durability	System expected lifetime [year]	Lifetime of the treatment system.	(Kamble et al., 2017 ;Kalbar et al., 2012 ; Balkema et al., 2002)
	Low system blockage	System blockage occurrence [1-5]: rare (1), occasional (2), regular (3), frequent (4), persistent (5)	The system can be blocked or cease to work leading to wastewater flowing into the city or soil or receiving water bodies without suitable treatment.	(Zheng et al., 2016)
	High flexibility	Ease to adjust system capacity [1-5], very difficult (1), difficult (2), moderate (3), easy (4), very easy (5)	Capacity/ease to adapt to changing needs in the future regarding hydraulic and organic load capacity	(Kamble et al., 2017 ; Kalbar et al., 2012 ; Mahjouri et al., 2017 ; Balkema et al., 2002 ; Zheng et al., 2016)
	Low energy consumption	Energy [kWh/m^3]	The energy used in the system for treating the wastewater.	(Aubert et al., 2022)
2.High treatment performance	High nitrogen removal	Nitrogen concentration [mg/L]	Wastewater treatment system improve the quality of the effluent by removing the nitrogen from the influent.	(Mahjouri et al., 2017 ; Molinos-Senante et al., 2015)

Table 3.2 Comprehensive objectives for the evaluation of wastewater management systems from extensive literature review, including main objectives, objectives, attributes used to measure the performance, description and references (cont'd)

	High phosphorus removal	Phosphorus concentration [mg/L]	Wastewater treatment system improve the quality of the effluent by removing the phosphorus from the influent.	(Mahjouri et al., 2017 ; Molinos-Senante et al., 2015)
	High suspended solid (SS) and organic matter removal	SS and BOD5 concentration [mg/L]	Wastewater treatment system can remove the suspended solid and organic matter from the influent.	(Mahjouri et al., 2017 ; Molinos-Senante et al., 2015)
3.High environmental protection	High system protection against overflow	System potential to create overflow [discrete value between 0 and 1]	The system can reach its maximum capacity during an heavy rainfall event leading to wastewater and rain water overflow.	(Zheng et al., 2016)
	High nutrient recovery	Nitrogen recovery rate [%], Phosphorus recovery rate [%]	System capability to recover the nutrients (nitrogen and phosphorus)	(Zeferino et al., 2009 ;Poustie et al., 2015 ; Molinos-Senante et al., 2015)
4.High social acceptability	Low impact on cities' infrastructure	City infrastructures that can be impacted such as streets, water and sewer pipes, wires, gas infrastructures [number]	City's infrastructures can be impacted including streets, water and sewer pipes, electricity wires and gas infrastructure	(Zheng et al., 2016)

Table 3.2 Comprehensive objectives for the evaluation of wastewater management systems from extensive literature review, including main objectives, objectives, attributes used to measure the performance, description and references (cont'd)

	Low noise and odor	Noise and odor generation [1-5]: Very Low (1), low (2), medium (3), high (4), very high (5)	Treatment system produces unpleasant noise and odor in the area	(Molinos-Senante et al., 2014 ; Kamble et al., 2017)
	Low end-user time demand	Time required [h cap^{-1} yr^{-1}]	End-user may need to perform minor control duties or contacting and accompanying technical operator for maintenance of the system	(Zheng et al., 2016)
	High attractiveness for end-user	Attractiveness level for end-user [1-5]: very uncomfortable (1), uncomfortable (2), moderate (3), comfortable (4), very comfortable (5)	In some cases, wastewater treatment is carried out in individual houses. Depending on the individual, these systems could be viewed as uncomfortable or unpleasant	(Zeferino et al., 2009 ; Balkema et al., 2002 ; Kalbar et al., 2012 ; Molinos-Senante et al., 2015)
5.Low costs	Low capital cost	Discounted investment cost [CAD cap^{-1} yr^{-1}]	Initial needed investment for construction of the system	(Singh et al., 2019 ; Poustie et al., 2015 ; Zeferino et al., 2009 ; Mahjouri et al., 2017 ; Zheng et al., 2016)
	Low operational and maintenance cost	Annual cost [CAD cap^{-1} yr^{-1}]	Operation and maintenance costs during the life time of the system	(Singh et al., 2019 ; Poustie et al., 2015 ; Zeferino et al., 2009 ; Mahjouri et al., 2017)

Table 3.2 Comprehensive objectives for the evaluation of wastewater management systems from extensive literature review, including main objectives, objectives, attributes used to measure the performance, description and references (cont'd)

	Low additional land requirement for system implementation for end-user	Land area per person [m^2 cap^{-1}]	Implementation of a treatment system requires additional land of the final user property	(Zheng et al., 2016)

We further used this table to create a master list of objectives. Master list includes all the relevant objectives from the literature that should be considered when assessing wastewater treatment systems (Haag et al., 2019). This list thus served as basis for the construction of a final hierarchy of objectives with the stakeholders (during Workshop 1, described in the next section) in the context of Quebec.

3.2.2 Workshop 1: development of the evaluation objectives

To facilitate the engagement of the identified stakeholders (see section 3.1.2), we organized a set of workshops aiming to bring them together to share their insights and perspectives. The first workshop served to obtain their opinions on the selection of objectives for evaluating wastewater management alternatives.

The first workshop was held on February 16, 2023 in an online mode, for a duration of 1.5 hours. The objectives development process was based on an online survey which was created using Limesurvey (the full survey questionnaire is attached in appendix B). The workshop included five main activities(Table 3.3).

Table 3.3 Agenda for the first workshop

Section	Planned activity	Purpose of each activity	Duration of each activity
1	Presentation of the workshop team	Facilitation of participant introductions and enabling participants to be familiar with each other	5 minutes
2	Presentation of the participants		5 minutes
3	Explanation of the project	I explained the contextual background, objectives, methodology of the research project and the procedure for completing the online survey	35 minutes
4	Completing the online survey	We sent the link of the survey to each of the stakeholders and gave 35 minutes to them to complete the survey	35 minutes

Table 3.3 Agenda for the first workshop (cont'd)

5	Brief discussion from the survey	I shared some results from the comments and feedbacks of stakeholders and some of the stakeholders gave their insights on the survey	10 minutes

Stakeholders completed the survey individually that included 4 sections (Figure 3.2). **Step 1 (individual brainstorm)**: participants individually wrote down all the objectives that they had in mind and that they thought to be relevant in the evaluation of the wastewater management alternatives and not only the most important ones. **Step 2 (comparison to the master list)**: we provided a master list of objectives (based on literature analysis) to all the participants. Objectives in the master list were numbered to facilitate the next exercise in the workshop. The second part of the survey was divided into two questions : first, we asked participants to compare their stated objectives (generated at step 1) and the objectives from the master list (presented at step 2). If they thought that a stated objective has a similar meaning to a master list objective, they were asked to write down the corresponding number of the master list objective to associate it with their own previously formulated objective. At the second question, we asked participants to indicate the objectives from the master list for which none of their stated objectives during the brainstorming stage (step 1) had a similar meaning, but which are still important to them. In s**teps 3 and 4,** open questions were asked to gather stakeholders' feedback and comments regarding the survey format and procedure.

Figure 3.2 Steps of the objectives development survey

After the workshop, we downloaded the responses of each participant and started analyzing the results. we created an individual list of objectives for each participant by including all the objectives selected from the master list in addition to the new objectives that did not have corresponding objectives in the master list. Thereafter, the new version of objectives hierarchy based on the responses of the stakeholders was defined.

The goal of the workshop was to obtain a comprehensive list of objectives from each participant and then create a final objectives hierarchy including all the new objectives stated by the participant for the first time that did not have a corresponding objective in the master list and the existing objectives from the master list without any redundancy while all the objectives in the objectives hierarchy be relevant to the scope of the research study. The final objectives' hierarchy consists of main objectives at top-level described by measurable sub-objectives.

3.2.3 Clarifying stated objectives: individual interviews with stakeholders

Following the workshop, the research team found that some of the objectives mentioned by the participants were unclear. To address this, we conducted individual interviews to obtain a clearer understanding of all the objectives stated in the survey during the workshop. We held the interviews with five out of the six stakeholders from Workshop 1 in an online mode within two to three weeks of the first workshop. The approximate duration of each interview was 15-20 minutes. By doing so, we aimed to ensure that all objectives were accurately captured and understood, enabling us to effectively analyze and interpret the data gathered during the workshop. During these interviews, we asked for a more precise definition of the objectives that were ambiguous for the research team and the attributes that participants believed could be used to measure these objectives. Since for the last participant, only one objective was ambiguous, we sought clarification regarding the specific objective by email.

3.2.4 Finalizing the hierarchy

Upon completing the individual interviews, we used four exclusion criteria to select from the newly stated objectives by the stakeholders while ensuring the relevancy of master list objectives within the context of Quebec. To include an objective, it must be (1) measurable, (2) relevant to the scope of the project (for instance, certain objectives within the list were found to be related to aspects such as the design of wastewater treatment systems or the location of treatment systems, which fall outside the scope of the present framework), (3) widely agreed upon (50% of the participants had included the objective on their final list) and, (4) non-redundant.

One of the reasons for having these exclusion criteria was to reduce the number of objectives, as the total number of objectives after the workshop was 30. We aimed to have approximately 15 objectives, which is roughly the maximum desirable number seen in the literature in MDCA frameworks (Zheng et al., 2016). By doing so, we were able to narrow down the objectives to those that were the most significant.

Despite defining clear exclusion criteria, we found that some of the objectives were still on the threshold of the third criterion (be widely agreed upon). To ensure that we were making the right decisions regarding which objectives to keep or remove, we decided to seek further input from the participants. To this end, we discussed these 'borderline objectives' to decide if they should be included or not in the final hierarchy of objectives. In the first part of the second workshop, we initially provided a comprehensive definition of each borderline objectives to the participants before allocating one minute to each of the participants for them to express their opinion concisely (workshop 2, first round). Upon gathering the individual opinions, if a unanimous agreement or disagreement was reached, the objective was either included or excluded accordingly. However, in cases where consensus was not achieved in this first stage, in the second round, we facilitated a focused discussion among the participants by asking targeted questions regarding the opinions of diverging members (second round). Based on the unanimous agreement or disagreement, the objective was either included or excluded.

3.3 Developing wastewater management alternatives

Our objective was to follow an approach that allows connecting different scales of wastewater management including decentralized, hybrid, and centralized systems. We employed a strategy generation table, which facilitates co-development of various alternatives by structuring the generation of a complete range of possible alternatives (Gregory et al., 2012). Moreover, it ensures the creation of alternatives that are considered relevant and sufficiently different from each other.

The strategy table includes column headings that represent the system elements, and the rows show the possible characteristics of each element. A strategy is defined first (e.g., cheapest system), then based on that strategy we select one option from each column and connect them to create system alternatives (Gregory et al., 2012).

Wastewater management systems consist of several elements that together ensure the appropriate level of treatment according to the guidelines and standards on water quality at the effluent. We organized meetings with the participation of the supervisors of the project to determine the necessary elements that should be considered in the treatment chain according to their knowledge and experiences. Therefore, we developed eight system elements (Figure 3.3):

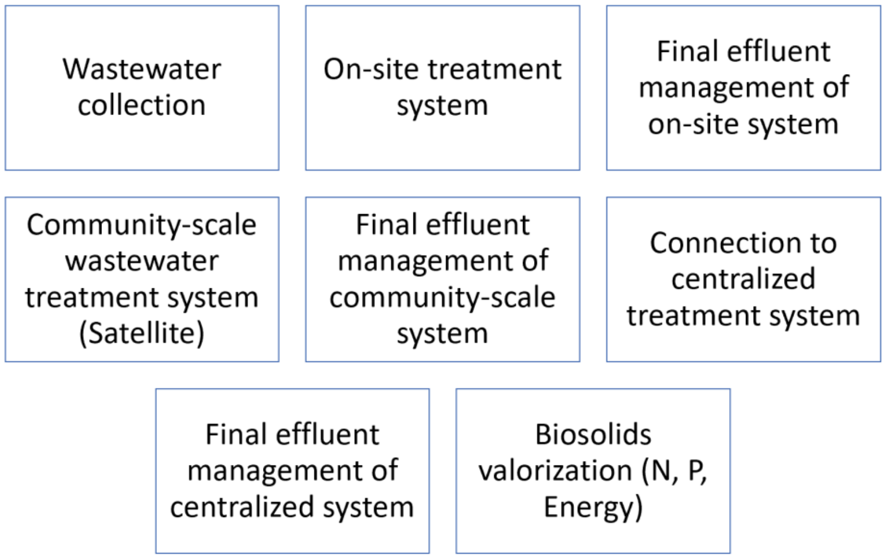


Figure 3.3 System elements considered in this study for the development of wastewater management systems

The strategy generation table for the development of the alternatives can be seen in Table 3.4. The strategy table includes all the system elements with their corresponding characteristics. In the current strategy generation table, for the 'on-site wastewater treatment' and 'community scale wastewater treatment (satellite)', the combination of phosphorus and nitrogen removal and disinfection is not included, and these systems can be integrated to each of the treatment levels. In this study, fully decentralized systems refer to only implementation of on-site treatment plants for individual houses. Satellite systems refer to wastewater facilities that treat the wastewater of 4-12 houses.

Table 3.4 Strategy generation table for the development of wastewater management alternatives

Wastewater collection	**On-site wastewater treatment**	**Final effluent management of on-site system**	**Community-scale wastewater treatment (satellite)**	**Final effluent management of community-scale system**	**Connection to centralized treatment system**	**Final effluent management of centralized system**	**Biosolids valorization**
No source separation	No on-site treatment	No final effluent	No community scale treatment system	No final effluent	No connection to centralized system	No final effluent	No resource recovery
Gray and black water separation	Primary treatment	Discharging treated effluent to the nearby water stream	Primary treatment	Discharging treated effluent to the nearby water stream	Expansion of the sewer network and use centralized system	Discharging treated effluent to the river	Nitrogen recovery

Table 3.4 Strategy generation table for the development of wastewater management alternatives (cont'd)

Gray, black water and urine separation	Secondary treatment	Reusing of the treated effluent for non-potable water use in house	Secondary treatment	Reusing of the treated effluent for non-potable water use in house	Use current sewer network and centralized system	Reusing of the treated effluent for non-potable water use in house	Phosphorus recovery
	Advanced secondary treatment	Reusing of the treated effluent for irrigation	Advanced secondary treatment	Reusing of the treated effluent for irrigation		Reusing of the treated effluent for irrigation	Nitrogen and phosphorus recovery
	Tertiary treatment	Infiltrating the treated effluent into soil	Tertiary treatment	Infiltrating the treated effluent into soil			Energy recovery
							Nitrogen, phosphorus and energy recovery

Hereafter, each of the system elements and their characteristics will be explained.

3.3.1 Wastewater collection

Wastewater collection is the first step of wastewater management. Source separation involves separating different types of wastewater such as blackwater (from toilets), greywater (from sinks, showers, and washing machines) and urine. Source separation leads to concentrated wastewater with high levels of nutrients and can result in improving efficiency in recovering nutrients and removing pollutants (McConville et al., 2017). For this study, three options are defined including: (1) no source separation, (2) greywater and blackwater separation, (3) and greywater, blackwater and urine separation.

3.3.2 On-site wastewater treatment system

When considering wastewater treatment options, it is important to understand the different levels of treatment available. The option of 'no onsite treatment system' indicates that no treatment will take place at the site of generation. When a specific level of treatment is selected, all the previous levels of treatment will be included in the system.

For nutrient removal (nitrogen and phosphorus removal) and any further elimination of microbial contaminants we considered the possibility of adding nitrogen or/and phosphorus removal treatment or/and disinfection treatment to the main level of treatment (Health Canada, 2010).

3.3.3 Effluent management of on-site treatment systems

Once wastewater has been treated at the on-site scale, the resulting effluent must be properly managed. Five possibilities are considered (Table 3.4). The concept of 'no final effluent' refers to a scenario in which either there is no onsite treatment of wastewater, or all of the effluent produced after treatment at the chosen scale is sent to further treatment scales such as satellite systems or centralized treatment facilities. The option 'discharging treated effluent to the nearby water stream' is related to the characteristics of the development area, i.e., implying that there is the presence of a small water stream that can be used for effluent discharge.

3.3.4 Community-scale wastewater treatment (satellite)

At satellite treatment (at the community scale), besides different treatment levels, we considered the possibility of adding nitrogen or/and phosphorus removal treatment or/and disinfection treatment to the main level of treatment (Health Canada, 2010).

3.3.5 Effluent management of community-scale treatment systems

Once the wastewater has been treated at the community (satellite) scale, the next step is to manage the effluent from the system. Similar characteristics to the on-site scale were considered. The 'no final effluent' indicates that whether there is no community-scale treatment, or all the effluent after the treatment at this scale will be sent further to the centralized treatment system.

3.3.6 Connection to centralized treatment system

Unlike the two previous scales, treatment levels (primary, secondary, tertiary) were not included as possible characteristics for the centralized treatment system Instead, the focus was on considering the connection and expansion of the centralized system as potential characteristics. This means that the possibility of connecting the development area to an existing centralized treatment system or to expand the system to accommodate the additional wastewater generated by the development were considered.

3.3.7 Effluent management of centralized system

After the treatment of wastewater at the centralized scale, for the effluent management, four possible characteristics were considered (see Table 3.4). The 'no final effluent' indicates that all the wastewater management process happens at the previous scales.

3.3.8 Biosolids valorization

Sludge is a valuable resource and the possibility of recovering the nutrients it contains such as nitrogen and phosphorus can be considered in system alternatives. In addition, the sludge contains organic matter which can be used as an energy source and this potential can also be included in the proposed system processes (Molinos-Senante et al., 2015).

At the next step, we organized two to three meetings with the participation of the supervisors of the project and a meeting with project collaborator from the municipality and one of the supervisors of the project within the timeframe of February to March 2023 to determine names of the alternatives and the most suitable characteristics for each element of the system. Therefore, the names and the components of the associated alternatives were defined before assessing the performance of the objectives. These meetings were essential in allowing us to discuss and decide on the best options for managing wastewater at each stage of the process.

3.4 Alternative performance prediction

The approach to predict the performance of each wastewater system alternative according to each of the objectives included in the MCDA framework is divided into two main parts: (1) using literature and (2) consulting an expert to obtain values regarding the system performance for considered objectives in the study (Figure 3.4).

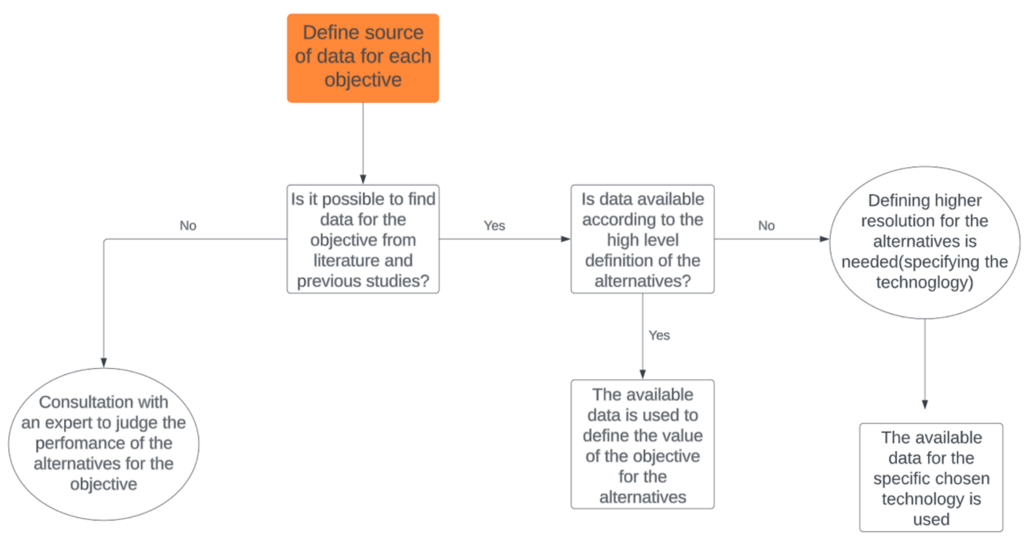


Figure 3.4 Procedure for obtaining the data for the performance of alternatives on the objectives

Regarding obtaining data from existing literature and previous studies, the objectives were categorized in two distinct sets. The first set comprised objectives where it was feasible to assess the performance of alternatives based on the existing high-level definition of treatment levels. However, for the second set of objectives, a more detailed determination of the specific technology to be employed for the alternative was required to allow evaluation of the performance of alternatives for these objectives. This higher resolution approach was deemed necessary to obtain data from the literature for the objectives in the second set. With this in mind, it was essential to identify systems that can be studied and exist at various scales, with pre-existing data readily accessible for the objectives in this category without undergoing extensive studies, which was not the aim of this study. Therefore, we made a hypothesis to use the wastewater management systems from the Premier Tech company, which produces the Ecoflo technology and has obtained the required BNQ standards (BNQ, 2023) (Table 3.5 and Table 3.6). First and foremost, this is a system that has attained the established standards and is employed within the Quebec province. Secondly, the selection of Ecoflo technology affords us access to the essential data for both on-site and satellite systems, as pre-established by Premier Tech. Lastly, the data associated with the Ecoflo Technology is notably more comprehensive and accessible compared to alternative technologies utilized on both on-site and satellite scales. This decision allows roughly to remove the need to identify the 'type of process' selection for the on-site and satellite scale.

