MULTI-CRITERIA EVALUATION AND RANKING OF CIRCULAR ECONOMY WATER MANAGEMENT ALTERNATIVES FOR PORSUK BASIN

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NAZANIN MORADI

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submitted by **NAZANIN MORADI** in partial fulfillment of the requirements for the degree of **Master of Science in Industrial Engineering, Middle East Technical University** by,

Prof. Dr. Halil Kalıpçılar
Dean, Graduate School of **Natural and Applied Sciences** ________________

Prof. Dr. Esra Karasakal
Head of the Department, **Industrial Engineering** ________________

Prof. Dr. Gülser Köksal
Supervisor, **Industrial Engineering, METU** ________________

Assoc. Prof. Dr. Emre Alp
Co-Supervisor, **Environmental Engineering, METU** ________________

Examining Committee Members:

Prof. Dr. Zeynep Pelin Bayındır
Industrial Engineering, METU ________________

Prof. Dr. Gülser Köksal
Industrial Engineering, METU ________________

Assoc. Prof. Dr. Emre Alp
Environmental Engineering, METU ________________

Assoc. Prof. Dr. Seçil Savaşaneril
Industrial Engineering, METU ________________

Assist. Prof. Dr. Derya Dinler
Industrial Engineering, Hacettepe University ________________

Date: 08.05.2023

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Name Last name: Nazanin Moradi
Signature:

ABSTRACT

GENERATION AND MULTI-CRITERIA EVALUATION OF CIRCULAR ECONOMY WATER MANAGEMENT ALTERNATIVES FOR PORSUK BASIN

MORADI, NAZANIN
Master of Science, Industrial Engineering
Supervisor: Prof. Dr. Gülser Köksal
Co-Supervisor: Assoc. Prof. Dr. Emre Alp

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Rapid urbanization and the overall expansion of the world's population have led to a greater demand for natural resources, particularly water. While most of the earth is covered in water, only a small portion is freshwater. This has prompted a move from the traditional approach of extracting, using, and discarding towards a more sustainable system of resource management that involves reusing and recycling materials. This thesis aims to explore using treated wastewater in the Porsuk Basin to generate circular economy alternatives considering both environmental and economic factors. The allocation of recycled wastewater among various stakeholders, including agricultural, recreational irrigation, industrial, and domestic use, can be difficult due to increasing competition for water. This thesis employs a Multi-Criteria Decision-Making (MCDM) method, namely the Extended VIKOR method, to evaluate and rank various alternatives to determine the best way to allocate recycled wastewater.

Keywords: Circular Economy, Multi-Criteria Decision-Making, Alternatives, Design of Experiments, Extended VIKOR

ÖZ

PORSUK HAVZASI İÇİN DÖNGÜSEL EKONOMİ SU YÖNETİM ALTERNATİFLERİNİN ÜRETİMİ VE ÇOK KRİTERLİ DEĞERLENDİRİLMESİ

MORADI, NAZANIN
Yüksek Lisans, Endüstri Mühendisliği
Tez Yöneticisi: Prof. Dr. Gülser Köksal
Ortak Tez Yöneticisi: Doç. Dr. Emre Alp

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Hızlı kentleşme ve dünya nüfusunun genel olarak artması, başta su olmak üzere doğal kaynaklara yönelik daha büyük bir talebe yol açmıştır. Dünyanın büyük bir kısmı sularla kaplı iken, sadece küçük bir kısmı tatlı sudur. Bu, geleneksel çıkarma, kullanma ve atma yaklaşımından, malzemelerin yeniden kullanılmasını ve geri dönüştürülmesini içeren daha sürdürülebilir bir kaynak yönetimi sistemine doğru bir hareketi teşvik etmiştir. Bu tez, hem çevresel hem de ekonomik faktörleri göz önünde bulundurarak döngüsel ekonomi alternatifleri oluşturmak için Porsuk Havzasında arıtılmış atık su kullanımını keşfetmeyi amaçlamaktadır. Tarımsal, rekreasyonel sulama, endüstriyel ve evsel kullanım dahil olmak üzere çeşitli paydaşlar arasında geri dönüştürülmüş atık suyun tahsisi, artan su rekabeti nedeniyle zor olabilir. Bu tezde, geri dönüştürülmüş atık suyu tahsis etmenin en iyi yolunu belirlemek amacıyla çeşitli alternatifleri değerlendirmek ve sıralamak için bir çok kriterli karar verme (ÇKKV) yöntemi olan genişletilmiş VIKOR yöntemi kullanılmıştır.