Table 3.5 Explanation regarding the selected on-site systems in the study

System specification	**Technology**	**Average house size**[1]	**Average people living in each house**[2]
On-site system with advanced secondary treatment level	Ecoflo technology	Three-bedroom household	Three
On-site system with advanced secondary treatment level and phosphorus removal	Ecoflo Rewatec nitrogen removal technology	Three-bedroom household	Three

[1] The average Canadian house size is 2.7 bedrooms in house and we chose the model to be closest to this number
[2] The average household size is 2.4, however it is more logical to consider full person for calculation of small systems

Table 3.5 Explanation regarding the selected on-site systems in the study (cont'd)

On-site system with advanced secondary treatment level and nitrogen removal	Ecoflo Rewatec phosphorus removal technology	Three-bedroom household	Three
On-site system with advanced secondary treatment level and nitrogen and phosphorus removal	Ecoflo Rewatec nitrogen and phosphorus removal technology	Three-bedroom household	Three
On-site system with advanced secondary treatment level with UV disinfection	Ecoflo Rewatec integrated UV disinfection technology	Three-bedroom household	Three

Table 3.6 Explanation regarding the selected satellite systems in the study

System scale	**Objectives to be calculated**	**Technology**	**Connected houses to each system**	**Average people living in each house**
Satellite system	Low capital and operational &maintenance cost	Same as on-site systems	Ten	Three
Satellite system	Low energy consumption	Ecoflo Rewatec moving bed biofilm reactor (MBBR)[3]	Ten	Three

[3] As data for energy consumption was available for this technology, we considered a different technology to prevent the same value for energy consumption same as costs objectives between on-site and satellite systems (Garrido-Baserba et al., 2018)

We assumed certain specific assumptions to obtain the results for the cost objectives including:

- To determine the sewer network cost for alternatives including the centralized system, we followed the approach based on (Garrido-Baserba et al., 2018). The area of the new development area is approximately 75 ha. The area is divided into 3 districts of 25 ha each. Each of the districts are subsequently divided into 10 neighborhoods, each including 50 houses with the average household size of 2.4 people. Figure 3.5 shows the components of the sewer network that were considered for the calculation of the costs. The lengths of the sewer component for the case study has been considered same as the source article (Garrido-Baserba et al., 2018). We also considered the part of the public sewer network need to be changed in terms of connecting the entire development area to the centralized treatment plant. The details of the sewer components can be seen in Table 3.7.

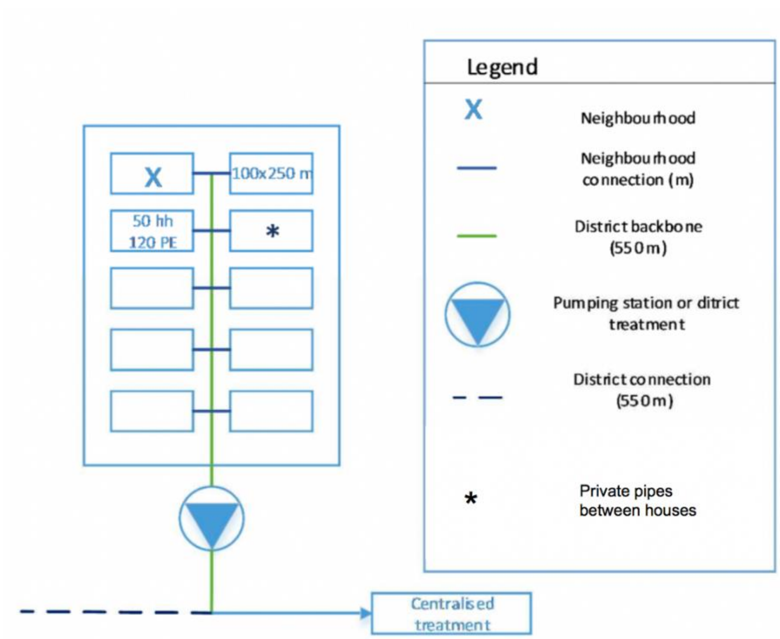


Figure 3.5 Components of the sewer network (adapted from (Garrido-Baserba et al., 2018))

Table 3.7 components of the sewer network for the centralized system

Network type	**Pipeline lengths (m)**
District backbone	1650
Neighbourhood connection	375
District connection	1650
Private sewer	19710
Public sewer	3700

- As currently the city has its own centralized treatment plant and sewer network, some parts of the treatment plant and sewer network might need to be upgraded or renewed in the future; we estimated the costs associated with such upgrades for the next ten years from a report of the CERIU based on an portrait of water infrastructures in Quebec municipalities (Centre d'expertise et de recherche en infrastructures urbaines [CERIU], 2022).
- Cost of pumping stations was not considered in this study.
- Satellite systems include the construction of a small sewer network among houses; to calculate the cost of this sewer network, only private pipes shown in Figure 3.5 were considered.
- For the centralized system, we obtained the maintenance cost from our partner in the case study municipality.

Table 3.8 Determination of the different systems lifetime and the interest rate used in the capital cost and operational and maintenance cost calculation

System scale	**Lifetime**	**Interest rate** (Garrido-Baserba et al., 2018)

Table 3.8 Determination of the different systems lifetime and the interest rate used in the capital cost and operational and maintenance cost calculation (cont'd)

On-site system	10 years for the filter media and 30 years[4] for the other components	5%
Satellite system	10 years for the filter media, 30 years for the other components and 60 years for the sewer network	5%
Centralized system	60 years for the sewer network (Garrido-Baserba et al., 2018)	5%

For the assessment of the *low energy consumption* objective, different sources were used according to the availability of data (Table 3.9).

Table 3.9 Source of data used to calculate the energy consumption of different systems

Technology/system	**Reference for energy consumption**
Ecoflo	(Premier Tech, 2023)
Ecoflo Rewatec nitrogen removal	(Stillwell et al., 2010)
Ecoflo Rewatec phosphorus removal	(Sadik, 2019)
Ecoflo Rewatec integrated UV disinfection technology	(U.S. Department of Energy, 2021)
MBBR	(Singh et al., 2017)
Centralized system	(Wang et al., 2016)

[4] The Premier Tech mentioned on its website that the Ecoflo technology has a lifetime installation. However, for the purpose of calculation, the company told that 30 years lifetime is appropriate

To evaluate the last objective in this set, *low end-user time demand*, the following assumptions have been considered:

- The Ecoflo systems need to be checked once every year. Therefore, we considered a working day of eight hours and 1 hour for arranging works for the presence of the technician that end-user need to allocate (Premier Tech, 2023).
- Rewatec phosphorus removal systems need to be checked twice a year. Therefore, we assumed that once is done with the checking of the entire Ecoflo system and another eight hours working day is needed to do the second maintenance check of the system (Premier Tech, 2023).

For certain objectives for which data were not available in the literature, it was necessary to obtain expert judgment, in order to predict the performance of different alternatives. To gather expert judgments for this study, we reached out to a consultant in the field of wastewater management who works as an engineer in a consultant company. By involving an expert with specific and relevant experience, we aimed to ensure that the judgments obtained were well-informed and grounded in expertise.

To allow a more focused and detailed discussion regarding the six objectives that needed to be judged by an expert, we organized an individual meeting in an online mode. By engaging in one-on-one conversations, the expert was able to provide a more nuanced and detailed understanding of the objectives and the potential performance of different alternatives. During the interview, we discussed each objective one after the other and the expert judged each objective for all the alternatives in a sorting approach. She defined the worst and best alternatives by using a high-level definition in the alternatives, without explicitly specifying the treatment technology (higher resolution), and classified the other alternatives in between.

3.5 Obtaining stakeholder preferences

In the context of Multi-Attribute Value Theory (MAVT) and Value-Focused Thinking (VFT), subjective preferences are incorporated through the assignment of weights to each objective and the determination of marginal value functions (Aubert et al., 2020). The methodology and procedure employed to conduct each of these two parts are elaborated upon in the following sub-sections.

3.5.1 Objectives' weight elicitation

Eliciting the weights (importance) of each objective is a fundamental step in MCDA that impacts the results and rankings of the alternatives (Aubert et al., 2020). There are three distinct methods commonly employed to elicit weights for objectives: the trade-off method, the swing method, and the direct ratio method (Eisenführ et al., 2010). Among these methods, the swing method offers certain advantages over the other two. Firstly, the swing method does not necessitate the availability of objective value functions during the weight elicitation process unlike the trade-off method, which contributes to its simplicity and ease of use (Eisenführ et al., 2010). Secondly, the hierarchical nature of the swing method in weight elicitation reduces the probability of encountering biases (Aubert et al., 2020).Moreover direct ratio method has faced criticism in the research domain, as it has been deemed unreliable for weight elicitation (Eisenführ et al., 2010). In the direct ratio method, the objectives variables are compared to each other. However, considering the difference in the level of the variables makes the comparison more robust, and this is achieved using the swing method (Eisenführ et al., 2010). Consequently, researchers and practitioners have expressed reservations about relying on this method for accurate and robust results (Eisenführ et al., 2010). It should be noted that the other two methods are less cognitively demanding and faster, aspects that may be perceived as shortcomings of the swing method.

The swing method considers the contribution of the stakeholders in the weight elicitation process and includes three main repetitive steps for each branch of the objectives hierarchy (Aubert et al., 2020 ; Eisenführ et al., 2010). (1) In the first step, objectives with their definition and the worst and best possible cases are shown to the individuals. (2) In the second step, initially, a hypothetical option in which all the objectives are at their worst level is introduced. Then, other hypothetical options are presented where, in each of them, one objective has been improved from its worst case to its best case while other objectives remain at their worst case. Then, individuals need to rank the options according to their preferences to improve a goal from its worst case to its best possible case. The option that is ranked first, should be the one that represents the objective that is most important to improve from its worst case to its best possible case. (3) The third step, individuals need to assign a score from 0 to 100 to each of the options. By default, the dominant worst-case option whose all objectives are at their worst -level always gets a score of 0 and the option ranked first is given a score of 100. Individuals should give a score to the other remaining options. After determination of the weights of all of the objectives in each branch of the hierarchy, one more step is needed to obtain the weight of each main objective (branch) in the objective hierarchy. To do this, the most important objective of each branch is selected as representative of the branch and individuals need to perform steps 2 and 3 again for this final swing process (the swing survey used in second workshop is attached in appendix C).

According to the swing method, three different categories of weights for the objectives can be obtained, consisting of (1) objectives' weights within a branch, (2) weight of each main objective (branch) in the objective hierarchy, and (3) global weight of each objective in the entire objective hierarchy.

To calculate the normalized weights of the objectives in each branch, the following equation is used (Eisenführ et al., 2010):

$$w_r = \frac{t_r}{\sum_{i=1}^{m} t_i}$$

where w_r represent the weight of objective *r* in its branch, t_r shows the score given to the objecitve r in its branch and m indicates the number of objectives within a branch.

To calculate the normalized weights of main objectives in the objectives hierarchy, the following equation is used (Aubert et al., 2020):

$$w_R = \frac{t_R}{\sum_{j=1}^{n} t_j}$$

where w_R represents the weight of main objective R among all the main objectives, t_R shows the score given to the main objective R among all the main objectives, and *n* indicates the number of main objectives (branches) in the objective hierarchy.

Eventually, to calculate the normalized global weights of each objective in the objective hierarchy, the following equation is used, which is a multiplication of the normalized weight of an objective in its branch to the normalized weight of its main objective in the objective hierarchy:

$$W_r = \frac{t_r}{\sum_{i=1}^{m} t_i} \times \frac{t_R}{\sum_{j=1}^{n} t_j}$$

where W_r indicates the normalised global weight of the objective in the objective hierarchy.

To obtain the weights of all objectives in our framework reflecting the stakeholders' priorities, we organized a second workshop with the same stakeholders who had participated in the first workshop. To establish the timing for the second workshop, we created a doodle pool and distributed to the participants, allowing them to collectively determine a suitable time. This weight elicitation workshop was held on May 11, 2023, through an online platform. The duration of this workshop was 2 hours with eight main activities (Table 3.10).

Table 3.10 The agenda of the second workshop

Section	**Planned activity**	**Purpose of the activity**	**Duration**
1	Presentation of the workshop team	Enabling participants to be familiar with the research team	5 minutes
2	Presentation of the participants	Allowing participants to be familiar with each other	5 minutes
3	Brief recall of the research project	We explained the project to the participants in case they have forgotten some parts of the project	10 minutes
4	Group discussion for validation of the objective hierarchy	We organized a group discussion to determine the inclusion or exclusion of specific objectives within the objective hierarchy, as detailed in Section 3.2.2 of this thesis	40 minutes
5	Explanation of the wastewater management alternatives	We elucidated the strategy employed in developing each alternative and provided specifications for each of them	5 minutes

Table 3.10 The agenda of the second workshop (cont'd)

6	Explanation of the swing method	We explained the process of objective weight elicitation, utilizing the selected method (swing), and providing participants with a practical example for better comprehension of the method's procedures.	5 minutes
7	Completing the swing survey	We sent the survey to the stakeholders and give 35 minutes to them to complete it and send it back to us	35 minutes
8	Brief final discussion	We designated a discussion for identifying the most important main objective for each stakeholder	10 minutes

The survey was created in Excel and included all the steps outlined in the swing method. The survey also featured a section displaying an instant summary of the weights assigned to the main objectives within the objective hierarchy. This enabled participants to discuss their most important main objective during the final section of the workshop. Since the final objective hierarchy to be employed in the swing survey had not been established prior to the second workshop, we generated all possible combinations of the objective hierarchy, considering the inclusion or exclusion of the objectives that would be decided on at the beginning of the workshop. Following the group discussion and the subsequent formulation of the final version of the objective hierarchy, the appropriate survey was distributed to the participants.

3.5.2 Marginal value functions

Various objectives possess distinct attributes, resulting in the utilization of different units for their measurement. The presence of diverse units impedes the ability to compare alternatives directly, considering all objectives simultaneously through a singular score. Value functions are employed to transform the attribute levels of each of the objectives into a normalized interval scale measuring performance and ranging from 0 to 1. More specifically, the value function is a graphical representation wherein the attribute level is plotted along the horizontal axis, while the corresponding normalized values are depicted along the vertical axis. This diagram provides a visual depiction of the relationship between attribute levels and their corresponding normalized values. This transformation allows the integration of all objectives into a unified score, enabling comprehensive calculations across multiple objectives. The determination of value functions for the objectives necessitates consideration of the knowledge and preference of decision makers or experts. This approach should incorporate the input and insights of decision makers or experts to ensure that the value functions accurately reflect their preferences. The existing literature presents various methods for defining value functions. For this study, the bisection method has been selected (Aubert et al., 2020 ; Eisenführ et al., 2010).

To determine the value function based on the bisection method, initially the worst (x^-) and best (x^+) level of the attribute of the objective should be specified in the plot. Then after, the decision maker needs to determine three points between the best and worst level of the attribute including median point, 25 percentile point and 75 percentile point. The first point that need to be determined is the attribute level that bisects the (x^-) and (x^+) of the attribute level from a value perspective which is called $x_{0,5}$. The point $x_{0,5}$ indicates that improvement of the attribute from the x^- to $x_{0,5}$ is equal to the improvement of the attribute from $x_{0,5}$ to x^+. The second point to be defined is $x_{0,25}$ that bisects the attribute level from the (x^-) to the median point ($x_{0,5}$). The point $x_{0,25}$ defines that improvement of the attribute from the x^- to $x_{0,25}$ is equal to the improvement of the attribute from $x_{0,25}$ to $x_{0,25}$. The third point to be specified is the $x_{0,75}$ that bisects the the attribute level from $x_{0,5}$ to x^+. The point $x_{0,75}$ demonstrates that improvement of the attribute from the x^- to $x_{0,25}$ is equal to the improvement of the attribute from $x_{0,25}$ to $x_{0,25}$ (Eisenführ et al., 2010).

Due to time constraints, this thesis focuses on deriving value functions in detail for the most significant objective (highest weight) of each the four main objectives. Value functions of the objectives judged by the expert were assumed to be linear as the expert ranked and rated the alternatives performance for each of the alternatives from 1-5 and it was assumed that these rates were given in a linear scale. For the other sub-objectives, a rough estimation of the value function shapes was considered, which gives minimal information on the value functions (Zheng et al., 2016). More specifically, a linear function was used for the attribute value functions not specified by an expert.

To accomplish the creation of detailed value functions for certain objectives, we organized a meeting with an expert who has worked for over 20 years as a researcher and technical representative in the field of wastewater management to seek his preferences concerning this step. The meeting lasted ninety minutes, divided into three distinct sections. Firstly, we presented a thorough explanation of the research project and the methodology employed. Subsequently, we provided detailed explanations specifically pertaining to the bisection method utilized for defining the value functions to the expert. Finally, we engaged in an exercise to define the value functions for the four selected objectives (Figure 3.6).

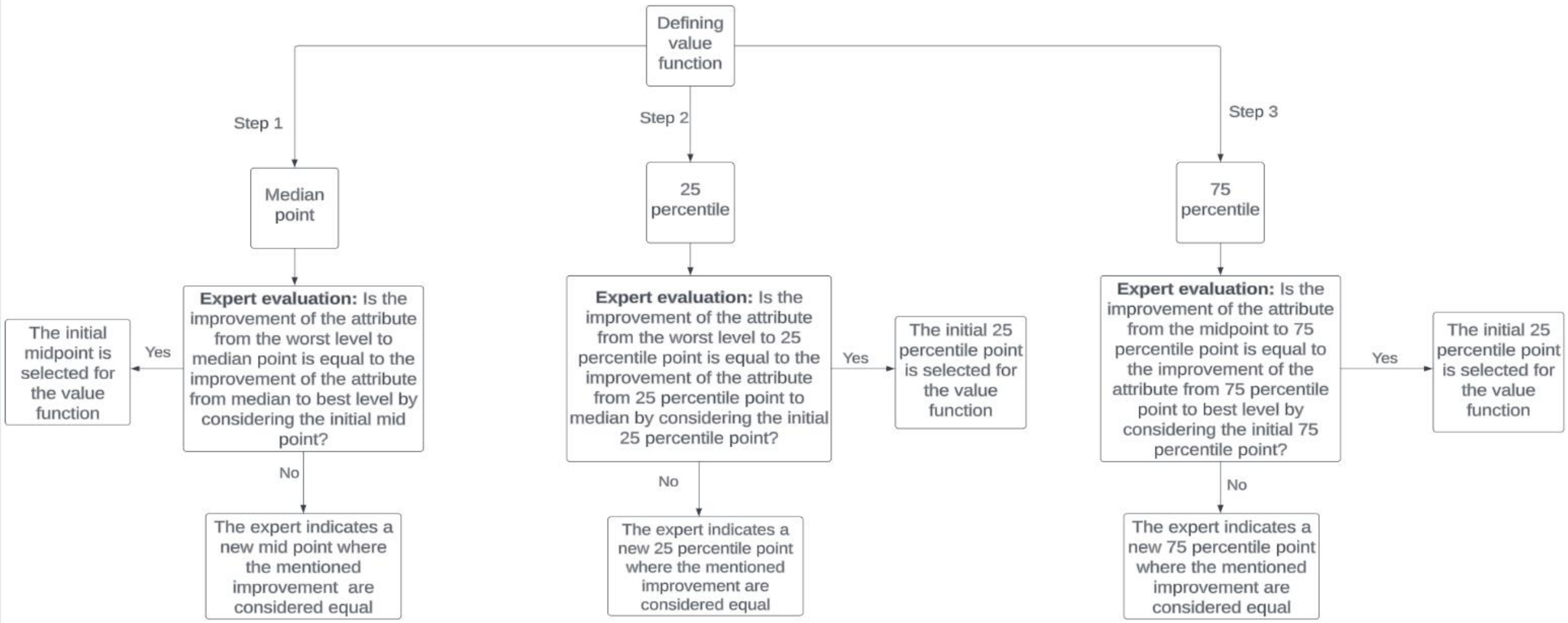


Figure 3.6 Procedure for defining the value function of each attribute for each objective

In order to define the value function for one of the attribute, namely high suspended solid (SS) for the objective *high SS and organic matter removal*, the expert expressed that as tertiary treatment also removes the SS and by looking globally that tertiary level exists in certain cases, from his point of view, it was more appropriate to determine the 90th percentile, 95th, and 97th percentiles to determine the value function. This approach is similar to an approach called *direct-rating method* for determination of value function (Eisenführ et al., 2010).

3.5.3 Alternatives' performance calculation

To rank the alternatives with respect to their performance, we calculate an overall value for each alternative using an additive aggregation model (Eisenführ et al., 2010):

$$v(a) = \sum_{i=1}^{m} w_i \times v_i(a_i)$$

where $v(a)$ shows the overall value of alternative a, w_i is the weight (importance) of the attribute of the objective i obtained in the weight elicitation step, *m* represents the number of attributes of an objective, a_i is the performance of alternative *a* according to the attribute of objective i defined in the alternative performance prediction, and $v_i(a_i)$ stands for the marginal value function of the attribute i defined at the marginal value function step.

3.6 Note on collaborative work implications

This research project presents a collaborative endeavor involving the valuable contributions of stakeholders and wastewater experts. Their participation is essential for gathering diverse perspectives, opinions, and judgments concerning different aspects of the project.

In line with the regulations established by Polytechnique Montreal, it is mandatory to obtain ethical approval prior to any engagement with human participants in the research project. To this end, meticulous attention was given to fulfilling the prerequisites outlined by the institution, and I completed the comprehensive ethics documents including the required forms from Polytechnique Montreal, the methodology of the study, the planned activities in the study that intended to involve humans and the approach for preservation of the data. I submitted these documents then to the ethics committee for their review and evaluation.

The committee meticulously assessed the submitted documents and posed insightful inquiries aimed at ensuring the project's adherence to ethical standards and guidelines. In response to the committee's queries, I provided a thorough and comprehensive set of answers and clarifications. This demonstrated a firm commitment to addressing any ethical concerns and reinforcing the project's compliance with established ethical norms. Subsequently, after careful consideration and evaluation, the committee approved the ethics documents pertaining to the research project (the ethics consent forms are attached in appendix A).

CHAPTER 4 RESULTS and DISCUSSION

4.1 Creating a hierarchy of objectives

All the objectives from the master list were chosen by the stakeholders and included in their respective individual lists (in the worst case the objective has been selected by two participants (Figure 4.1). Among the newly stated objectives, a significant proportion aligned with the overarching goal of *high environmental protection*. This observation underscored the stakeholders' evident concern for addressing diverse environmental issues when constructing or upgrading wastewater treatment systems. The initial workshop highlighted the imperative of involving stakeholders in the decision-making process, as they introduced objectives specific to the Quebec context that had not been previously considered during the objective development phase in the literature.

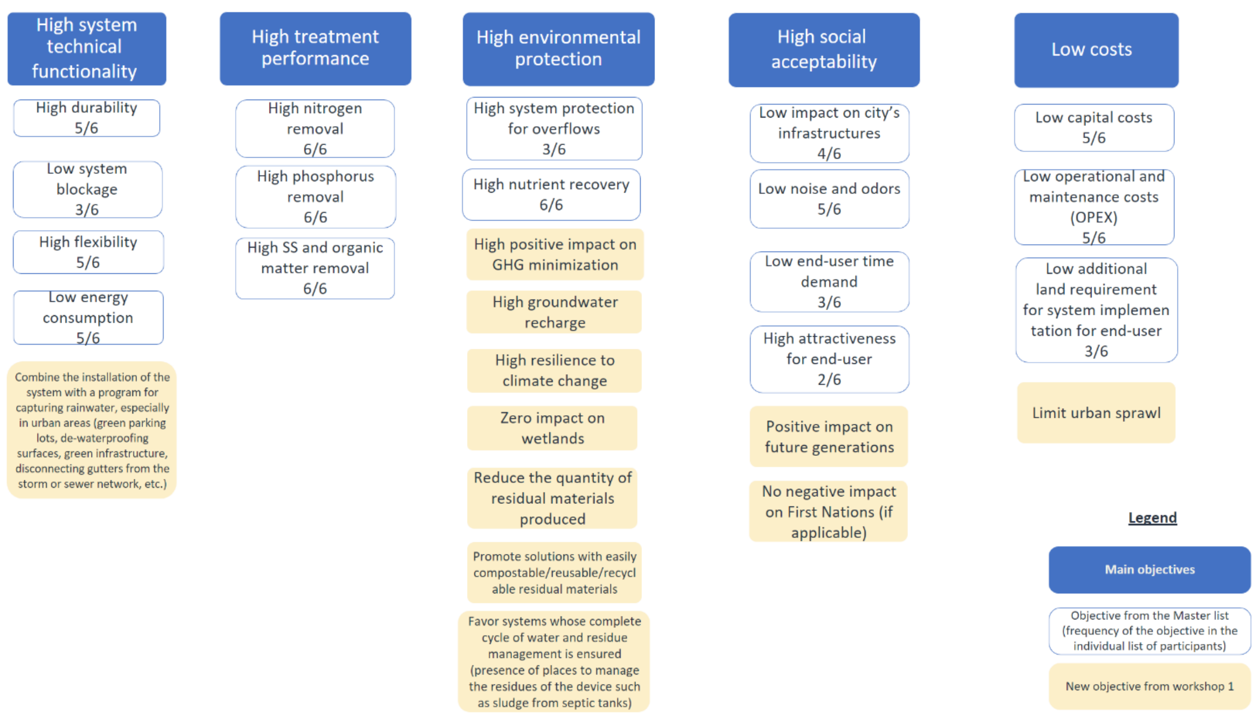


Figure 4.1 Initial objectives hierarchy after the first workshop and individual interviews

The analysis of the exclusion or inclusion of the objectives led to the rejection of 9 objectives from the initial objective hierarchy (Table 4.1). In the table 4.1, red objectives were excluded based on the three criteria, green objectives were accepted to be included in the objectives hierarchy, yellow objectives were discussed with the stakeholders for exclusion or inclusion at the beginning of workshop 2 and gray objective required specific method like LCA for calculation and was not included in the weight elicitation. The objective to '*Combine the installation of the system with a program for capturing rainwater, especially in urban areas'* was excluded by based on relevancy and measurability criteria, but also based on the explanation of the stakeholder mentioning this objective, i.e., the objective aims at improving the quality of the effluent, which is redundant with other objectives (high SS and organic matter removal and nitrogen and phosphorus removal). Therefore this objective was excluded as well.

Table 4.1 Result of the analysis of exclusion or inclusion of the objectives in the objective hierarchy

		Is the objective excluded by the exclusion criteria?		
Main objective	Objective	Agreed upon 50% or more of stakeholders	Relevancy	Measurability
High system technical functionality	1.1. High durability	No	No	No
	1.2. Low system blockage	On the threshold	No	No
	1.3. High flexibility	No	No	No
	1.4. Low energy consumption	No	No	No
	1.5. Combine the installation of the system with a program for capturing rainwater, especially in urban areas	-	Yes	Yes
High treatment performance	2.1. High nitrogen removal	No	No	No
	2.2. High phosphorus removal	No	No	No

Table 4.1 Result of the analysis of exclusion or inclusion of the objectives in the objective hierarchy (cont'd)

	2.3. High suspended solid and organic matter removal	No	No	No
High environmental protection	3.1. High system protection for overflow	On the threshold	No	No
	3.2. High nutrient recovery	No	No	No
	3.3. High positive impact on GHG emission	-	No	No
	3.4. High ground water recharge	-	No	No
	3.5. High resilience to climate change	-	No	Yes
	3.6. Zero impact on wetland	-	Yes	Yes
	3.7. Reduce the quantity of residual matter produced	-	Yes	Yes
	3.8. Promote solutions with easily compostable/reusable/recyclable residual materials	-	Yes	Yes
	3.9. Favor systems whose complete cycle of water and residue management is ensured	-	Yes	Yes
High social acceptability	4.1. Low impact on city's infrastructures	No	No	No
	4.2. Low noise and odor	No	No	No
	4.3. Low end-user time demand	On the threshold	No	No

Table 4.1 Result of the analysis of exclusion or inclusion of the objectives in the objective hierarchy (cont'd)

	4.4. High attractiveness for end-user	Yes	No	No
	4.5. Positive impact on future generation	-	Yes	Yes
	4.6. No negative impact on First Nations	-	Yes	Yes
Low costs	5.1. Low capital cost	No	No	No
	5.2. Low operational and maintenance cost	No	No	No
	5.3. Low additional land requirement for system implementation for end-user	On the threshold	No	No
	5.4. Limit urban sprawl	-	Yes	Yes

For the objective *high resilience to climate change*, beside exclusion based on the measurability criterion, there was redundancy between this objective and other objectives such as *high positive impact on GHG emission* and *high system protection for overflow*. Objective *zero impact on wetland,* based on the explanation of the stakeholder, relates to the space that will be allocated for the wastewater treatment plant and the work for the implementation of the infrastructure and the way that the effluent will be discharged to the wetland which led to exclusion based on relevancy and measurability criteria. Objectives *reduce the quantity of residual matter produced* and *promote solutions with easily compostable/reusable/recyclable residual materials* need higher level of sludge treatment resolution to allow calculating them and therefore they were excluded. The same issue was faced with the objective *favor systems whose complete cycle of water and residue management is ensured,* as it requires higher sludge treatment resolution and therefore it was excluded. From the point of the stakeholder who mentioned the objective *positive impact on future* *generation*, the objective aims at minimizing the impact on ecosystems and ensuring long-term security of drinking water supply. The first goal is in line with other objectives such as high treatment performance or high resource recovery, which causes redundancy. The second goal falls outside the scope of the project and is difficult to measure by an attribute. The objective *no negative impact on First Nations* relates to the involvement of First Nations in the decision-making process and to the requirement not to encroach on their territory, which are out of the scope of the project as this project does not focus on contacting First Nations and also there is not an attribute to allow measuring this objective. The last objective *limit urban sprawl* in this category is related to the location of the treatment plant, which is out of the scope of the project because location of the development area is already defined. Although we excluded some of these newly stated objectives due to the study's scope, their significance should not be disregarded and in future developments of the framework, these objectives could potentially be considered. Although the *high impact on GHG emission* was not include in the weight elicitation step due to the fact that we did not calculate the GHG emission of different alternatives which was needed for doing the weigh elicitation it is considered relevant to the study and can be included in future research by doing approaches such as LCA.

The remaining objectives in yellow have been discussed with stakeholders during the second workshop. Despite *the high attractiveness for end-user* objective not meeting criterion 1(agreed upon 50% or more of the stakeholders), we opted to discuss it further with the stakeholders to gather their opinions once again, ensuring thorough consideration of all perspectives (Table 4.2).

Table 4.2 Discussed objectives in the second workshop for further clarification on inclusion/exclusion with stakeholders

Objective	**Exclusion**	**Stakeholder's comments**
Low system blockage	No	- The objective is related to the contamination of both surface and groundwater, as blockages can lead to overflows. - The goal is to have systems that will be easy to maintain and that will not block easily.

Table 4.2 Discussed objectives in the second workshop for further clarification on inclusion/exclusion with stakeholders (cont'd)

High system protection for overflow	Yes	- The new regulations in Quebec do not allow the wastewater management systems to generate combined sewer overflow. - All the alternatives should follow this objective (mask objective) . Therefore, we kept it in the hierarchy but did not consider it in the weight elicitation step.
High attractiveness	No	- It is important to be considered, to have beautiful facilities, educational paths, it is an opportunity to raise awareness and create a beautiful living environment.
Low end-user time demand	No	-Low time demand is favorable to ensure the appropriate maintenance of the systems
Low additional land requirement	Yes	- It indirectly relates to the capital cost - It is included with the choice of the technology

From the five objectives discussed with the stakeholders, it was decided to include three objectives in the hierarchy, i.e.: *low system blockage*, *low end-user time demand* and *high attractiveness for end-user*. The other two objectives *high system protection for overflow* and *low additional land requirement for system implementation for end-user* were excluded based on the group discussion with stakeholders. Regarding the *high system protection for overflow*, as all the wastewater management systems should follow the guidelines to not to involve in the generation of more combines sewer overflow (CSO), this objective is considered as a mask objective, meaning that it ensures all the alternatives to follow this objective. The stakeholders mentioned that the *low additional land requirement for system implementation for end-user* has redundancy with the other cost objectives and should be excluded.

The comparison of the final objectives hierarchy (Figure 4.2) with the existing literature such as (Aubert et al., 2020 ; Aubert et al., 2022 ; Zheng et al., 2016) indicates that this study considers more objectives for evaluation, with the potential of resulting in more comprehensive results. The five main objectives are consistent with the specified categories of objectives that wastewater management systems should adhere to, as defined by (Hellström et al., 2000).

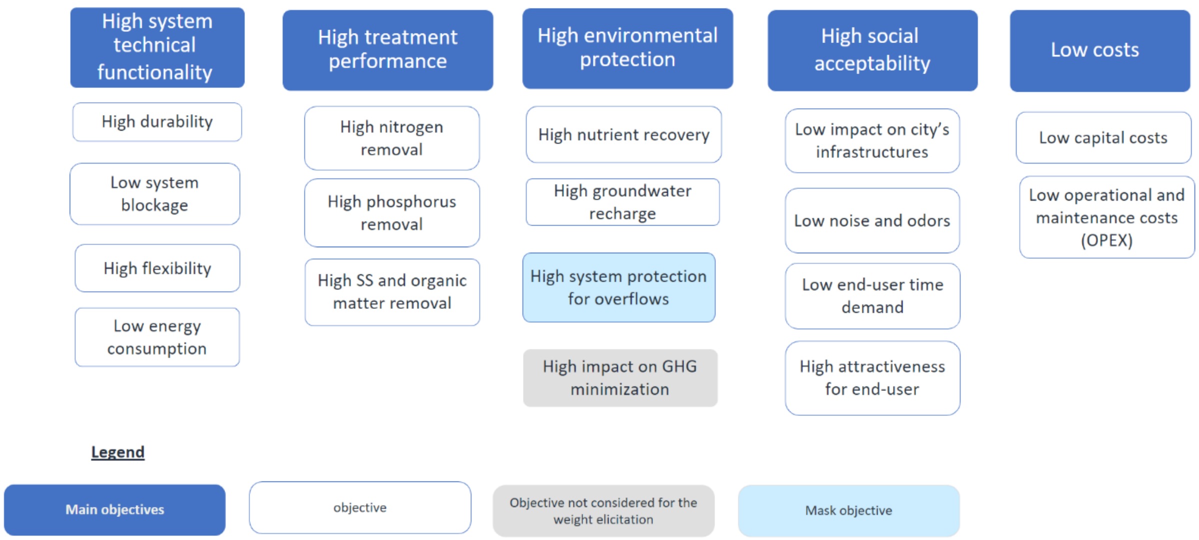


Figure 4.2 Final objectives' hierarchy in this thesis

4.2 Alternatives development

The characteristics of the six developed alternatives are shown in the created strategy generation table (Table 4.3). We made an endeavor to comprehensively encompass the entire range of wastewater management options, including fully centralized and fully decentralized with four hybrid options developed in between both extremes. Comprehensive explanations regarding each alternative will be given in the following parts.

Table 4.3 Overview of the developed alternatives characteristics

Most collaborative system
Fully centralized system
System contributing most to social resilience
Fully decentralized alternative
Most environmental-friendly system
Most flexible system

Wastewater collection	On-site wastewater treatment	Final effluent management of on-site system	Community scale wastewater treatment (satellite)	Final effluent management of community scale system	Connection to centralized treatment system	Final effluent management of centralized system	Biosolids valorization
No source separation	No on-site treatment system	No final effluent	No community scale treatment system	No final effluent	No connection to centralized system	No final effluent	No resource recovery
Gray and black water separation	Primary treatment	Discharging treated effluent to the nearby water stream	Primary treatment	Discharging treated effluent to the nearby water stream	Expansion of the sewer network and use centralized system	Discharging treated effluent to the river	Nitrogen recovery
Gray, black water and urine separation	Secondary treatment	Reusing of the treated effluent for non-potable water use in house	Secondary treatment	Reusing of the treated effluent for non-potable water use in house	Use current sewer network and centralized system	Reusing of the treated effluent for non-potable water use in house	Phosphorus recovery
	Advanced secondary treatment	Reusing of the treated effluent for irrigation	Advanced secondary treatment	Reusing of the treated effluent for irrigation		Reusing of the treated effluent for irrigation	Nitrogen and phosphorus recovery
	Advanced secondary treatment with N, P removal and disinfection	Infiltrating the treated effluent into the soil	Advanced secondary treatment with N, P removal	Infiltrating the treated effluent into the soil			Energy recovery
	Advanced secondary treatment with disinfection		Advanced secondary treatment with disinfection				Nitrogen, phosphorus and energy recovery
	Tertiary treatment		Tertiary treatment				

4.2.1 Fully centralized system (status quo)

This alternative has been developed based on the city's current wastewater management plan, which uses a centralized treatment system for wastewater management and can be considered as the status quo alternative. The residential buildings in the new development area will be seamlessly connected to the city's centralized treatment plant through the existing sewer network. However, a specific section of the sewer network, namely the initial pipeline responsible for collecting and transporting wastewater from the new area, requires reconstruction. This is primarily due to the pipeline's limited capacity, which can only accommodate the current wastewater load from the connected houses. Therefore, modifications are necessary to accommodate the additional wastewater flow from the new development area (Figure 4.3).

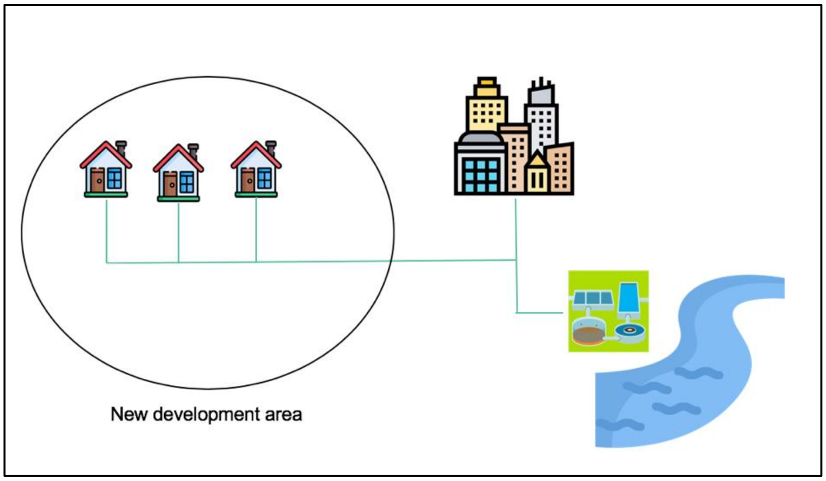


Figure 4.3 Illustration of the fully centralized system

4.2.2 Fully decentralized system (most autonomous)

In the fully decentralized alternative, the concept of high autonomy is embraced, wherein residential houses are equipped with on-site wastewater treatment plants. These treatment plants are designed to meet provincial regulations by employing a combination of primary level treatment and advanced secondary treatment. Following the treatment processes, the treated effluent is intended to be infiltrated into the soil (Figure 4.4). To present a more comprehensive alternative, three additional sub-alternatives have been considered. These sub-alternatives involve the inclusion of (1) nitrogen removal, (2) phosphorus removal, and (3) both nitrogen and phosphorus removal in the treatment process.

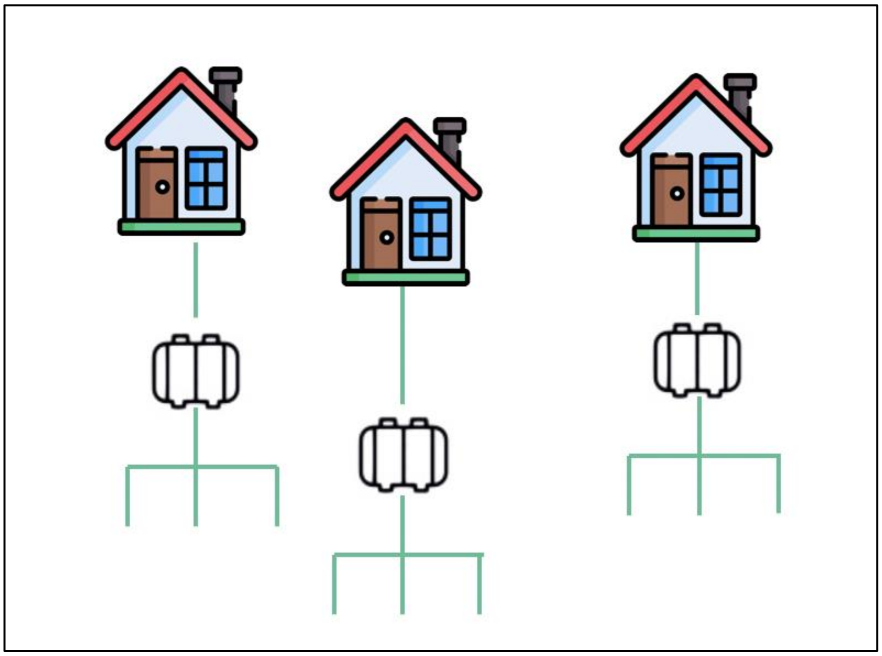


Figure 4.4 Illustration of the fully decentralized system

4.2.3 Most flexible system

The characteristics of the most flexible alternative were developed by considering the possibility of the system to adapt to changes to meet the future treatment needs within the local condition of the case study. To be able to consider all possibilities, two sub-alternatives are defined that differ in the first system element, which is separation of wastewater. In the first sub-alternative, wastewater is separated into gray- and blackwater and the second one allows for gray-, blackwater and urine separation by adding a urine tank. Under this alternative, the new development area will be equipped with satellite treatment systems providing advanced secondary treatment with phosphorus and nitrogen removal and disinfection. Nutrient recovery is also included in this alternative (Figure 4.5).