Anahtar Kelimeler: Döngüsel Ekonomi, Çok Kriterli Karar Verme, Alternatifler, Deney Tasarımı, Genişletilmiş VIKOR

This thesis is heartily dedicated to my father and mother, who have always believed in me and supported me.

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CHAPTER 1

INTRODUCTION

As cities continue to grow and more people move into urban areas, their demand for water and other natural resources also grows, placing strain on local resources and leading to water scarcity and other environmental concerns. As population growth persists, so does the demand for food, energy, and resources increase--thereby exacerbating an already pressing problem. To address these challenges, governments, organizations, and individuals must work collaboratively on developing sustainable solutions which protect and manage natural resources effectively. Investment may include purchasing new technologies, implementing conservation measures, and supporting sustainable practices within agriculture and industry. One solution to this challenge lies within circular economies, prioritizing using materials in closed-loop systems by recycling or reusing to decrease pollution, promote economic development, and conserve natural resources [1].

The Porsuk Basin, situated in the Central Anatolia region of Turkey, is a vital watershed that spans 18,000 km^2 and sustains over four million inhabitants. Regrettably, this basin is experiencing significant pressure due to rapid urbanization coupled with intensive agriculture and industrial activities. Urbanization in the Porsuk Basin led to an augmented demand for water resources, resulting in untreated or poorly treated wastewater discharge into its watersheds. Furthermore, these growing metropolises are causing deforestation and land-use change which can severely impact hydrological cycles - thus posing a significant threat to sustaining life here. This study is conducted as a part of a TUBITAK project that aims to suggest strategies for allocating treated wastewater in this region. This thesis investigates a particular region the researcher has visited on numerous occasions. The firsthand experience of witnessing challenges faced by locals and factories in this area sets this research apart—comprehensive interviews among farmers and other local stakeholders back it up. The scarcity of water is a pressing matter that plagues numerous regions across the globe. Although multiple solutions are available to tackle this issue, it is much more challenging than it seems.

Let me bring your attention to the dryness in certain parts of Porsuk. We captured pictures during our fieldwork on June 19th, 2022 at coordinates latitude: 39.18261°N and longitude: 29.98591°W (Yağcılar Deresi), which vividly showcases how arid and parched this area has become and its dwindling water flow due to climate change is shown in Figure 1.1.

Figure 1.1 The Dried Yagcilar Creek on June 19th,2022

Allocating water resources among various sectors is a complex and challenging task, as the demand for this precious resource far exceeds its availability. The competing demands of households, agriculture, and industries often lead to conflicts requiring trade-offs between priorities.

In addition to these challenges, decision-makers must consider multiple criteria, such as economic efficiency, social equity, and environmental sustainability, while allocating water resources. These conflicting and intricate objectives make it difficult for them to identify the most favorable alternative.

Therefore, there is an urgent need for effective policies to ensure equitable distribution of limited water supplies amongst all stakeholders without compromising on any sector's needs or causing harm to our environment. We must take collective action toward sustainable management practices so future generations do not suffer from scarcity issues.

The indicators used throughout this research were meticulously chosen to accurately reflect the economic and environmental conditions under scrutiny. Nonetheless, some indicators were not examined due to insufficient information. Global temperatures rise alongside altered weather patterns leading up to reduced availability and increased demand, exacerbating existing challenges that require immediate attention through sustainable measures to mitigate climate impact while ensuring adequate resource allocation strategies remain intact. Water distribution decisions tend towards complexity with an added layer of politics involved - influenced by power dynamics, financial interests, and historical injustices making equitable decision-making processes essential for resolving shortages sustainably.

The thesis is committed to adopting a circular economy approach, prioritizing waste minimization and resource utilization through an efficient flow system for the treated wastewater. Additionally, we employ a Multi-Criteria Decision-Making method that considers multiple factors in assessing water management alternatives. This strategy finds different criteria, such as environmental impact and economic feasibility. By focusing specifically on this basin's needs, we develop sustainable strategies that address these issues effectively while minimizing negative effects.

This thesis explores how the Multi-Criteria Decision-Making method and ranking alternatives can help decision-makers navigate these challenges when selecting circular economy water management alternatives for Porsuk Basin. We discuss how these tools can lead to more sustainable solutions that balance economic growth with environmental responsibility.

We must adopt sustainable practices such as recycling and reusing existing resources to reduce our reliance on new water sources. One effective method is using greywater systems that collect wastewater for purification before it is repurposed for non-drinking purposes like irrigation. Using a mixture design of experiment approach to generate circular economy alternatives, we evaluate their effectiveness based on four key indicators: River Flow Rate, Water Quality Index, Withdrawing Water (amount), and Net Cost.

The extended version of the VIKOR methodology is utilized in this study to assess circular economy alternatives. With the ability to simultaneously rank options based on multiple criteria, decision-makers can arrive at a compromise solution that satisfies all decision-makers involved while considering their preferences and priorities and any associated risks or uncertainties. The final solution is determined by its relative importance and effectiveness in meeting specific criteria.

Water allocation decisions can significantly impact diverse groups depending on their unique contexts. It involves deciding how much water should be allocated for agricultural irrigation, municipal drinking purposes, or industrial processes while also considering environmental flows and economic aspects in decision-making processes. The conclusion drawn from this study suggests that there is much room for further exploration within various elements related to designing sustainable economies, including those centered around water resources management.

In Chapter 2, we have compiled an extensive literature review on the Circular Economy and Multi-Criteria Decision-Making methods and water management. Chapter 3 includes designing a circular economy model while considering constraints and generating the circular economy alternatives that provide comprehensive problem definitions associated with these models. In Chapter 4, we present our proposed method along with parameters used during the testing phases of the research and how to modify the method. In Chapter 5, we applied the extended VIKOR method to examine different alternatives and analyze results by running the sensitivity analysis. In Chapter 6, we obtained some conclusions and suggestions for future studies.

CHAPTER 2

LITERATURE REVIEW

This section includes the Circular Economy concept and Multi-Criteria Decision-Making techniques. The Circular Economy seeks to minimize waste and optimize resource utilization by creating products and systems that can be reused, repaired, refurbished, or recycled. Multi-Criteria Decision-Making techniques play a crucial role in analyzing different alternatives available under circular economies based on their environmental impact assessment alongside economic costs incurred while taking social benefits into account. This helps decision-makers make informed choices leading towards enhanced outcomes through better decisions using reliable data-driven insights.

2.1 Circular Economy

Circular Economy were initially proposed as an alternative to linear economic systems that involve taking resources, using them to produce products, and discarding waste afterward. Unfortunately, such traditional models can often result in detrimental environmental consequences by becoming places for waste disposal. The circular economy began emerging during the 1960s due to contributions by various researchers who suggested an economic cycle as a practical solution that furthered sustainability goals. One such researcher [2] proposed an option and effective means by which social sustainability principles could be established.

[3] proposed the spiral-loop theory, which emphasizes minimizing matter and energy flows within economic structures. Material Flow and Circular Economy theories have strong connections with improving natural sources use and building sustainable economies, as well as new business models or design strategies centered around creating closed cyclical loop systems [4]. The circular economy encompasses much

more than simply managing materials; their definition extends further than that by considering efficient energy use, proper land utilization practice, and effective water management - taking many ideas and actions into account [5].

The article [6] highlights that Dalian (China) has made significant advances toward adopting circular economy concepts, including developing recycling and waste management systems, encouraging green consumption and production practices, and setting up green supply chains. They have implemented several policies and measures to support circularity, such as creating a circular economy development plan, adopting green procurement policy implementation guidelines, and financing programs specifically toward green infrastructures. Furthermore, Dalian faces unique obstacles when implementing circular economies, such as coordination among various departments or lack of awareness from citizens.

Case study [7] explores the intersection of circular economy and inclusive development in Argentina by looking at urban recycling and rural water access as two specific examples. Authors use information collected from existing literature as well as their field research to analyze challenges and possible solutions associated with each issue, taking a comparative approach by comparing experiences in Argentina against lessons learned elsewhere; overall, they take an integrative multi-disciplinary approach comprising economic, environmental, and social perspectives in their understanding of this complex relationship between circular economy and inclusive development.

2.2 Water in a Circular Economy

Water is essential in any circular economy, playing a crucial role in both industrial processes and human survival. We recognized the actual value of water as a precious commodity instead of treating it like a waste. To make this happen, we need to adopt efficient technologies such as recycling systems that can help conserve and reuse greywater and rainwater resources.

Moreover, sustainable agricultural practices are another critical solution for effectively managing our limited water resources. By implementing intelligent irrigation techniques along with other conservation measures at either household or regional levels, we can reduce freshwater demand while minimizing flooding risks and preventing pollution simultaneously.