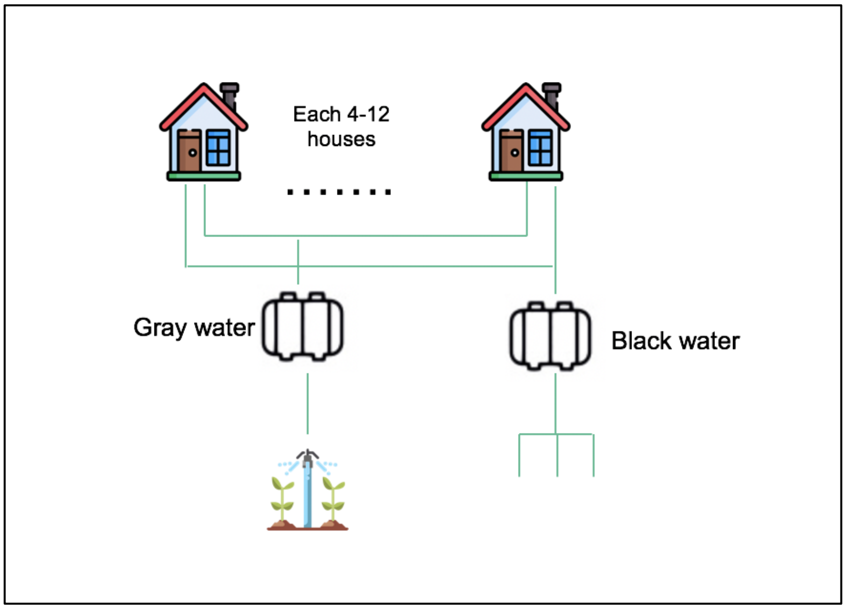


Figure 4.5 Illustration of the most flexible system

4.2.4 Most collaborative system

In the case study area, wastewater treatment has historically relied on centralized system and, for some rural parts, on on-site systems. However, an on-site treatment system has not yet been implemented in the city, and the combination of on-site systems and centralized systems for wastewater treatment and management will require a collaboration between the people in the city and the municipality for management of the wastewater. For the houses with on-site systems people will be responsible and for houses connected to the centralized system, the municipality is responsible. Therefore, in order to adopt the most collaborative development strategy, this alternative proposes the integration of on-site systems providing advanced secondary treatment and the centralized system. To implement this approach, the new development area will be divided into two halves. One half will be equipped with on-site systems, while the other half will be connected to the centralized facility (Figure 4.6). By this division, only the sewer system needs to be built for the half of the development area and there is no need to expand the main pipeline connecting the development area to the rest of the sewer network of the city. The effluent from the on-site systems will be infiltrated into the soil, and the effluent from the centralized system will be discharged into the river.

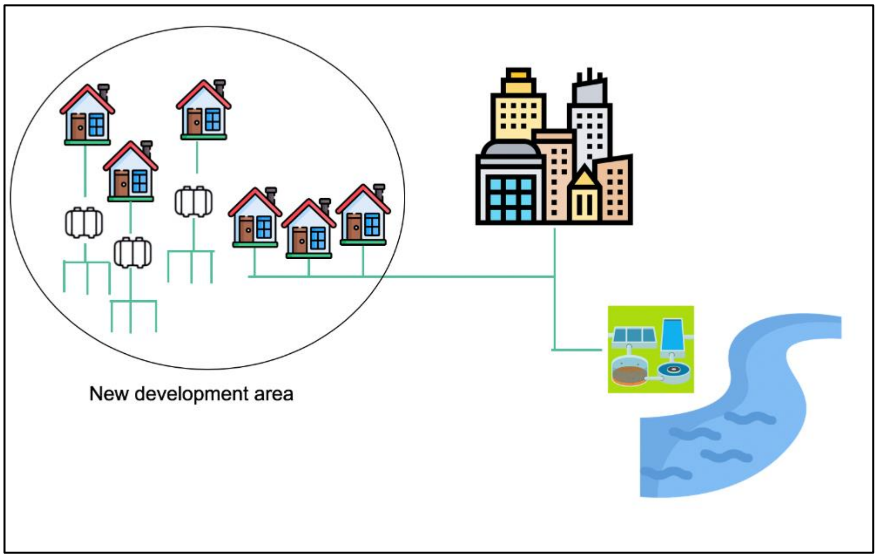


Figure 4.6 Illustration of the most collaborative system

4.2.5 Most environment-friendly system

The primary objective of this most environment-friendly wastewater management alternative is to establish a system that is harmonious with the environment. According to Besson et al. (2021) and Sun et al. (2020), source separation, which involves separating blackwater and graywater, offers significant benefits for both resource recovery potential in wastewater treatment facilities and reduced carbon emissions. With this in mind and guided by a strategic development approach, the initial step in this alternative involves separating gray- and blackwater. The blackwater will be treated at satellite facilities with advanced secondary treatment in addition to nitrogen and phosphorus removal, while the graywater will be directed to the centralized treatment system. The proportions of blackwater and graywater for this alternative are considered as follow: 35% of the produced wastewater consists of blackwater, and 65% is comprised of graywater (Abdalla et al., 2021). This approach eliminates the need for expanding the size of pipes of current sewer network and the city's centralized facility. The effluent from the satellite facilities will be infiltrated into the soil to replenish groundwater levels, while the effluent from the centralized facility will be discharged into surface water bodies. Nitrogen and phosphorus are essential elements for plant growth and agricultural productivity, and their recovery contributes to sustainable resource management. By considering the recovery of nutrients, the alternative aims to optimize nutrient utilization while minimizing their release into the environment (Figure 4.7).

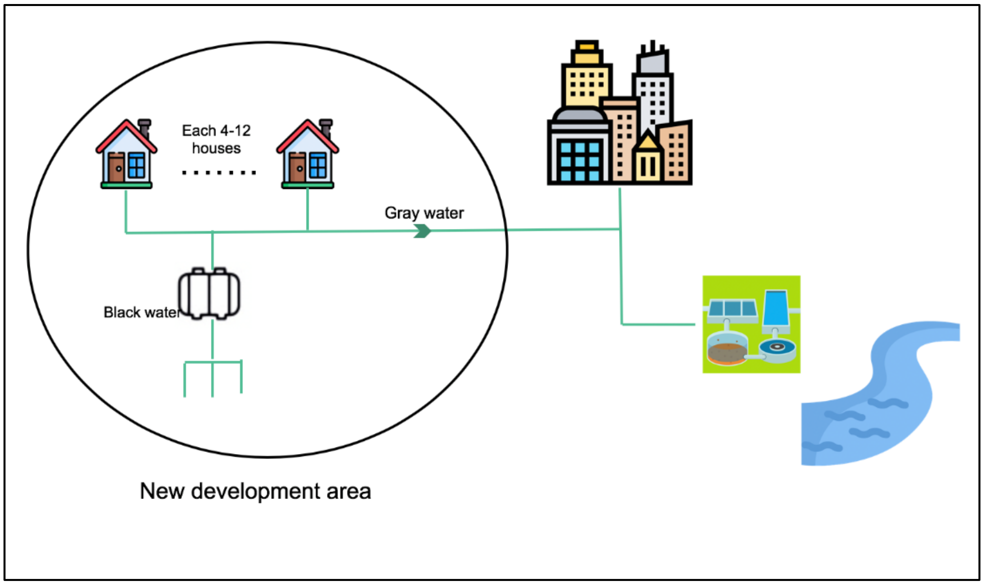


Figure 4.7 Illustration of most environmentally friendly system

4.2.6 System contributing most to social resilience

The combination of decentralized and satellite systems has been assessed as a strategic approach to minimize the overall environmental impact, while ensuring a substantial level of performance for the society to sustain uninterrupted wastewater treatment in urban areas (Sun et al., 2020). Additionally, by increasing the number of systems, individuals can rely on various wastewater systems. Consequently, if one system becomes non-operational, only a few people within the community will be affected, while the rest will still have access to functional wastewater systems. With this concept in mind, the proposed strategy involves equipping half of the development area with on-site treatment plants, while the other half will be equipped with satellite systems. Both types of systems are designed to achieve advanced secondary treatment and disinfection. The effluent from on-site systems is intended for non-potable uses within the households, while the effluent from satellite systems is intended for irrigation purposes (Figure 4.8).

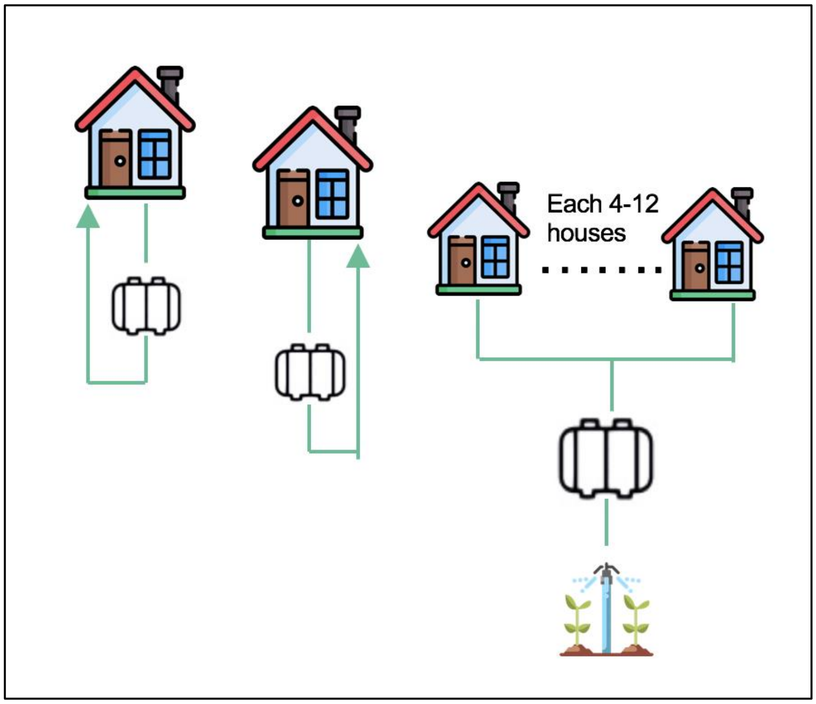


Figure 4.8 Illustration of the system contributing most to social resilience

Our research approach resulted in the development of novel hybrid wastewater management alternatives and includes some detailed system characteristics unexplored in existing literature when developing alternatives such as effluent management across different system scales. The absence of these newly devised alternatives in both scholarly works and practical applications may introduce biases among municipalities seeking to adopt innovative systems. As they have yet to encounter these systems and may still rely on previously established alternatives, it becomes crucial to provide a comprehensive explanation of the new alternatives to ensure their successful acceptance.

4.3 Predicting the performance of the alternatives

The performance results for the objectives that could be based on literature data by considering the current resolution of the treatment level for all alternatives are presented in Table 4.4.

Table 4.4 Assessment of objectives with current resolution of treatment level for each alternative. SS: suspended solids, BOD5: biological oxygen demand

		Objectives					
Alternative name	**Treatment level**	**High nitrogen removal (Nitrogen concentration [mg/L])**	**High phosphorus removal (Phosphorus concentration [mg/L])**	**High SS removal (SS concentration [mg/L])**	**High organic matter removal (BOD5 concentration [mg/L])**	**High nutrient recovery (resource recovery rate [%])**	**High groundwater recharge**
		(Metcalf & Eddy-AECOM 2013) (Mavinic et al., 2018)	(Metcalf & Eddy-AECOM 2013) (Mavinic et al., 2018)(MELCCFP, 2020)	(MDDELCC 2009) (Mavinic et al., 2018)	(MDELCC 2009) (Mavinic et al., 2018)	(Zheng et al., 2016)	
Fully centralized	Centralized treatment plant	20	1	25	25	0	0

Table 4.4 Assessment of objectives with current resolution of treatment level for each alternative. SS: suspended solids, BOD5: biological oxygen demand (cont'd)

Fully decentralized	Advanced secondary treatment	20	3.4	15	15	0	1
	Advanced secondary treatment with nitrogen removal	10	3.4	15	15	0	1
	Advanced secondary treatment with phosphorus removal	20	0.1	15	15	0	1
	Advanced secondary treatment with nitrogen and phosphorus removal	10	0.1	15	15	0	1
Most flexible system	Advanced secondary treatment with nitrogen and phosphorus removal and disinfection	10	0.1	15	15	90	0
Most collaborative system	Advanced secondary treatment + centralized system	20	2.2	20	20	0	1

Table 4.4 Assessment of objectives with current resolution of treatment level for each alternative. SS: suspended solids, BOD5: biological oxygen demand (cont'd)

Most environmental-friendly system	Advanced secondary treatment with disinfection and nitrogen and phosphorus removal for blackwater + centralized system for graywater	13.5	0.685	21.5	21.5	90	1
System contributing most to social resilience	Advanced secondary treatment and disinfection	20	3.4	15	15	0	0

The values obtained for the objectives *high nitrogen, phosphorus, SS and organic matter removal*, are more theoretical in nature rather than absolute. While these values provide a possibility for assessing the expected system performance, actual performance may vary in practice. Certain objectives may exhibit different levels of system performance in Quebec, either higher or lower than the theoretical values. This variation could be influenced by factors such as local conditions such as characteristics of the wastewater, operational practices, and specific design considerations. Regarding the most environmental-friendly system, it obtained the highest value for high *nutrient recovery* and *high groundwater recharge*. However, for the high nitrogen, phosphorus, SS and organic matter removal objectives, it did not perform as the best system. This can result from the fact that the names of the alternatives were determined before assessing the performance of objectives.

The results of the performance of the alternatives for the objectives that need higher resolution regarding the treatment technology are presented in Table 4.5.

Table 4.5 Assessment of objectives requiring higher resolution for the treatment level for each alternative

Alternative name	**Low capital cost (CAD cap^{-1} yr^{-1})**	**Low operational and maintenance cost (CAD cap^{-1} yr^{-1})**	**Low energy consumption (kwh/m^3)**	**Low end-user time demand (h cap^{-1} yr^{-1})**
Fully centralized	145	34	0.68	0
Fully decentralized	384	40	0	3
Fully decentralized (addition of nitrogen removal)	401	40	0.02	3
Fully decentralized (addition of phosphorus removal)	801	96	0.2	5.67

Table 4.5 Assessment of objectives requiring higher resolution for the treatment level for each alternative (cont'd)

Fully decentralized (removal of nitrogen and phosphorus removal)	819	96	0.22	5.67
Most flexible system (black- and graywater separation)	537	88	0.73	0
Most flexible system (black-, graywater and urine separation)	553	88	0.73	0
Most collaborative system	260	37	0.34	2.84
Most environmental-friendly system	277	55	0.71	0
System contributing most to social resilience	476	133	0.52	2.84

Table 4.5 reveals significant variations in capital and operational and maintenance costs objectives. The centralized facility has the lowest capital costs because the city already has its own sewer network, pumping station and treatment plant. Therefore, these costs were excluded from the cost calculation of the fully centralized alternative. The costs of decentralized alternatives were three to five times more than the centralized system because the three-bedroom Ecoflo system has the capacity to treat the wastewater for 6-7 persons; however, to have a realistic assumption, we considered three people per household as explained in Table 3.5. Meanwhile, when considering operational and maintenance costs, the system that contributed the most to social resilience entails on-site and satellite-scale facilities with advanced secondary treatment and UV disinfection, resulting in the highest costs. These results are in line with the study of (Garrido-Baserba et al., 2018), showing that the centralized system had the lowest capital cost followed by on-site systems

and hybrid systems. The results pertaining to the energy consumption objective demonstrated notable differences. The fully decentralized system showed the lowest energy usage, while the most flexible system, incorporating satellite-scale infrastructure and advanced secondary treatment with nitrogen and phosphorus removal, had the highest energy consumption.

The performances of the last category of objectives (six objectives) were defined by consulting an expert (Table 4.6).

Table 4.6 Assessment of the performance of objectives obtained by consulting an expert for each alternative

Alternative name	Low system blockage (System blockage occurrence [1-5]: rare (1), occasional (2), regular (3), frequent (4), persistent (5))	High system flexibility (Ease to adjust system capacity [1-5]: very difficult (1), difficult (2), moderate (3), easy (4), very easy (5))	Low impact on city's infrastructures (Number of city's impacted infrastructure [0-5])	High attractiveness for end-user (Attractiveness level for end-user [1-5]: very uncomfortable (1), uncomfortable (2), moderate (3), comfortable (4), very comfortable (5))	Low noise and odors (Noise and odor generation [1-5]; 1: very low, 2: low, 3: medium, 4: high, 5: very high)	High durability (equipment quality [1-5]: 1: very long, 2: long, 3: average, 4: short, 5: very short)
Fully centralized	1	5	5	5	3	1
Fully decentralized	5	1	0	1	1	5
Most flexible system	3	3	5	4	5	3
Most environmental-friendly system	2	4	5	2	4	2
Most collaborative system	4	2	5	4	2	4

Table 4.6 Assessment of the performance of objectives obtained by consulting an expert for each alternative (cont'd)

System contributing most to social resilience	4	2	5	3	4	4

For the objective *low system blockage*, the expert rated the alternatives based on the number of system units: a large number of units increases the likelihood of system blockage (or obstruction). Furthermore, inspection and correction of blockages is easier in a single location than in multiple systems. The fully decentralized alternative, with one unit per new house, was therefore considered to be a system with a persistent risk of blockage, while blockage was expected to occur rarely in the fully centralized alternative composed of one single unit.

Regarding the *system flexibility*, the expert considered it in terms of the ease of upgrading the treatment system. The expert followed the same logic as done previously for the number of units: it would be more cost-effective and easier to upgrade a single centralized facility compared to numerous small systems. Moreover, she noted that once decentralized systems are implemented on a site, upgrading them becomes challenging. Thus, the centralized system was assigned the highest level of flexibility, while the decentralized system was assigned the lowest level. The expert only considered the flexibility of the treatment system, neglecting factors such as the sewer network, flexibility in the operational phase or the deconstruction of the systems. This led to considering the centralized system as the most flexible system, which is in contradiction with the findings of the Zheng et al. (2016), indicating that the centralized system is not very flexible due to the path-dependency of these systems. Consequently, the most flexible alternative did not obtain the highest level of flexibility. This might be the result of that the names of the alternatives were defined before assessing the alternatives or the approach that the expert used to assess the flexibility objective for the alternatives.

The objective *low noise and odor* in treatment systems was evaluated based on the efficacy of both noise and odor control strategies used by each treatment system. The expert concluded that decentralized systems excel in this regard. Since they are buried underground, they offer the best performance in terms of managing both noise and odor. On the other hand, satellite systems were deemed to have the poorest performance in the expert's assessment. The expert pointed out that the control systems of these systems near residential areas are not as effective. The remaining alternatives were ranked based on the treatment scale used in each option.

The *durability* objective was rated based on the quality of the equipment typically found in decentralized or centralized systems rather than on the actual lifetime, which she was not able to evaluate without precise information on the treatment processes. In addition, information from the

CERIU report on assessment of portrait of water infrastructures in Quebec municipalities indicates that the lifetime of a similar centralized treatment facility to that considered in the case study is 30 years (CERIU, 2022). Based on the Karczmarczyk et al. (2021), the lifetime of the on-site treatment systems is considered to be 10 years. Therefore, for this objective, two attributes were defined for measurement of durability and for the weight elicitation and value scaling, the attribute counting the durability in number of years was used as it was more realistic to have number of years for the lifetime of a system.

4.4 Stakeholder preferences

4.4.1 Weight elicitation of main objectives

Figures 4.9 and 4.10 show the weights of the five main objectives obtained during workshop 2. The survey took participants between 18 and 35 minutes to complete. Given the diverse educational and professional backgrounds of stakeholders, along with their varied roles in different sectors, it was expected that individual preferences would differ, as reflected by distinct rankings of the main objectives, considering each of their unique perspectives (Figure 4.9).