[8] provides a case study evaluating and selecting rural wastewater treatment technologies; the authors use a multi-period evaluation approach that analyzes costs and benefits for various technologies, considering population growth, regulations, technological advancement, and cost considerations over time. They conclude that multiple-period evaluation helps select appropriate wastewater treatments in rural areas by considering long-term factors that might not become apparent during one single evaluation approach.

Wastewater is a type of water that results from human activities and comprises hazardous elements like sewage, food leftovers, chemicals, and other harmful materials. It originates from diverse origins such as residences or commercial facilities. To ensure the safety of our environment and promote sustainable practices in water usage for non-potable purposes, wastewater treatment plants are essential infrastructures designed to eliminate pollutants effectively while ensuring safe disposal into the ecosystem or reuse without posing any health risks.

The process involves several stages, starting with pre-treatment, followed by primary treatment. Then secondary treatment until a tertiary stage, where all impurities have been removed, leaving only clean water behind. These sewage systems play an essential role in protecting public health while keeping our natural resources free from pollution. In conclusion, wastewater management should not be taken lightly since its proper disposal helps protect both people's well-being and environmental conservation efforts, ultimately benefiting us all.

2.3 Circular Economy Indicators

By utilizing circular economy indicators, businesses and governments can effectively evaluate their economic, environmental, and social impacts while identifying growth opportunities. It is essential to know that different organizations may have varying methods of tracking progress. Nonetheless, implementing such metrics is crucial for achieving sustainable development goals and creating positive change locally and globally.

According to research done for the literature review [9], results demonstrated that environmental and economic dimensions were most frequently covered in academic literature and industrial practice, while social aspects were rarely mentioned. Thus, policymakers and businesses must consider all four dimensions - environmental, economic, social, and technical - when measuring the performance of circular economies to gain a comprehensive picture and monitor the creation of more eco-friendly economies with lasting regenerative systems.

The article [9] has revealed various indicators for measuring Circular Economy, but none can be universally applied. Therefore, it is recommended by the authors to use context-specific and relevant combinations of indicators when assessing particular Circular Economy systems. Regarding water allocation management, circular economy indicators help evaluate sustainable and efficient water usage and control practices. These include measures such as the reuse rate of water within a system, efficiency ratios regarding production per unit volume used, quality assessments based on pollutants and nutrient presence levels, along with monitoring the overall balance between supply and demand factors.

Recent research [10] has proposed a novel approach to evaluate the sustainability of wastewater treatment systems. The study employs multi-criteria decision analysis (MCDA) methodology and identifies critical indicators for assessing system performance. Environmental criteria precede economic and technical ones, reflecting crucial aspects such as pollutant reduction and resource conservation that determine sustainable operation. By prioritizing these factors in evaluating wastewater treatment systems, we can ensure their long-term viability while minimizing negative environmental and societal impacts.

The article [11] presents a compelling argument for adopting circular economy practices to combat resource scarcity and environmental pollution. Wastewater treatment plants can play an essential role in this approach, with proposed indicators measuring the efficiency of nutrient and energy recovery from wastewater alongside reductions in greenhouse gas emissions and water pollution. When implementing these initiatives, it is crucial to consider social and economic factors such as job creation and revenue generation, ensuring sustainability while promoting equity. The framework outlined provides valuable guidance on monitoring progress toward achieving success within the wastewater sector's circular economy efforts.

In literature we identify various indicators to measure the impact of circular economy practices on environmental, economic, and social aspects. Some include carbon footprint, material and resource efficiency, and economic value added. These indicators represent a small portion of the extensive range of indicators [9].

Carbon footprint is an essential indicator measuring greenhouse gas emissions associated with producing, using, or disposing of products/services. It provides valuable insights into how circular economy practices can reduce emissions while mitigating climate change impacts.

Material and Resource Efficiency focuses on optimizing resources throughout product life cycles by measuring waste generation rates, recycling rates, etc., which helps identify opportunities for reducing waste while conserving natural resources, thereby improving overall circulatory performance.

The water footprint is a crucial indicator that evaluates the total freshwater consumption of any product or service, from extraction to disposal. It's an insightful measure for assessing sustainability and efficiency in circular economy activities.

Economic Value Added quantifies benefits generated by implementing Circular Economy Practices, including cost savings from resource recovery/recycling efforts, revenue streams created via remanufacturing/refurbishment activities, and job creation resulting in overall growth stimulated by implementing sustainable business models [12].

These indicators are just a fraction of the vast array available. However, they have been widely used in literature due to their relevance and ability to capture crucial aspects of the circular economy impacts. It is vital to emphasize that selecting appropriate indicators should be tailored according to each study or project's specific objectives, scope, and context for an all-encompassing assessment of circular economy performance.