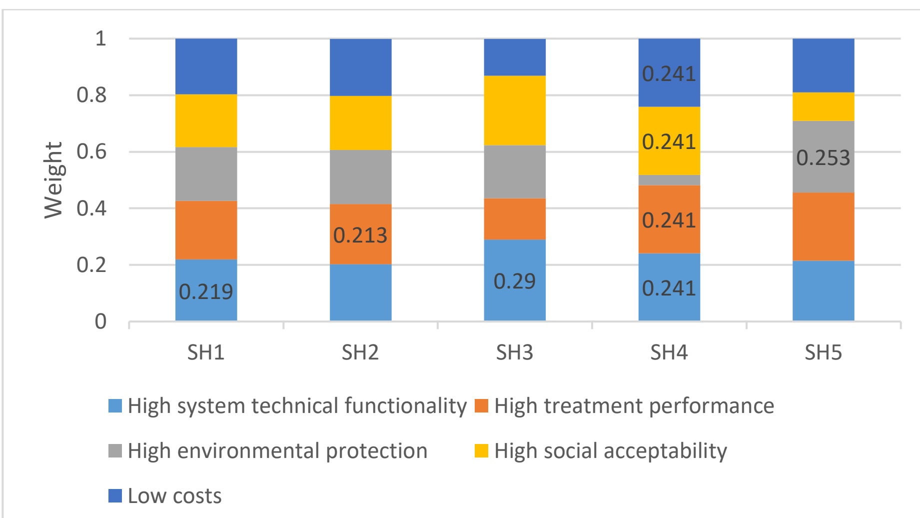


Figure 4.9 Weights for the five main objectives given by individual stakeholders (the number in each bar identifies the most important objective for each stakeholder)

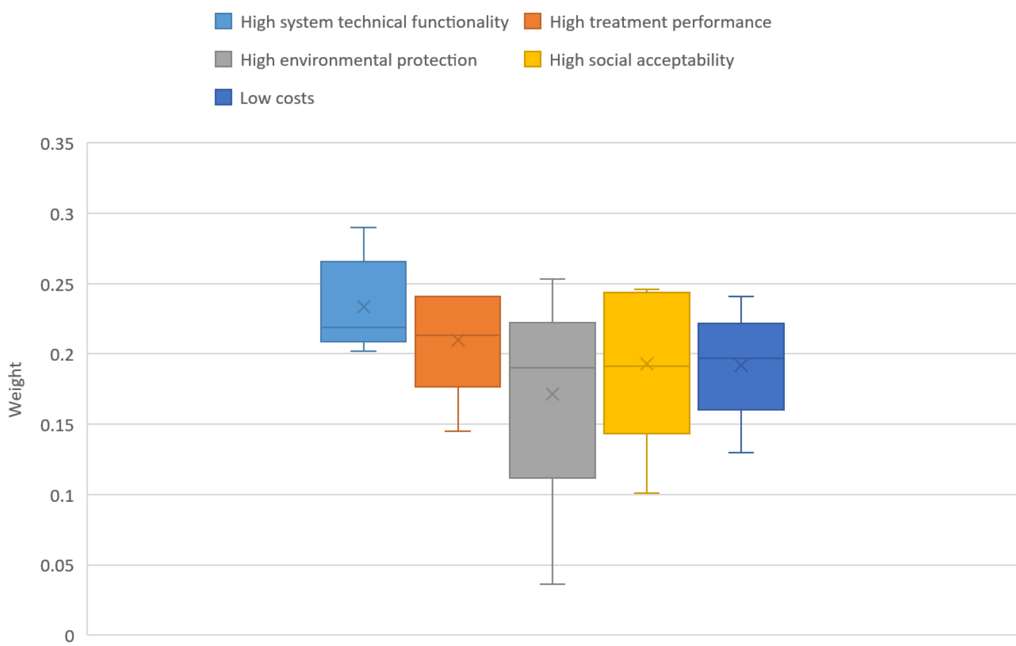


Figure 4.10 Spread of the weights given to the five main objectives by the stakeholders

According to Figure 4.9, it is interesting to note that for one of the stakeholders (SH5), four out of five objectives were equally important. Given the highest and least average weights to the main objectives (Figure 4.10), the main objectives *high system technical functionality* and *high treatment performance* obtained the highest weights. This is justifiable as the first objective relates to the challenges and functionality of the system in the long run and the second objective is one of the main goals of wastewater treatment facilities. Surprisingly, the main objective *high environmental protection*, which considers environmental benefits such as nutrient recovery and groundwater recharge, obtained the lowest weight. However, this was not the only main objective that considers environmental benefits: another main objective, the *high treatment performance*, also has an important impact on the environment by improving the receiving water quality such as groundwater and surface water, as well as by preventing phenomenon such as eutrophication. Therefore, the result for the *high environmental protection* may significate that the specific environmental challenges included in this objective were less important for stakeholders in comparison to the pollutant removal objectives considered under *high treatment performance*. The observed trend for the two most important objectives aligns with the results of a case study in Switzerland based on the same set of main objectives (Beutler & Lienert, 2020 ; Zheng et al., 2016). If the main objective *high environmental protection* would be merged with the other main objective *high treatment* *performance*, both related to environment in a certain way, the main objective *low cost* would become the least important main objective, which is similar to the findings from other studies in this field (Beutler & Lienert, 2020 ; Zheng et al., 2016). The similarity between the results of this study and previous studies undertaken in Europe suggests that environmental issues are considered of the highest importance in countries of the Global North. Although cost issues were considered of lower importance in this study when merging the two related environmental main objectives, budget constraints and financial sustainability are key factors in any infrastructure project (Zheng et al., 2016). While stakeholders prioritize environmental concerns, it is imperative to strike a balance between preserving the environment and managing costs effectively.

It becomes evident that the stakeholders' preferences for four out of the five main objectives exhibit considerable similarity while for the objective *high environmental protection,* a more pronounced disparity emerges among the stakeholders' choices (Figure 4.10).

4.4.2 Sub-objectives' weight elicitation

The sub-objective *low operational and maintenance cost* emerged as the most significant among all the sub-objectives (Figure 4.11). Conversely, the sub-objective *high attractiveness for end-users* ranked the lowest in terms of importance. It is worth noting that the weight assigned to the most crucial objective was 2.3 times higher than that assigned to the least important one.

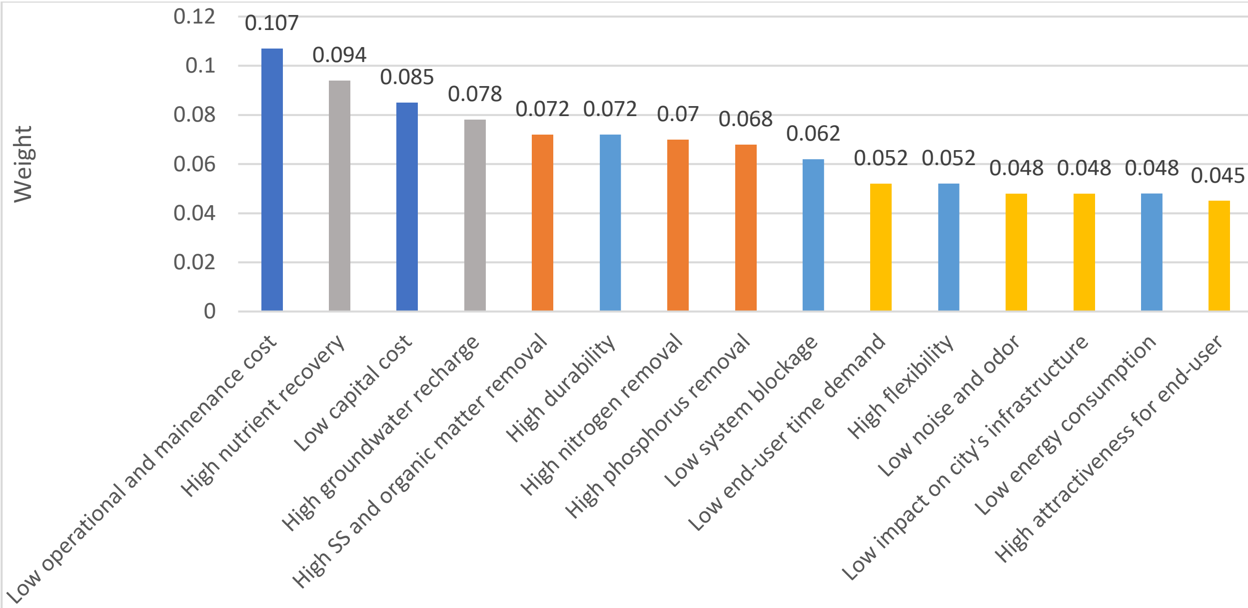


Figure 4.11 Average global weight of the 15 sub-objectives (colors correspond to the diferent five main objectives; dark blue: low costs, gray: high environmental protection, light blue: high system technical functionality, orange: high treatment perfromance and yellow: high social acceptance)

Regarding the results of sub-objectives, it might be surprising to see that although the main objective *low cost* was not among the most important main objectives, both of its sub-objectives, i.e., *low operational and maintenance cost* and *low capital cost*, were among the first three most important sub-objectives. The same pattern was observed for the two objectives under *high environmental protection*, which are among the first four most important sub-objectives. This trend can be explained by the relatively balanced distribution of weights assigned to both main objectives and sub-objectives within each branch, and the fact that there is not a significant difference between the weights. Consequently, within branches that encompass a smaller number of sub-objectives, the locally assigned weights for the sub-objectives hold greater weights, consequently resulting in higher final global weights for the corresponding sub-objectives. If the number of sub-objectives was more uniform or similar in each branch (i.e. difference of one sub-objective instead of two in our case), it could have led to less bias. Considering the same number of sub-objectives in each branch is not mandatory: several studies considered different numbers of sub-objectives in each branch, which still allowed the ranking of the objectives. For instance, Zheng et al. (2016) had a difference of two to three sub-objectives between their branches. Schuwirth et al. (2012) had a difference of two sub-objectives among their branches. The average weights of the sub-objectives with respect to their branches beside their minimum and maximum weights are shown in Figure 4.12 to Figure 4.16. Interestingly, in the *high system technical functionality*, stakeholders assigned a nearly 1.5 times greater importance to the lifespan of the system compared to the least important objective. This observation underscores the practical reality that decision-makers allocate considerable attention to the longevity of the selected system.

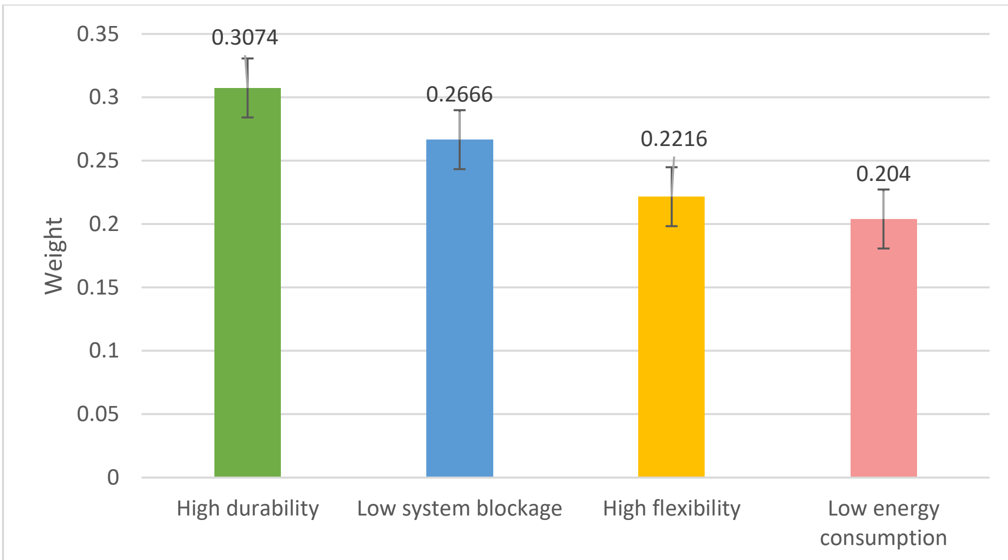


Figure 4.12 Spread of weights given to the sub-objectives for the main objective *High system technical functionality*

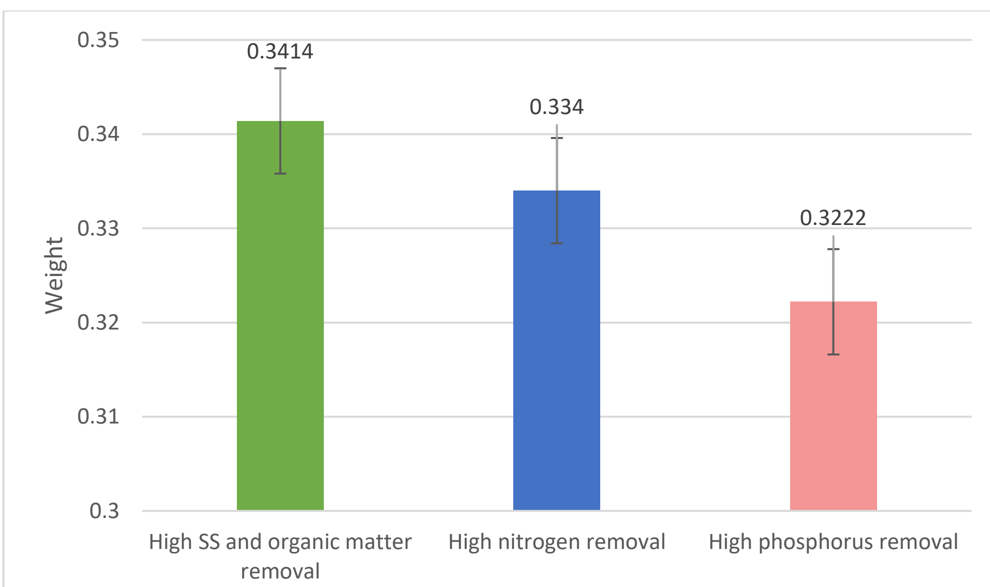


Figure 4.13 Spread of weights given to the sub-objectives for the main objective *High treatment performance*

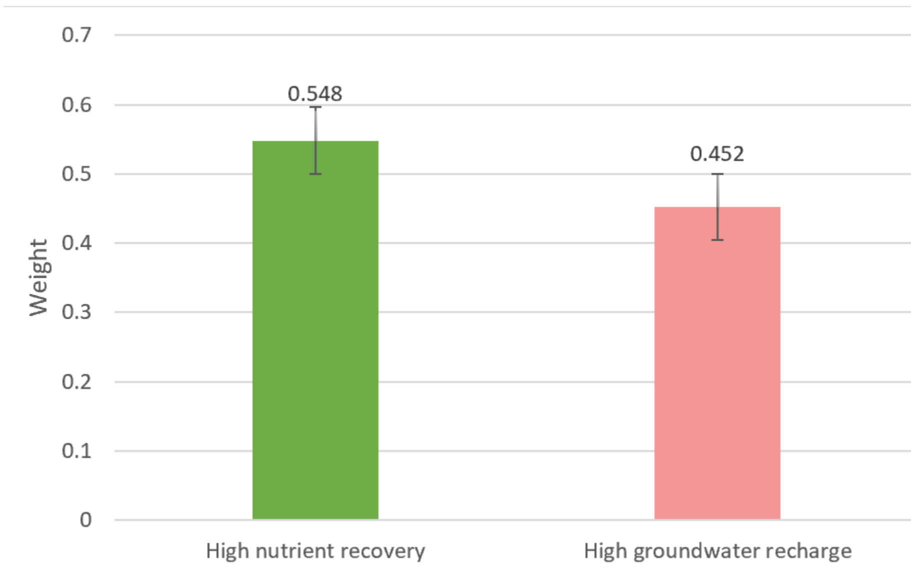


Figure 4.14 Spread of weights given to the sub-objectives for the main objective *High environmental protection*

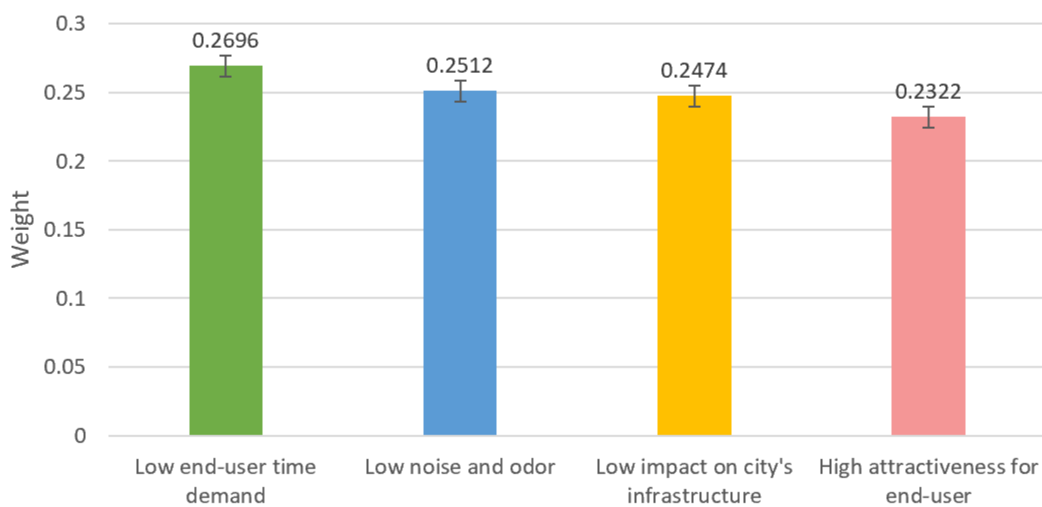


Figure 4.15 Spread of weights given to the sub-objectives for the main objective *High social acceptability*

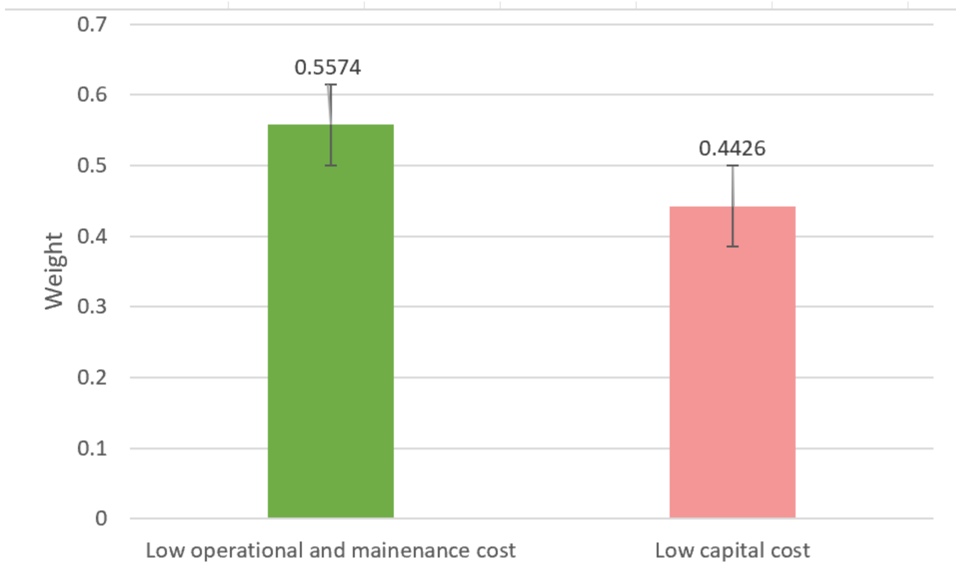
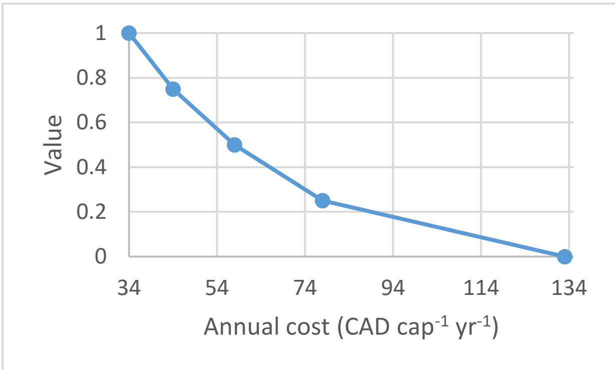


Figure 4.16 Spread of weights given to the sub-objectives for the main objective *low cost*

4.4.3 Marginal value functions

Figure 4.17 presents the marginal value functions obtained through consultation with the wastewater expert for the most important objectives of the 4 main branches of the objective hierarchy: *low operational and maintenance cost, high durability, high SS and organic matter removal* and *low end-user time demand.* Figure 4.17a illustrates that the span between the lowest level and the 25th percentile point is notably greater than the span between the 25th percentile point and the highest level. This observation indicates that the annual cost within the initial interval is not truly feasible, resulting in a low value for assessing alternative performances. Figure 4.17d shows that the concentration of the suspended solid up to 25 mg/L in the effluent is highly acceptable and obtained a high value for the calculation of the overall performance of alternatives.

a



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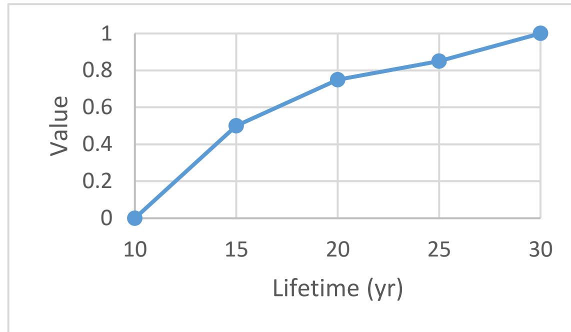

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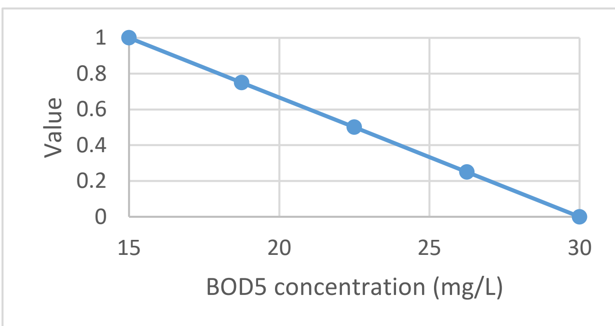

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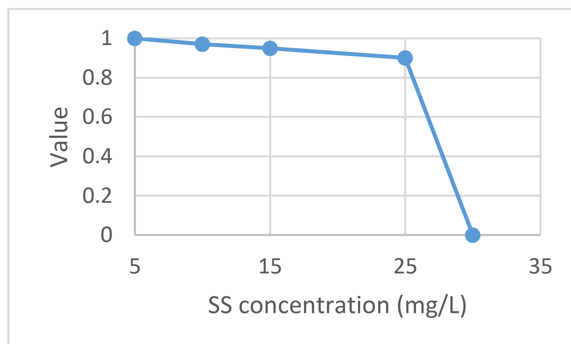

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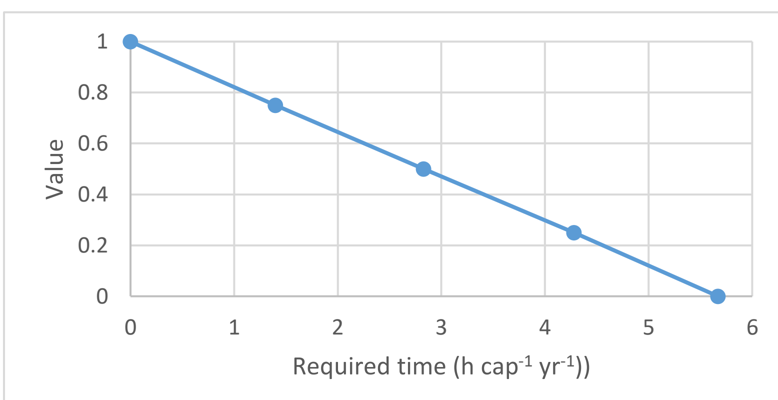

Figure 4.17 Marginal value functions defined by the wastewater treatment expert: (a) objective *low operational and maintenance cost*, (b) objective *high durability*, (c) for the BOD5 concentration attribute of the objective *high SS and organic matter removal*, (d) for the SS

concentration attribute of *high SS and organic matter removal* and (e) objective *low end-user time demand*

4.4.4 Overall value of the alternatives

The overall values of the centralized and hybrid (most environmental-friendly system) alternatives were respectively 0.629 and 0.729, which suggests that the hybrid alternative performs 15.9% better than the centralized alternative according to the objectives considered in our MCDA frameworks and their weights assigned by stakeholders (Figure 4.18). Specifically, the hybrid alternative performed better for the objectives in the *high environmental protection* category, leading to its better ranking compared to the centralized alternative. Another big difference between the two alternatives was related to the *low operational and maintenance cost* objective: the centralized system was assigned a significantly superior performance for this objective. The findings of the study provide valuable insights for the municipality of our case study, indicating that a hybrid alternative exists that has the potential to outperform traditional wastewater management systems across multiple evaluation objectives. Nevertheless, it is imperative to acknowledge that the implementation of a hybrid alternative may entail greater intricacy compared to centralized systems due to their recent emergence. Additionally, the higher investment cost associated with the hybrid alternative may significantly influence the municipality's decision in selecting a particular system (Zheng et al., 2016).

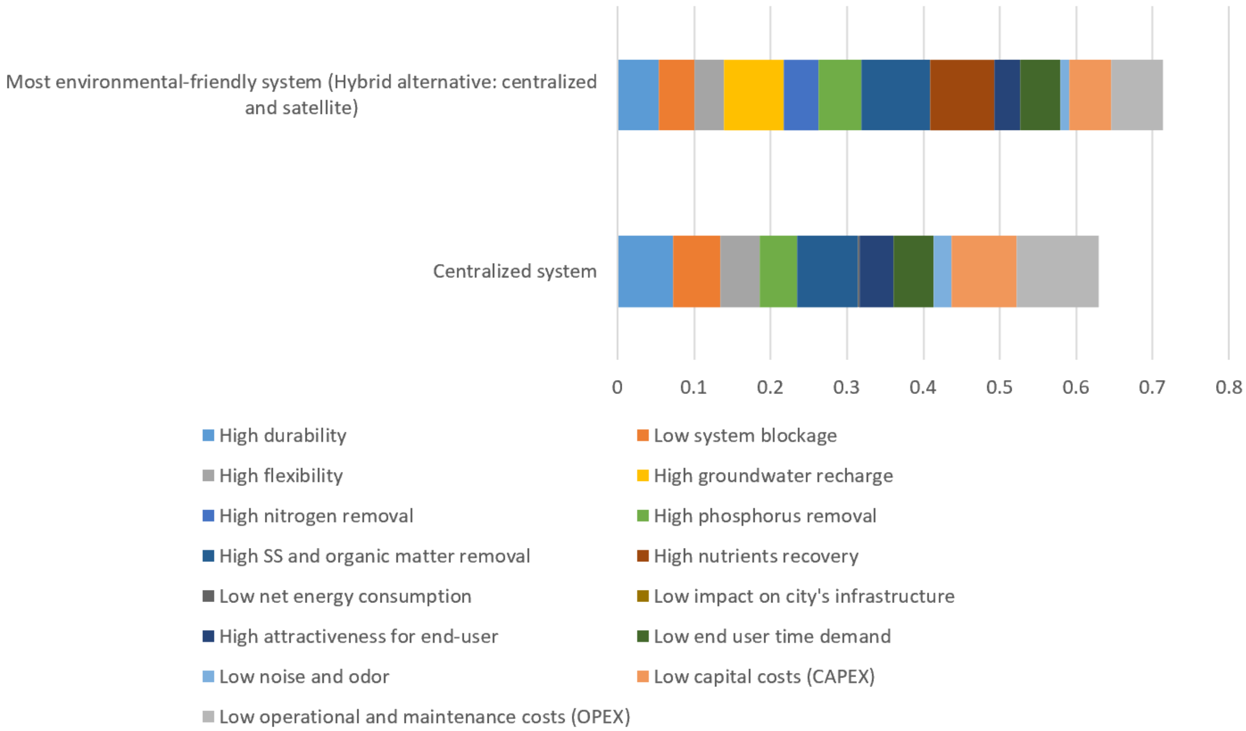

Figure 4.18 Comparison between the overall value of fully centralized and most environmentally friendly alternatives

CHAPTER 5 LIMITATION AND FUTURE WORK

5.1 Limitations observed when developing the alternatives

Despite the clear definition of wastewater management alternatives, the development process has some limitations that should be noted. Firstly, the decision was made not to include the sludge line in the alternatives with the same level of detail as the water streamline. The sludge line is a significant component of the wastewater management system (Metcalf & Eddy-AECOM, 2013); however, this decision was made to simplify the first version of the framework given the timeline of the master's project. Therefore, the processes for the recovery of nutrients and the costs of these systems are not considered while developing the alternatives, and future studies can focus on improving this aspect of the development of alternatives.

Secondly, the process selection and the specific technologies for the treatment levels were not examined in detail during the development of the alternatives and within the strategy generation table. This approach resulted in a reduction of the resolution of the project outcomes; however, it was necessary to focus efforts on a macro scale. Therefore, it led to having two sets of objectives when obtaining data from the literature for the assessment of the alternatives' performance.

Another point to mention is that the name of the alternatives and their characteristics were defined according to the position of the case study and point of view of our partner, the decisions made within the research team and the literature. Therefore, there is a possibility that for another case study or another project, the current names do not align with the systems' characteristics, for instance for the most flexible alternative. These limitations should be taken into consideration when interpreting the results of the project.

5.2 Alternatives' performance prediction

Certain objectives in this study necessitated higher technological resolution to acquire the required data, leading to the incorporation of specific assumptions and technologies for performance assessment. Consequently, these factors introduced uncertainty into the obtained performance results as certain assumptions were made to calculate these objectives. From another standpoint, when considering another perspective, two of these objectives, namely *low operational and maintenance cost* and *low capital cost* emerged as among the top-three most important objectives based on the results of weight elicitation. Notably, *low operational and maintenance cost* obtained the highest importance. Therefore, these objectives exert a significant influence on the final ranking of the alternatives. Given the inherent uncertainties associated with the outcomes of these objectives, conducting a sensitivity analysis becomes imperative (Zheng et al., 2016). This analysis enables the opportunity to assess the extent to which variations in both cost categories impact the final ranking of the alternatives, thereby providing valuable insights into the robustness of the findings.

Regarding the acquisition of expert judgment for assessing the performance of alternatives, it is important to acknowledge that due to project time constraints, only one expert with specialization in more centralized systems was interviewed to obtain performance evaluations for certain objectives. Consequently, the project outcomes reflect the perspective of a single individual, providing a limited viewpoint in determining the performance of the objectives. Inclusion of multiple experts who are specialized in centralized and decentralized wastewater systems would have resulted in more comprehensive results for evaluating the performance of alternatives across the objectives. Different experts would bring diverse mindsets and judgments to the table, potentially yielding different outcomes compared to the current results for the consulted objectives. It is important to note that evaluating technological flexibility or flexibility in the operational phase requires a higher level of detail and resolution, which needs to be done before obtaining the experts' opinion. Hence, it is crucial to recognize that the current findings for the objectives assessed through consultation are contingent on the limitations imposed by the involvement of a single expert. Consideration of a broader range of experts and conducting more in-depth analyses would enhance the comprehensiveness and reliability of the results for future studies.

5.3 Marginal value functions

During the determination of the five value functions for the most important sub-objectives within branches in consultation with an expert, it was observed that two of them followed a linear pattern, whereas the remaining three exhibited non-linear characteristics. This outcome emphasizes the significance of conducting similar analyses for the five remaining objectives, (which within the time constraints of this study were assumed to have linear value functions), through expert consultation to obtain more detailed functions. To ensure more fruitful results during consultations with experts, a valuable approach is to group similar objectives together and seek input from multiple experts who possess extensive experience within the specific category. It is important that these experts have a comprehensive understanding of both centralized and decentralized systems. By adopting this approach and considering the uncertainty analysis, the defined functions might be expected to offer a higher level of accuracy and reliability.

5.4 Overall value of the alternatives

The main contribution of the present thesis lies in the development of a novel MCDA framework allowing to assess and compare a broad range of wastewater system alternative across the full spectrum of possible operating scales, as such a framework was not available to date. Due to time constraints of the master's project, we conducted evaluations, using the developed framework, only for the most traditional wastewater system (fully centralized, considered as the business-as-usual scenario) and one of the novel hybrid systems. Despite this limitation, the results provided valuable insights into the efficiency and potential benefits of the more 'out-of-the-box' hybrid system compared to the conventional system. Moving forward, future works could focus on completing the evaluation of the remaining alternatives to gain a comprehensive understanding of their performance. Additionally, investigating the long-term effects of implementing a hybrid novel system on environmental sustainability, cost-effectiveness, and community well-being would be crucial in shaping sustainable wastewater management strategies for the municipality. The framework has the potential to be used in different cities in Quebec facing similar challenges to our case study. Furthermore, the framework's adaptability extends to other Canadian cities, albeit with adjustments in the objective weights to align with the stakeholders chosen in different provinces. It is imperative to consider provincial regulations to ensure the alignment of objectives with the regulations.

CHAPTER 6 CONCLUSION

We have developed a novel decision-support framework based on Multi-Criteria Decision Analysis (MCDA) to support wastewater management planning for a new development zone in a medium-sized city in Quebec. We developed a comprehensive objectives' hierarchy by including 17 economic, environmental and social sub-objectives through active involvement of stakeholders from wastewater and environmental management sectors to ensure that the hierarchy aligns with the specific context and priorities of Quebec. We created six wastewater management systems that are different in their characteristics in order to cover the spectrum ranging from fully on-site systems to fully centralized systems, including four hybrid systems. A key contribution of our work was to incorporate the preferences of stakeholders for determining the objectives' weights. Stakeholders determined the importance of main objectives for planning of a wastewater management system in the following order, which is in line with the results of simal studies: *high system technical functionality, high treatment performance, high social acceptance, low costs* and *high environmental protection.* Assessment of the alternatives' performance on the objectives shows that each alternative performs well for certain objectives. Considering the varying importance of objectives as well, integrating the importance of objectives along with the value from the performance of alternatives provides a reliable approach for evaluating the alternatives. The comparative analysis between the traditional wastewater management system and one of the novel hybrid systems reveals the potential superior performance potential of the hybrid system across environmental criteria and highlights the benefits for municipalities to consider alternative wastewater management approaches beyond the traditional system. By utilizing this decision analysis framework, decision makers in the wastewater management sector can make more informed and evidence-based decisions. This framework aims at enhancing the overall efficiency and effectiveness of decision-making processes, leading to improved wastewater management practices in Quebec and Canada, ultimately benefiting the environment and society as a whole.

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APPENDIX A ETHICS CONSENT FORMS

Consent form used for the stakeholders:

POLYTECHNIQUE MONTRÉAL
UNIVERSITÉ D'INGÉNIERIE

Formulaire d'information et de consentement

Titre de l'activité de recherche :

Un nouveau cadre multicritère de support à la décision sur les systèmes d'assainissement hybrides : application à une municipalité du Québec, Canada.

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Financement de l'activité de recherche :

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Conflits d'intérêts

L'équipe de recherche n'est pas en situation de conflit d'intérêts dans le contexte de la présente activité de recherche.

Préambule

Nous vous invitons à participer à un projet de recherche qui vise à développer des alternatives de gestion des eaux usées, notamment des systèmes centralisés, décentralisés et hybrides, et à déterminer la meilleure alternative en intégrant des critères de décision complets.

Dans cette étude, nous utiliserons l'analyse décisionnelle multicritère (ADMC) pour construire un cadre analytique permettant de classer les alternatives de gestion des eaux usées et de définir la meilleure alternative. Nous développerons un vaste éventail d'alternatives possibles en matière de systèmes d'assainissement, allant des systèmes centralisés aux systèmes décentralisés, y compris les systèmes hybrides, appliqués à une étude de cas d'une ville du sud du Québec, au Canada. Nous organiserons le premier atelier avec les parties prenantes municipales pour valider l'ensemble des critères de décision en termes d'objectifs environnementaux, économiques, sociaux et techniques et pour vérifier et développer des alternatives de gestion des eaux usées. Ensuite, nous estimerons la performance des alternatives de systèmes d'assainissement par rapport à chaque objectif en nous basant sur les connaissances d'experts et la revue de la littérature. Dans une prochaine étape, nous organiserons le deuxième atelier sur l'élicitation des poids avec les parties prenantes municipales pour tenir compte de leurs priorités et préférences dans le classement et la pondération des objectifs.

Cependant, avant d'accepter de participer à cette activité et de signer le présent formulaire d'information et de consentement, veuillez prendre le temps de lire l'information présentée.

Nous vous invitons à poser toutes les questions que vous jugerez utiles à la responsable ou au responsable de l'activité de recherche ou à tout autre membre de l'équipe de recherche et à leur demander de vous expliquer tout mot ou renseignement qui ne serait pas clair. Nous vous invitons également à prendre conseil auprès de toute autre personne de qui vous aimeriez obtenir un avis à propos de votre éventuelle participation.

Présentation générale du projet de recherche

Les principaux objectifs de ce projet de recherche sont :
1. Développer des alternatives de gestion des eaux usées allant des systèmes centralisés aux systèmes décentralisés, y compris les systèmes hybrides, pour une nouvelle zone de développement dans une ville du sud du Québec, au Canada.
2. Développer un nouveau cadre d'analyse décisionnelle multicritère en intégrant les critères de décision en termes d'objectifs environnementaux, économiques, sociaux et techniques.
3. Déterminer la meilleure alternative pour la gestion des eaux usées en utilisant le cadre développé.

Critères d'inclusion et d'exclusion

Pour ce projet de recherche, nous recrutons des parties prenantes qui ont un rôle professionnel dans le secteur de la gestion de l'eau, de la gestion des eaux usées, de la planification urbaine, de l'environnement, de la gouvernance ou de l'ingénierie des municipalités. Les facteurs de genre, d'âge, de religion, d'ethnicité, de handicap et d'orientation politique ou sexuelle ne seront pas décisifs.

Nature et durée de votre participation à l'activité de recherche

Premier atelier:
Cet atelier avec la participation des parties prenantes a pour but de valider les critères de décision que nous utiliserons pour évaluer les alternatives de gestion des eaux usées et d'obtenir leurs opinions concernant les alternatives de gestion des eaux usées développées. Le questionnaire utilisé dans cette activité permettra d'obtenir les opinions des participants dans deux domaines : les critères de décision (objectifs) et les alternatives de gestion des eaux usées. Les participants seront invités à générer leur propre ensemble d'objectifs et d'alternatives de gestion des eaux usées, ainsi qu'à donner leur avis sur les critères de décision et les alternatives actuellement développés. La participation à cet atelier nécessitera probablement 2 à 3 heures et le responsable du projet de recherche sera disponible pour répondre à toutes les questions pendant cette période.

Deuxième atelier:
Cet atelier avec la participation des parties prenantes sera organisé dans le but d'obtenir des poids pour les critères de décision (objectifs). Les pondérations attribuées aux objectifs seront ensuite utilisées dans le cadre d'un processus de prise de décision multicritère pour classer les alternatives de gestion des eaux usées. Les participants répondront à un questionnaire axé sur la pondération des critères qui permettra de choisir la meilleure solution pour la gestion des eaux usées. Dans ce questionnaire, les parties prenantes se verront présenter une liste d'objectifs visés lors du choix d'une alternative de gestion des eaux usées. Les participants devront répondre au questionnaire individuellement et ils disposeront de 2 heures pour le

remplir. Le responsable du projet de recherche sera disponible pour répondre à toutes les questions pendant cette période.

Risques pouvant découler de votre participation à l'activité de recherche :

La présente activité de ne devrait pas entraîner des risques plus grands que ceux que vous rencontrez dans votre vie de tous les jours. Toutefois, si vous vous sentez découragé ou si vous rencontrez un quelconque malentendu en répondant au questionnaire, le responsable du projet sera disponible pour répondre à vos questions par e-mail pendant le temps prévu. En outre, un exemple sera mis à votre disposition pour vous guider dans le processus de pondération.

Inconvénients pouvant découler de votre participation à l'activité de recherche

L'activité se déroulera pendant les heures de travail. Par conséquent, il sera de la responsabilité des participants de s'assurer qu'ils sont en mesure de réaliser l'activité dans leur horaire de travail.

Avantages pouvant découler de votre participation à l'activité de recherche

La participation à cette activité de recherche ne vous procurera aucun avantage personnel direct. Cependant, votre participation est considérée comme une étape importante de l'analyse décisionnelle multicritère et contribuera à faire progresser les connaissances concernant le développement d'un cadre de support à la décision multicritère sur les systèmes d'assainissement. Il aidera les praticiens à réfléchir de manière structurée à leurs alternatives et leur permettra de prendre des décisions plus éclairées sur les investissements futurs pour le traitement des eaux usées.

Compensation financière

La participation à cette activité de recherche est volontaire et bénévole et aucune compensation financière n'est prévue.

Participation volontaire et possibilité de retrait :

Votre participation à la présente activité de recherche est volontaire. Vous êtes donc libre de refuser d'y participer et pouvez à tout moment décider de vous en retirer sans avoir à motiver votre décision et sans risquer d'en subir de préjudice. Vous n'avez qu'à en informer la personne-ressource de l'équipe de recherche et ce, par simple avis verbal.

En cas de retrait, vous pouvez demander la destruction des données vous concernant. Cependant, il sera impossible de retirer vos données ou votre matériel des analyses menées une fois ces dernières publiées ou diffusées.

Tout au long des activités de recherche, vous recevrez en temps opportun l'information pertinente en lien avec votre participation.

L'équipe de recherche et le comité d'éthique de la recherche se réservent le droit de vous retirer de l'étude si vous ne respectez pas les consignes, s'il existe des raisons administratives d'abandonner l'activité, ou pour toutes autres raisons concernant la faisabilité de l'étude. Si une telle situation survient, l'équipe de recherche vous en informera dès que possible.

Confidentialité et protection de vos données

L'équipe de recherche recueillera et consignera toutes vos données de manière sécuritaire de façon à en protéger le caractère confidentiel.