Moreover, there are additional commonly utilized indicators that measure environmental sustainability as well as economic and social impacts resulting from implementing circular practices: Energy efficiency, this indicator focuses on maximizing energy resource utilization throughout the product life cycle by measuring factors such as energy consumption rate per unit produced or service rendered; intensity levels achieved through efficient use strategies like recycling/reusing materials; savings realized via adopting sustainable production methods while also incorporating renewable sources into operations.

Innovation and technological advancements are essential for measuring progress in circular economy practices. This metric considers factors such as new business models, recycling technologies, remanufacturing techniques, and adoption of digital solutions- all contributing to enhancing circularity levels.

When making informed decisions about our products and services, understanding their impact on our environment is crucial. That's why measuring energy consumption, water footprint, ecological footprint, toxicity levels, and pollution is essential for promoting sustainability.

The ecological footprint takes things one step further by evaluating human activities' impact on ecosystems through land and resource usage patterns. This assessment emphasizes preserving natural resources such as biodiversity that are vital for maintaining healthy environments worldwide.

The literature has identified many indicators to evaluate the environmental, economic, and social impacts of circular economy practices. These metrics offer valuable insights into sustainability aspects and enable practical evaluation of progress made by initiatives.

However, choosing appropriate indicators for any project or study is context-dependent and objective-specific. In our research, we have meticulously picked four relevant parameters that apply to our investigation's unique circumstances. We believe these selected markers can effectively capture crucial dimensions concerning ecological impact, financial implication within the scope of our work.

2.3.1 Economic Indicators

Academic research usually centers on financial aspects, particularly those related to costs. Circular economy indicators serve as benchmarks that demonstrate the advancement of this model from an economic standpoint. These measures aid decision-makers, companies, and other interested parties in evaluating the financial advantages of embracing a circular approach.

Life Cycle Costing (LCC) has been used to evaluate the economic feasibility of circular economy projects [13], noting its applicability by considering costs related to production, transportation, use maintenance, and disposal over its life. Furthermore, this article features case studies using LCC in circular economies, such as recycling or repurposing waste material for a new use or assessing costs/benefits across several circular economy business models.

The article [14] analyzed 42 studies published between 2000 to 2017, focusing on municipal wastewater treatment from various regions worldwide. According to the study's findings, LCCA is a tool for evaluating costs associated with these systems; initial capital expenses represent most total expenditures, followed by operation and maintenance costs. Moreover, factors influencing such costs were identified, including technology used during treatments, plant size, level automation, and monitoring required, all playing significant roles when determining overall expense rates. In conclusion, this literature review provides valuable insights into how we might utilize LCCAs to evaluate the investment options within water management practices- especially those explicitly related to wastewater processing needs where efficiency matters significantly, given its long-term environmental, social, and economic implications.

This article delves into the financial feasibility of a decentralized hybrid rainwater-wastewater-greywater (HRWG) system in transitioning to a Circular Economy (CE). To evaluate circular water systems' economic performance, our authors suggest using Shadow Pricing-Life Cycle Cost-Benefit (SLCCB), which divides CWS implementation costs and benefits into Internal and External categories. Our study concludes that investing in CWS is financially sound when considering external factors, underscoring how crucial it is to incorporate shadow pricing and life cycle cost-benefit analysis for evaluating circular water systems economically.

This comprehensive research [15] evaluates various economic markers, including employment rates, Gross Domestic Product (GDP), and investments. These indicators can effectively demonstrate the positive impact of circular economy initiatives on the water and wastewater sector. We could reduce the net costs by implementing circular practices in this industry while increasing resource efficiency. Measuring progress towards achieving greater circulatory within this field requires accurate assessment using these critical economic metrics.

By minimizing the net costs and labor involved in disassembling products, we can significantly enhance their economic viability for extended use. It will ultimately pave the way toward establishing a circular economy in developed areas with improved product longevity. The Effective Disassembly Time is an approach to assess how effectively a product can be taken apart using data mining techniques that scrutinize disassembling methodologies and conditions. It involves devising a matrix that identifies key factors of utmost importance during the disassembly process, thus streamlining it considerably [16], [17].