Voici comment nous protégerons vos données **lors de la collecte :**

- Aucune information personnelle, à l'exception du nom, du domaine d'expertise et du rôle professionnel (affiliation) du participant, ne sera collectée. Il convient de mentionner que pour le classement et l'analyse des données, nous rendrons anonyme le nom des participants en les codant et nous garderons le fichier de décodage complètement séparé de l'analyse des données. En outre, nous enregistrons le rôle professionnel (affiliation) des parties prenantes et leur adresse électronique dans un fichier séparé et ce fichier ne sera jamais utilisé, sauf pour les contacter. Ces informations ne seront collectées que si vous y consentez (voir page 8). Les données collectées seront celles obtenues à partir des questionnaires. Toutes les informations des participants et les données collectées seront conservées sur l'ordinateur portable personnel de la responsable du projet (Pouria Soleimani) qui est protégé par un mot de passe pour se connecter à l'ordinateur portable. Toutes les données seront accessibles à l'équipe de recherche, qui comprend Françoise Bichai, Dominique Claveau-Mallet et Martijn Kuller, en téléchargeant les données sur le disque partagé protégé par mot de passe de Polytechnique Montréal.

Voici comment nous protégerons vos données **lors des analyses et du transfert des données** entre les membres de l'équipe :

- Pour le premier atelier: Les données et les opinions recueillies par les questionnaires seront utilisées dans le cadre d'un processus de prise de décision multicritère pour classer les alternatives de gestion des eaux usées. Ces données permettront de finaliser la hiérarchie des objectifs et les alternatives de gestion des eaux usées. Les données personnelles utilisées seront votre nom anonyme et votre domaine d'expertise. Toutes les informations des participants et les données collectées seront conservées sur l'ordinateur portable personnel de la responsable du projet (Pouria Soleimani) qui est protégé par un mot de passe pour se connecter à l'ordinateur portable. Toutes les données seront accessibles à l'équipe de recherche, qui comprend Françoise Bichai, Dominique Claveau-Mallet et Martijn Kuller, en téléchargeant les données sur le disque partagé protégé par mot de passe de Polytechnique Montréal.

- Pour le deuxième atelier : Les données recueillies par les questionnaires seront utilisées dans le cadre d'un processus de prise de décision multicritère pour classer les alternatives de gestion des eaux usées. Les pondérations obtenues sont des valeurs d'entrée pour les calculs de classement des alternatives. Les données personnelles utilisées seront votre nom anonyme et votre domaine d'expertise. Toutes les informations des participants et les données collectées seront conservées sur l'ordinateur portable personnel de la responsable du projet (Pouria Soleimani) qui est protégé par un mot de passe pour se connecter à l'ordinateur portable. Toutes les données seront accessibles à l'équipe de recherche, qui comprend Françoise Bichai, Dominique Claveau-Mallet et Martijn Kuller, en téléchargeant les données sur le disque partagé protégé par mot de passe de Polytechnique Montréal.

Voici comment nous protégerons vos données **lors des publications** :

- Les données brutes obtenues par les questionnaires dans les ateliers ne seront pas divulguées lors de la publication des résultats ou dans tout autre cas sans accord préalable. Les pondérations obtenues et le jugement des experts permettront d'obtenir des résultats pour classer les alternatives de gestion des eaux usées et la publication de ceux-ci ne concernera que le projet de recherche. Si ces données doivent être utilisées pour d'autres travaux, ceux-ci doivent s'appuyer sur une charte ou une entente de confidentialité ou s'inscrire dans la continuité de ce projet de recherche.

Enfin, voici comment nous protégerons vos données **après le projet de recherche** :

- Vos données seront conservées par l'équipe de recherche pendant 7 ans après la fin du projet de recherche.
- Aucune information personnelle ne sera collectée, à l'exception du nom, du domaine d'expertise et du rôle professionnel du participant. Ces informations vous seront demandées avant de remplir le questionnaire et de participer aux ateliers.

Nous vous invitons à la discrétion afin de maintenir la confidentialité des échanges du groupe de discussion. Ainsi, nous vous demandons de ne divulguer les propos entendus lors du groupe de discussion avec des personnes n'y ayant pas participé.

Pendant les activités, nous prévoyons prendre une photo. Nous demanderons d'abord la permission. La prise de photo des participants sera soumise à l'accpetation de tous les participants. Les photos prises seront enregistrées dans l'ordinateur portable personnel du responsable du projet, protégé par un mot de passe pour se connecter, et accessibles aux collaborateurs du projet, Françoise Bichai, Dominique Claveau-Mallet et Martijn Kuller sur le disque partagé protégé par mot de passe de Polytechnique Montréal.

Vous avez le droit de consulter votre dossier de recherche pour vérifier l'exactitude des renseignements recueillis aussi longtemps que l'équipe de recherche ou Polytechnique Montréal détiendront ces informations. Cependant, afin de préserver l'intégrité scientifique du projet de recherche, certaines informations seront accessibles seulement à la fin du projet de recherche.

Diffusion des résultats de la recherche

La diffusion des résultats de la recherche ne comprendra pas d'informations personnelles relatives aux participants à l'enquête. Les participants à ces ateliers pourront suivre l'évolution du projet de recherche s'ils le souhaitent et auront accès aux résultats globaux de l'étude à la fin du projet.

Indemnisation en cas de préjudice et droits des participant(e)s

Si vous deviez subir quelque préjudice que ce soit par suite de votre participation à cette activité de recherche, vous ne renoncez à aucun de vos droits ni ne libérez les chercheurs, l'organisme de financement ou Polytechnique Montréal de leurs responsabilités légales et professionnelles.

Personnes-ressources

Si vous avez des questions sur les **aspects scientifiques** du projet de recherche ou pour vous **retirer de l'étude**, vous pouvez contacter Pouria Soleimani par courriel à pouria.soleimani@polymtl.ca.

Pour toute préoccupation sur vos droits ou sur les responsabilités de l'équipe de recherche concernant votre participation à ce projet, vous pouvez contacter le Comité d'éthique de la recherche de Polytechnique Montréal au (514) 340-4711, poste 4420 ou encore par courriel à ethique@polymtl.ca

Consentement à la participation au projet de recherche

1. J'ai pris connaissance de la documentation ci-jointe, décrivant la nature et le déroulement du projet de même que les risques et les inconvénients qui pourraient survenir.
2. Je comprends que j'ai droit à des réponses satisfaisantes aux questions que je poserais quant à mon implication dans ce projet tout au long de ma participation.
3. Je consens à participer librement à ce projet, après avoir obtenu et pris le temps d'y réfléchir à ma satisfaction et sans avoir subi de pression à cet effet.
4. Je comprends qu'en participant à ce projet de recherche, je ne renonce à aucun de mes droits ni ne dégage les chercheurs de leurs responsabilités.
5. Je comprends que je peux consulter le dossier que l'équipe de recherche constitue sur moi.
6. Je pourrai à tout moment, sur simple avis de ma part, revenir sur ma décision de participer et serai alors immédiatement libéré de mon engagement.
7. J'ai reçu une copie du présent document.

Prénom et nom du participant (caractère d'imprimerie)	Signature du participant Date :

Engagement de l'équipe de recherche

Je confirme que moi ou mon représentant avons expliqué à la personne précitée la nature de sa participation à la présente activité de recherche, demandé si elle avait des questions, répondu à ses questions questions. Nous avons clairement indiqué qu'elle ou il demeurait libre de participer et de mettre un terme à sa participation à tout moment, par simple avis verbal. Je m'engage, avec l'équipe de recherche, à respecter les modalités décrites dans le présent formulaire d'information et de consentement et déclare en avoir remis une copie signée à la personne.

Dominique Claveau-Mallet	Dominique Claveau-Mallet 2022.12.14 08:35:23 -05'00' Signature du/de la responsable Date :
Pouria Soleimani	Signature de l'étudiant(e) Date : 12 Décembre 2022

Consent form used for experts:

POLYTECHNIQUE MONTRÉAL
UNIVERSITÉ D'INGÉNIERIE

Formulaire d'information et de consentement

<u>Titre de l'activité de recherche</u> :

Un nouveau cadre multicritère de support à la décision sur les systèmes d'assainissement hybrides : application à une municipalité du Québec, Canada.

<u>Équipe de recherche</u> :

Responsable de l'activité de recherche
Pouria Soleimani
Étudiant à la maîtrise recherche
Polytechnique Montréal – Département des génies civil, géologique et des mines (CGM)
Adresse courriel: pouria.soleimani@polymtl.ca

Sous la direction de
Françoise Bichai
Professeure adjointe
Polytechnique Montréal – Département des génies civil, géologique et des mines
Numéro de téléphone : 1-514-340-4711 poste 4256
Adresse courriel: fbichai@polymtl.ca

Sous la co-direction de
Dominique Claveau-Mallet
Professeure adjointe
Polytechnique Montréal – Département des génies civil, géologique et des mines
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Martijn Kuller
Chercheur postdoctoral
Eawag
+41 58 765 6752
Adresse courriel: martijn.kuller@eawag.ch

Financement de l'activité de recherche :

La présente activité de recherche est financée par le CRSNG et FRQNT.

Conflits d'intérêts

L'équipe de recherche n'est pas en situation de conflit d'intérêts dans le contexte de la présente activité de recherche.

Préambule

Nous vous invitons à participer à un projet de recherche qui vise à développer des alternatives de gestion des eaux usées, notamment des systèmes centralisés, décentralisés et hybrides, et à déterminer la meilleure alternative en intégrant des critères de décision complets.

Dans cette étude, nous utiliserons l'analyse décisionnelle multicritère (ADMC) pour construire un cadre analytique permettant de classer les alternatives de gestion des eaux usées et de définir la meilleure alternative. Nous développerons un vaste éventail d'alternatives possibles en matière de systèmes d'assainissement, allant des systèmes centralisés aux systèmes décentralisés, y compris les systèmes hybrides, appliqués à une étude de cas d'une ville du sud du Québec, au Canada. Nous organiserons le premier atelier avec les parties prenantes municipales pour valider l'ensemble des critères de décision en termes d'objectifs environnementaux, économiques, sociaux et techniques et pour vérifier et développer des alternatives de gestion des eaux usées. Ensuite, nous estimerons la performance des alternatives de systèmes d'assainissement par rapport à chaque objectif en nous basant sur les connaissances d'experts et la revue de la littérature. Dans une prochaine étape, nous organiserons le deuxième atelier sur l'élicitation des poids avec les parties prenantes municipales pour tenir compte de leurs priorités et préférences dans le classement et la pondération des objectifs.

Cependant, avant d'accepter de participer à cette activité et de signer le présent formulaire d'information et de consentement, veuillez prendre le temps de lire l'information présentée.

Nous vous invitons à poser toutes les questions que vous jugerez utiles à la responsable ou au responsable de l'activité de recherche ou à tout autre membre de l'équipe de recherche et à leur demander de vous expliquer tout mot ou renseignement qui ne serait pas clair. Nous vous invitons également à prendre conseil auprès de toute autre personne de qui vous aimeriez obtenir un avis à propos de votre éventuelle participation.

Présentation générale du projet de recherche

Les principaux objectifs de ce projet de recherche sont :
1. Développer des alternatives de gestion des eaux usées allant des systèmes centralisés aux systèmes décentralisés, y compris les systèmes hybrides, pour une nouvelle zone de développement dans une ville du sud du Québec, au Canada.
2. Développer un nouveau cadre d'analyse décisionnelle multicritère en intégrant les critères de décision en termes d'objectifs environnementaux, économiques, sociaux et techniques.
3. Déterminer la meilleure alternative pour la gestion des eaux usées en utilisant le cadre développé.

Critères d'inclusion et d'exclusion

Pour ce projet de recherche, pour les entrevues avec les experts, nous recrutons des experts qui sont dans le domaine de la gestion des eaux usées et de la mise en œuvre des systèmes de traitement des eaux usées. Les facteurs de genre, d'âge, de religion, d'ethnicité, de handicap et d'orientation politique ou sexuelle ne seront pas décisifs.

Nature et durée de votre participation à l'activité de recherche

Une entrevue avec la participation des experts permet d'obtenir le jugement des experts concernant la performance des différentes alternatives en termes d'objectifs (échelle de valeur). Au cours de cette entrevue, la liste des critères de décision sera d'abord présentée aux experts en leur présentant les attributs des critères. Ensuite, il leur sera demandé de fournir leur jugement ainsi que des échelles de valeur pour les critères.

Risques pouvant découler de votre participation à l'activité de recherche :

La présente activité de ne devrait pas entraîner des risques plus grands que ceux que vous rencontrez dans votre vie de tous les jours. Toutefois, si vous vous sentez découragé ou si vous rencontrez un quelconque malentendu en répondant au questionnaire, le responsable du projet sera disponible pour répondre à vos questions par e-mail pendant le temps prévu. En outre, un exemple sera mis à votre disposition pour vous guider dans le processus.

Inconvénients pouvant découler de votre participation à l'activité de recherche

L'activité se déroulera pendant les heures de travail. Par conséquent, il sera de la responsabilité des participants de s'assurer qu'ils sont en mesure de réaliser l'activité dans leur horaire de travail. Vous devrez passer 1 à 2 heures pour cette entrevue.

Avantages pouvant découler de votre participation à l'activité de recherche

La participation à cette activité de recherche ne vous procurera aucun avantage personnel direct. Cependant, votre participation est considérée comme une étape importante de l'analyse décisionnelle multicritère et contribuera à faire progresser les connaissances concernant le développement d'un cadre de support à la décision multicritère sur les systèmes d'assainissement. Il aidera les praticiens à réfléchir de manière structurée à leurs alternatives et leur permettra de prendre des décisions plus éclairées sur les investissements futurs pour le traitement des eaux usées.

Compensation financière

La participation à cette activité de recherche est volontaire et bénévole et aucune compensation financière n'est prévue.

Participation volontaire et possibilité de retrait :

Votre participation à la présente activité de recherche est volontaire. Vous êtes donc libre de refuser d'y participer et pouvez à tout moment décider de vous en retirer sans avoir à motiver votre décision et sans risquer d'en subir de préjudice. Vous n'avez qu'à en informer la personne-ressource de l'équipe de recherche et ce, par simple avis verbal.

En cas de retrait, vous pouvez demander la destruction des données vous concernant. Cependant, il sera impossible de retirer vos données ou votre matériel des analyses menées une fois ces dernières publiées ou diffusées.

Tout au long des activités de recherche, vous recevrez en temps opportun l'information pertinente en lien avec votre participation.

L'équipe de recherche et le comité d'éthique de la recherche se réservent le droit de vous retirer de l'étude si vous ne respectez pas les consignes, s'il existe des raisons administratives d'abandonner l'activité, ou pour toutes autres raisons concernant la faisabilité de l'étude. Si une telle situation survient, l'équipe de recherche vous en informera dès que possible.

Confidentialité et protection de vos données

L'équipe de recherche recueillera et consignera toutes vos données de manière sécuritaire de façon à en protéger le caractère confidentiel.

Voici comment nous protégerons vos données **lors de la collecte :**

- Aucune information personnelle, à l'exception du nom, du domaine d'expertise et du rôle professionnel (affiliation) du participant, ne sera collectée. Il convient de mentionner que pour le classement et l'analyse des données, nous rendrons anonyme le nom des participants en les codant et nous garderons le fichier de décodage complètement séparé de l'analyse des données. En outre, nous enregistrons le rôle professionnel (affiliation) des experts et leur adresse électronique dans un fichier séparé et ce fichier ne sera jamais utilisé, sauf pour les contacter. Ces informations ne seront collectées que si vous y consentez (voir page 7). Les données collectées seront celles obtenues à partir des questionnaires. Toutes les informations des participants et les données collectées seront conservées sur l'ordinateur portable personnel de la responsable du projet (Pouria Soleimani) qui est protégé par un mot de passe pour se connecter à l'ordinateur portable. Toutes les données seront accessibles à l'équipe de recherche, qui comprend Françoise Bichai, Dominique Claveau-Mallet et Martijn Kuller, en téléchargeant les données sur le disque partagé protégé par mot de passe de Polytechnique Montréal.

Voici comment nous protégerons vos données **lors des analyses et du transfert des données** entre les membres de l'équipe :

- Les données des échelles de valeur seront collectées lors d'une entrevue en personne ou en groupe et seront utilisées dans le développement de l'analyse décisionnelle multicritère. Toutes les informations des participants et les données collectées seront conservées sur l'ordinateur portable personnel de la responsable du projet (Pouria Soleimani) qui est protégé par un mot de passe pour se connecter à l'ordinateur portable. Toutes les données seront accessibles à l'équipe de recherche, qui comprend Françoise Bichai, Dominique Claveau-Mallet et Martijn Kuller, en téléchargeant les données sur le disque partagé protégé par mot de passe de Polytechnique Montréal.

Voici comment nous protégerons vos données **lors des publications** :

- Les données brutes obtenues par les questionnaires dans les entrevues ne seront pas divulguées lors de la publication des résultats ou dans tout autre cas sans accord préalable. Les pondérations obtenues et le jugement des experts permettront d'obtenir des résultats pour classer les alternatives de gestion des eaux usées et la publication de ceux-ci ne concernera que le projet de recherche. Si ces données doivent être utilisées pour d'autres travaux, ceux-ci doivent s'appuyer sur une charte ou une entente de confidentialité ou s'inscrire dans la continuité de ce projet de recherche.

Enfin, voici comment nous protégerons vos données **après le projet de recherche** :

- Vos données seront conservées par l'équipe de recherche pendant 7 ans après la fin du projet de recherche.
- Aucune information personnelle ne sera collectée, à l'exception du nom, du domaine d'expertise et du rôle professionnel du participant. Ces informations vous seront demandées avant de remplir le questionnaire et l'entrevue.

Nous vous invitons à la discrétion afin de maintenir la confidentialité des échanges du groupe de discussion. Ainsi, nous vous demandons de ne divulguer les propos entendus lors du groupe de discussion avec des personnes n'y ayant pas participé.

Pendant les activités, nous prévoyons prendre une photo. Nous demanderons d'abord la permission. La prise de photo des participants sera soumise à l'acceptation de tous les participants. Les photos prises seront enregistrées dans l'ordinateur portable personnel du responsable du projet, protégé par un mot de passe pour se connecter, et accessibles aux collaborateurs du projet, Françoise Bichai, Dominique Claveau-Mallet et Martijn Kuller sur le disque partagé protégé par mot de passe de Polytechnique Montréal.

Vous avez le droit de consulter votre dossier de recherche pour vérifier l'exactitude des renseignements recueillis aussi longtemps que l'équipe de recherche ou Polytechnique Montréal détiendront ces informations. Cependant, afin de préserver l'intégrité scientifique du projet de recherche, certaines informations seront accessibles seulement à la fin du projet de recherche.

Diffusion des résultats de la recherche

La diffusion des résultats de la recherche ne comprendra pas d'informations personnelles relatives aux participants à l'enquête. Les participants à ces entrevues pourront suivre l'évolution du projet de recherche s'ils le souhaitent et auront accès aux résultats globaux de l'étude à la fin du projet.

Indemnisation en cas de préjudice et droits des participant(e)s

Si vous deviez subir quelque préjudice que ce soit par suite de votre participation à cette activité de recherche, vous ne renoncez à aucun de vos droits ni ne libérez les chercheurs, l'organisme de financement ou Polytechnique Montréal de leurs responsabilités légales et professionnelles.

Personnes-ressources

Si vous avez des questions sur les **aspects scientifiques** du projet de recherche ou pour vous **retirer de l'étude**, vous pouvez contacter Pouria Soleimani par courriel à pouria.soleimani@polymtl.ca.

Pour toute préoccupation sur vos droits ou sur les responsabilités de l'équipe de recherche concernant votre participation à ce projet, vous pouvez contacter le Comité d'éthique de la recherche de Polytechnique Montréal au (514) 340-4711, poste 4420 ou encore par courriel à ethique@polymtl.ca

Consentement à la participation au projet de recherche

1. J'ai pris connaissance de la documentation ci-jointe, décrivant la nature et le déroulement du projet de même que les risques et les inconvénients qui pourraient survenir.
2. Je comprends que j'ai droit à des réponses satisfaisantes aux questions que je poserais quant à mon implication dans ce projet tout au long de ma participation.
3. Je consens à participer librement à ce projet, après avoir obtenu et pris le temps d'y réfléchir à ma satisfaction et sans avoir subi de pression à cet effet.
4. Je comprends qu'en participant à ce projet de recherche, je ne renonce à aucun de mes droits ni ne dégage les chercheurs de leurs responsabilités.
5. Je comprends que je peux consulter le dossier que l'équipe de recherche constitue sur moi.
6. Je pourrai à tout moment, sur simple avis de ma part, revenir sur ma décision de participer et serai alors immédiatement libéré de mon engagement.
7. J'ai reçu une copie du présent document.

Prénom et nom du participant (caractère d'imprimerie)	Signature du participant Date :

Engagement de l'équipe de recherche

Je confirme que moi ou mon représentant avons expliqué à la personne précitée la nature de sa participation à la présente activité de recherche, demandé si elle avait des questions, répondu à ses questions questions. Nous avons clairement indiqué qu'elle ou il demeurait libre de participer et de mettre un terme à sa participation à tout moment, par simple avis verbal. Je m'engage, avec l'équipe de recherche, à respecter les modalités décrites dans le présent formulaire d'information et de consentement et déclare en avoir remis une copie signée à la personne.

Dominique Claveau-Mallet	Dominique Claveau-Mallet 2022.12.14 08:34:41 -05'00' Signature du/de la responsable Date :
Pouria Soleimani	Signature de l'étudiant(e) Date : 12 Décembre 2022

APPENDIX B OBJECTIVES DEVELOPMENT ONLINE SURVEY

Bienvenu à ce questionnaire sur le développement d'objectifs pour évaluer les alternatives de gestion des eaux usées. Les objectifs sont souvent appelés critères de décision et sont considérés comme des valeurs qui sont fondamentalement importantes dans le processus de prise de décision, tandis que les alternatives sont différentes configurations du système qui sont des moyens d'atteindre les objectifs dans le processus de prise de décision. Ce questionnaire vise à obtenir les objectifs qui sont importants du point de vue des parties prenantes et des experts. Les objectifs sont utilisés pour la prise de décision et la planification des systèmes de gestion des eaux usées urbaines au Québec.

Veuillez répondre à toutes les questions de manière complète et sincère. Le temps total pour répondre au questionnaire est estimé à 40 minutes. Il n'y a pas de bonnes ou de mauvaises réponses. Nous sommes intéressés par votre opinion honnête en tant que partie prenante de ce projet.

Veuillez rester en ligne pendant que vous remplissez le questionnaire, afin que l'équipe de recherche puisse intervenir au besoin pour ajouter des explications. Si vous avez des questions pendant que vous remplissez le questionnaire, vous pouvez les poser directement dans la boîte de discussion de la plateforme ou nous contacter à l'adresse suivante pouria.soleimani@poymtl.ca ou

Note sur la protection de la vie privée:

Les données personnelles collectées (telles que le nom du participant) seront rendues anonymes par l'attribution d'un numéro d'identification aux participants. Il ne sera pas possible pour les participants d'identifier un autre participant. Seule l'équipe de recherche principale le pourra afin de suivre les informations fournies par les répondants (vous). Toutes vos réponses à ce questionnaire seront anonymes et les données collectées seront soigneusement stockées sur l'ordinateur portable personnel du responsable du projet (Pouria Soleimani). Cet ordinateur portable est protégé à la connexion par un mot de passe. Toutes les données seront accessibles aux autres membres de l'équipe de recherche de ce projet sur le disque partagé de Polytechnique Montréal protégé par mot de passe. Les données seront conservées de manière confidentielle pendant 7 ans, comme cela est exigé pour les données qui font l'objet d'une publication scientifique.

En répondant à ce questionnaire, vous acceptez l'utilisation des données dans les conditions suivantes.

Nous vous remercions de prendre le temps de répondre à ce questionnaire.

Votre participation est très précieuse pour notre équipe de recherche.

Précédent

Suivant

La prise de décision concernant les systèmes de traitement des eaux usées entre parfois en conflit avec les objectifs de la société, de l'économie et de l'environnement. Dans le processus décisionnel, les préférences des parties prenantes et les valeurs des décideurs sont cruciales. Les décisions relatives à la gestion des eaux usées affectent les générations futures et il convient de prendre en compte cette durée de vie. Pour aider ce processus décisionnel complexe, l'analyse décisionnelle multicritère (ADMC) est bien adaptée en raison de sa structure systématique, qui permet l'inclusion explicite d'informations objectives et de préférences subjectives. Dans notre approche ADMC, nous utilisons la réflexion axée sur les valeurs. La réflexion axée sur les valeurs est une approche de l'analyse des problèmes qui part de la notion du caractère fondamental des valeurs (objectifs) dans le processus décisionnel. En utilisant la réflexion axée sur les valeurs, nous considérons les valeurs (objectifs) comme la force motrice de l'analyse de décisions, plutôt que les alternatives. Ainsi, nous fondons les décisions sur les objectifs que les parties prenantes considèrent comme étant de haute importance. L'objectif de la réflexion axée sur les valeurs est de parvenir à une décision qui maximise la valeur pour toutes les parties concernées. Il existe une variété d'objectifs qui sont pertinents lors de la planification d'un système de gestion des eaux usées (alternative). Définir un ensemble complet, non redondant et clair d'objectifs est crucial pour la prise de décision. Un exemple d'objectif est celui des "faibles coûts". Une direction préférée est toujours exprimée dans la formulation d'un objectif. Dans cet exemple, des coûts plus bas sont préférables à des coûts plus élevés. Les objectifs sont utilisés pour discuter et évaluer les alternatives.

Ce questionnaire comprend deux étapes : (1) faire un remue-méninges individuel et (2) compléter les objectifs à l'aide d'une liste maîtresse d'objectifs fournie. Dans cette première étape, il vous sera demandé de noter tous les objectifs qui pourraient être considérés selon vous. Dans la deuxième étape, (2) une liste maîtresse d'objectifs vous sera fournie. Vous pourrez l'utiliser pour finaliser votre propre liste d'objectifs. Après avoir complété ces deux étapes, vous serez dirigé vers une série de questions destinées à obtenir votre opinion sur l'activité de recherche.

Précédent

Suivant

Remue-méninges individuel

Étape 1 : Remue-méninges individuel sur les Objectifs

Veuillez noter tous les objectifs qui, selon vous, pourraient jouer un rôle dans la planification d'un système de gestion des eaux usées, et pas seulement les plus importants. Par exemple, la connaissance du niveau de performance d'un système de gestion des eaux usées donné en fonction de chacun de ces objectifs devrait vous aider à choisir une alternative parmi une série d'alternatives possibles.

Note : Il s'agit d'une étape de remue-méninges. Il n'y a pas de bonnes ou de mauvaises réponses. Ainsi, énumérez tous les objectifs qui vous viennent spontanément à l'esprit, et pas seulement les plus importants. De plus, essayez de vous concentrer sur la définition des objectifs à l'étape du remue-méninge et ne pensez pas aux alternatives.

Veuillez écrire autant d'objectifs que vous pensez et il n'y aurait aucune limitation sur le nombre d'objectifs que vous spécifiez.

objectif A

objectif B

objectif C

✚ Ajouter une ligne

Précédent

Suivant

Étape 2 : Génération d'objectifs à l'aide d'une liste maîtresse

Après avoir pris connaissance de la liste maîtresse d'objectifs fournie, veuillez suivre les étapes suivantes :

Si l'un de vos objectifs générés lors du remue-méninges a une signification similaire à un objectif de la liste maîtresse, veuillez noter le numéro correspondant de l'objectif de la liste maîtresse afin de l'associer à votre propre objectif formulé précédemment. Veuillez faire de même pour chaque objectif du remue-méninges qui peut être associé avec l'un des objectifs de la liste maîtresse.

cost

Veuillez indiquer les numéros des objectifs de la liste maîtresse pour lesquels aucun de vos objectifs générés lors de l'étape du remue-méninges (étape 1) a une signification similaire, mais qui sont tout de même importants à vos yeux.

note : veuillez séparer les chiffres par un trait d'union

Précédent

Suivant

Nouvelles perspectives

*Avez-vous acquis de nouvelles prespective sur le développement des Objectifs dans le processus de prise de décision des systèmes de gestion durable des eaux usées ?

Veuillez sélectionner une réponse ci-dessous

- ○ Oui
- ○ Non

Y a-t-il une section spécifique du questionnaire où vous avez trouvé cette information ?

Cochez la ou les réponses

- ☐ Non
- ☐ Remue méninges individuel des Objectifs
- ☐ Comparaison de vos Objectifs individuels avec les Objectifs de la liste maîtresse
- ☐ Choisir de nouveaux Objectifs à partir de la liste maîtresse des Objectifs

*Dans quelle mesure avez-vous trouvé complète la liste maîtresse des Objectifs qui vous a été montrée ?

Veuillez sélectionner une réponse ci-dessous

- ○ Très complète
- ○ Assez complète
- ○ Plutôt complète
- ○ Assez incomplète
- ○ Très incomplète

Veuillez expliquer brièvement votre réponse à la question précédente

Précédent Suivant

Rétroaction

*Dans quelle mesure avez-vous eu de la difficulté à remplir le questionnaire?

Veuillez sélectionner une réponse ci-dessous

- Très facile
- Facile
- Ni l'un ni l'autre
- Difficile
- Très difficile

Si vous avez eu des difficultés à répondre au questionnaire, quelles en seraient les causes probables ?

Veuillez nous faire part de vos réactions ou commentaires sur le questionnaire ou le projet de recherche.

Précédent

Envoyer

APPENDIX C ONLINE SWING SURVEY

Questionnaire: Obtention des poids des objectifs (préférences) des parties prenantes pour évaluer les alternatives de gestion des eaux usées

Bienvenue dans ce questionnaire sur l'élicitation du poids des objectifs considérés dans la hiérarchie des objectifs de ce projet

L'obtention des préférences individuelles concernant les poids des objectifs considérés dans l'étude est l'une des principales étapes participatives de l'analyse décisionnelle multicritères. Ce questionnaire est basé sur la méthode de pondération Swing et vise à obtenir les préférences des différentes parties prenantes par rapport aux objectifs considérés dans le projet.

Veuillez répondre à toutes les questions de manière complète et sincère. Il n'y a pas de bonnes ou de mauvaises réponses. Nous sommes intéressés par votre opinion honnête en tant que partie prenante de ce projet.

Le temps total pour répondre au questionnaire est estimé à 35 minutes.

Veuillez rester en ligne pendant que vous remplissez le questionnaire, afin que l'équipe de recherche puisse intervenir au besoin pour ajouter des explications. Si vous avez des questions pendant que vous remplissez le questionnaire, vous pouvez les poser directement dans la boîte de discussion de la plateforme ou nous contacter à l'adresse suivante pouria.soleimani@poymtl.ca

Suivant

Remarque sur la protection de la vie privée

Les données personnelles collectées (telles que le nom du participant) seront rendues anonymes par l'attribution d'un numéro d'identification aux participants. Il ne sera pas possible pour les participants d'identifier un autre participant. Seule l'équipe de recherche principale le pourra afin de suivre les informations fournies par les répondants (vous). Toutes vos réponses à ce questionnaire seront anonymes et les données collectées seront soigneusement stockées sur l'ordinateur portable personnel du responsable du projet (Pouria Soleimani). Cet ordinateur portable est protégé à la connexion par un mot de passe. Toutes les données seront accessibles aux autres membres de l'équipe de recherche de ce projet sur le disque partagé de Polytechnique Montréal protégé par mot de passe. Les données seront conservées de manière confidentielle pendant 7 ans, comme cela est exigé pour les données qui font l'objet d'une publication scientifique.

En répondant à ce questionnaire, vous acceptez l'utilisation des données dans les conditions suivantes.

Nous vous remercions de prendre le temps de répondre à ce questionnaire.
Votre participation est très précieuse pour notre équipe de recherche.

Suivant

Pré-questionnaire

Précisez votre responsabilité au sein de votre entreprise/organisation.

Méthode Swing

Dans les prochaines étapes du questionnaire, vous utiliserez la méthode Swing qui est expliquée ci-dessous:

1. Présentation des objectifs
D'abord nous vous fournirons un tableau de tous les objectifs pour chaque objectif principal avec leurs définitions, attributs mesurables et leurs meilleur et pire des cas.

2. Classement des options
Dans l'onglet suivant, des options hypothétiques sont à classer. Chaque option consiste en un objectif amélioré de son pire cas à son meilleur cas, tandis que les autres objectifs restent au pire cas. Une option supplémentaire du pire cas où tous les objectifs sont à leur pire niveau est toujours affichée en bas de la page.

Vous devrez classer les options selon votre préférence pour améliorer un objectif de son pire cas à son meilleur cas possible. L'option que vous classez 1 devrait être celle qui représente l'objectif que vous jugez le plus important d'améliorer de son pire cas à son meilleur cas possible.

3. Noter les options
Dans l'onglet suivant, après avoir classé les options, vous devez attribuer une note de 0 à 100 à chacune des options. Par défaut, l'option de pire cas dominante dont tous les objectifs sont sur leur pire cas a toujours le score de 0 et l'option que vous avez classée en premier, a le score de 100. vous devez donner un score aux autres options.

Remarque: Les scores sont relatifs et cela signifie que l'objectif classé le plus haut devrait obtenir un score supérieur (ou égal). vous pouvez donner un score égal aux options et cela se produit lorsque vous pensez que les options sont également bonnes.

Remarque: Les scores sont relatifs et si vous attribuez un score d'option 50, cela indique que l'amélioration de son objectif du pire au meilleur est deux fois moins importante que l'amélioration de votre objectif le plus important.

Swing first step example: explanation of the sub-objectives for the main objective *high system technical functionality:*

Objectif principal	Haute fonctionnalité technique du système			
Objectifs	**Attributs [unité]**	**Description de l'objectif**	**Meilleur cas**	**Pire cas**
Haute durée de vie	Durée de vie prévue du système [an]	Durée de vie du système d'assainissement	Le système a une durée de vie estimée à près de 30 ans.	Le système a une durée de vie prévue de 10 ans
Faible blocage du système	Fréquence de blocage du système [1-5] ; 1: rare, 2: occasionnel, 3: régulier, 4: fréquent, 5: persistant	Le système peut être bloqué ou cesser de fonctionner, entraînant l'écoulement des eaux usées dans la ville ou le sol ou les masses d'eau réceptrices sans traitement approprié.	Le blocage du système est rare (1)	Le blocage du système est persistant (5)
Grande flexibilité	Facilité d'ajustement de la capacité du système [1-5] ; 1: très difficile, 2: difficile, 3: modéré, 4: facile, 5: très facile	Capacité/facilité à s'adapter à l'évolution des besoins futurs en matière de capacité de charge hydraulique et organique	Le système est très flexible pour les adaptations futures. Il est possible d'adapter facilement et rapidement les capacités pour répondre aux besoins futurs (5).	Le système n'est pas flexible et ne peut pas être facilement adapté pour répondre aux besoins futurs (1).
Faible consommation d'énergie	Énergie [kWh/m^3]	L'énergie utilisée dans le système de traitement des eaux usées.	Le bilan énergétique du système est nul (0 kWh/m^3).	Le bilan énergétique du système est élevé (il consomme beaucoup d'énergie, 0.71 kWh/m^3).

Swing second step example: ranking of the options regarding the sub-objectives in the main objective objective *high system technical functionality*:

Classer les options

L'option où tous les objectifs sont dans leur pire cas est affichée en bas de page et pour les autres options, un seul objectif à la fois est amélioré de son pire cas à son meilleur cas possible (objectif affiché en vert).

Veuillez classer les options en fonction de vos préférences pour améliorer un objectif à la fois, du pire au meilleur. (L'option que vous classez 1, devrait être l'objectif que vous trouvez le plus important d'améliorer du pire des cas au meilleur des cas)

				Rang	
Haute durée de vie	Faible blocage du système	Grande flexibilité	Faible consommation d'énergie		➤ **Veuillez entrer un nombre de 1 à 4**
Haute durée de vie	Faible blocage du système	Grande flexibilité	Faible consommation d'énergie		➤ **Veuillez entrer un nombre de 1 à 4**
Haute durée de vie	Faible blocage du système	Grande flexibilité	Faible consommation d'énergie		➤ **Veuillez entrer un nombre de 1 à 4**
Haute durée de vie	Faible blocage du système	Grande flexibilité	Faible consommation d'énergie		➤ **Veuillez entrer un nombre de 1 à 4**
Haute durée de vie	Faible blocage du système	Grande flexibilité	Faible consommation d'énergie		

Swing third step example: assigning score to the ranked options based on the preference of stakeholders (the ranking of the options is done hypothetically):

Vous devez évaluer les options restantes. L'attribution de la note dépend de l'importance que vous souhaitez accorder à cette option. Vous pouvez donner n'importe quel score de 0 à 100 à chacune des autres options selon vos préférences

Important : La note doit respecter l'ordre de classement que vous avez précédemment attribué à l'opton, c'est-à-dire qu'une option moins bien classée ne peut pas se voir attribuer une note plus élevée que celle mieux classée .
Important : Veuillez ne pas modifier les scores qui sont automatiquement définis sur 0 et 100.

				Rang	Note		
Haute durée de vie	Faible blocage du système	Grande flexibilité	Faible consommation d'énergie	1	100	➤	S'il vous plaît ne changez pas le score
Haute durée de vie	Faible blocage du système	Grande flexibilité	Faible consommation d'énergie	2		➤	Veuillez donner une note de 0 à 100
Haute durée de vie	Faible blocage du système	Grande flexibilité	Faible consommation d'énergie	3		➤	Veuillez donner une note de 0 à 100
Haute durée de vie	Faible blocage du système	Grande flexibilité	Faible consommation d'énergie	4		➤	Veuillez donner une note de 0 à 100
Haute durée de vie	Faible blocage du système	Grande flexibilité	Faible consommation d'énergie		0	➤	S'il vous plaît ne changez pas le score

Ranking step of the options regarding the main objectives in the objectives hierarchy according to the preferences of stakeholders:

Classer les meilleurs objectifs de chaque objectif principale

Vous verrez s'afficher ici tous les objectifs que vous avez classés 1 pour chacun des objectifs principaux. Les options possibles sont donc l'un de ces objectifs augmenté de son pire cas à son meilleur cas et tous les autres à leur pire cas (objectif représenté en vert).
Vous devez classer ces options selon la même procédure que précédemment.

Haute fonctionnalité technique du système	Haute performance de traitement	Haute protection de l'environnement	Haute acceptabilité sociale	Faibles coûts	Rang		
Faible blocage du système	Haute élimination de matière en suspension et la matière organique	Recharge élevée de la nappe phréatique	Faible niveau de bruit et d'odeur	Faibles coûts d'exploitation et de maintenance		➤	lez entrer un nombre de 1 à 5
Faible blocage du système	Haute élimination de matière en suspension et la matière organique	Recharge élevée de la nappe phréatique	Faible niveau de bruit et d'odeur	Faibles coûts d'exploitation et de maintenance		➤	lez entrer un nombre de 1 à 5
Faible blocage du système	Haute élimination de matière en suspension et la matière organique	Recharge élevée de la nappe phréatique	Faible niveau de bruit et d'odeur	Faibles coûts d'exploitation et de maintenance		➤	lez entrer un nombre de 1 à 5
Faible blocage du système	Haute élimination de matière en suspension et la matière organique	Recharge élevée de la nappe phréatique	Faible niveau de bruit et d'odeur	Faibles coûts d'exploitation et de maintenance		➤	lez entrer un nombre de 1 à 5
Faible blocage du système	Haute élimination de matière en suspension et la matière organique	Recharge élevée de la nappe phréatique	Faible niveau de bruit et d'odeur	Faibles coûts d'exploitation et de maintenance		➤	lez entrer un nombre de 1 à 5
Faible blocage du système	Haute élimination de matière en suspension et la matière organique	Recharge élevée de la nappe phréatique	Faible niveau de bruit et d'odeur	Faibles coûts d'exploitation et de maintenance			

Assigning score to the ranked options for main objectives (ranking is done hypothetically):

Noter les meilleurs objectifs de chaque objectif principale
Vous devez attribuer une note à ces options que vous venez de classer. Encore une fois, l'option classée au rang 1 reçoit le score maximum de 100. Le pire des cas, où tous les objectifs sont à leur pire cas, reçoit le score minimum de 0.

Haute fonctionnalité technique du système	Haute performance de traitement	Haute protection de l'environnement	Haute acceptabilité sociale	Faibles coûts	Rang	Note		
Faible blocage du système	Haute élimination de matière en suspension et la matière organique	Recharge élevée de la nappe phréatique	Faible niveau de bruit et d'odeur	Faibles coûts d'exploitation et de maintenance	1	100	➤	S'il vous plaît ne changez pas le score
Faible blocage du système	Haute élimination de matière en suspension et la matière organique	Recharge élevée de la nappe phréatique	Faible niveau de bruit et d'odeur	Faibles coûts d'exploitation et de maintenance	2		➤	Veuillez donner une note de 0 à 100
Faible blocage du système	Haute élimination de matière en suspension et la matière organique	Recharge élevée de la nappe phréatique	Faible niveau de bruit et d'odeur	Faibles coûts d'exploitation et de maintenance	3		➤	Veuillez donner une note de 0 à 100
Faible blocage du système	Haute élimination de matière en suspension et la matière organique	Recharge élevée de la nappe phréatique	Faible niveau de bruit et d'odeur	Faibles coûts d'exploitation et de maintenance	4		➤	Veuillez donner une note de 0 à 100
Faible blocage du système	Haute élimination de matière en suspension et la matière organique	Recharge élevée de la nappe phréatique	Faible niveau de bruit et d'odeur	Faibles coûts d'exploitation et de maintenance	5		➤	Veuillez donner une note de 0 à 100
Faible blocage du système	Haute élimination de matière en suspension et la matière organique	Recharge élevée de la nappe phréatique	Faible niveau de bruit et d'odeur	Faibles coûts d'exploitation et de maintenance		0	➤	S'il vous plaît ne changez pas le score

Figure A.15 Assigning score to the ranked options for main objectives (ranking is done hypothetically)