The current approach to managing water and wastewater is unsustainable, resulting in environmental degradation and economic inefficiency. However, the article [18] suggests a circular economy model that maximizes resource use while minimizing waste and pollution. To measure progress towards this goal, several economic indicators are proposed: using tariffs to promote conservation; ensuring full cost recovery from customers for services provided; improving energy efficiency during treatment processes; recovering resources such as energy or nutrients from wastewater for added value; encouraging innovation within the industry through new technologies and business models. These measures create a more sustainable future where precious natural resources are utilized effectively without harming the environment or compromising financial stability.

The study [19] focuses on an eco-touristic facility in Portugal, evaluating the economic impact of its decentralized circular water system using three key indicators - employment, value-added, and gross output. The results are impressive; the implementation of this innovative system generated 4.5 full-time equivalent jobs while increasing value added by €103,000 and gross output by €227,000. These findings demonstrate that such systems can help preserve our planet's precious resources and provide significant economic benefits.

Undertaking a cost-benefit analysis requires several crucial steps that must be followed. Firstly, it is imperative clearly define the project or policy being considered, including its objectives and scope. All costs and benefits associated with this endeavor are identified and quantified in detail - encompassing direct expenses such as construction and operating costs while also considering indirect factors like environmental impacts.

It is crucial to comprehensively evaluate both direct advantages, such as increased revenue, and indirect advantages, like decreased pollution levels or increased economic activity. Even though it may be difficult for certain aspects like social welfare and environmental impact, assigning monetary values becomes imperative. We can accurately assess the actual value of these factors before making any further decisions.

To factor in time value money considerations effectively over more extended periods, future costs and benefits need discount rates applied appropriately during calculation processes leading to generating net present value (NPV). This metric represents the difference between total discounted benefit and total discounted cost estimates from earlier analyses.

A positive NPV indicates expected higher returns than incurred expenditure on project and policy, whereas negative results imply otherwise. Finally comes sensitivity testing, where robustness against key assumptions and input changes is assessed through varying methodologies for estimating relevant figures and assessing uncertainty impact.

The article [20] presents compelling evidence that investing in a wastewater treatment plant (WWTP) is economically feasible and necessary to ensure long-term sustainability. By conducting an extensive cost-benefit analysis using the discounted cash flow method, the authors demonstrate that implementing such infrastructure projects yields positive net present value (NPV) and internal rate of return (IRR), exceeding required rates. Furthermore, this study emphasizes how crucial it is to implement cost-reflective tariffs to help recover project costs while ensuring its continued operation over time. The research highlights that governments must conduct analyses before embarking on significant infrastructural investments.

Policies and strategies can be developed by utilizing economic indicators to promote a circular economy in the water and wastewater sector. These measures include incentivizing efficiency, ensuring financial sustainability, encouraging innovation, and supporting resource recovery. By implementing these practices, overall resilience is increased. Water and wastewater tariffs are a tool for promoting the conservation of resources while generating revenue for infrastructure investment. A well-designed tariff system encourages efficient use of water by customers, which reduces waste while providing funds that improve both sectors' infrastructures.

This article [21] presents a compelling case for implementing an end-of-life tire recycling system within the framework of a circular economy. By conducting a comprehensive cost-benefit analysis, they thoroughly assess the project's economic viability and benefits. They start by defining clear objectives focusing on end-of-life tire recycling while identifying all costs associated with establishing and operating this new system.

Furthermore, their evaluation includes environmental impacts and potential economic gains from such initiatives. Monetary values are assigned to each factor to ensure accuracy, allowing direct comparisons despite challenges when quantifying environmental impact. They also consider future costs and benefits, discounting their value based on time and considering the long-term effects of these projects, which helps determine a net present value (NPV). This calculation measures total discounted costs against benefits, providing insights into whether it is economically viable to implement this type of initiative successfully.

2.3.2 Environmental Indicators

The circular economy model focuses on all stages of product life cycles - its design, creation, consumption, use, and disposal. To promote sustainable progress, various indicators, such as Life Cycle Thinking (LCT), can be employed to measure and monitor environmental impacts at each step in product creation and use. Product life cycles typically consist of three stages: initial (design and production), middle (distribution, promotion, and usage), and final disposal stages. A helpful evaluation tool is Life Cycle Assessment (LCA), which measures all materials and resources consumed throughout its entirety while considering environmental impacts and economic considerations [22].

Raw Material Consumption has long been proposed as one method to measure a company's environmental footprint, considering all materials utilized during production and any pre-made or semi-finished goods and parts sold or distributed, and trading of by-products could decrease total material usage [23].

Energy usage is an environmental concern that impacts every business. Energy use should be factored into the performance evaluation of information systems networks, as some exchanges require considerable energy consumption [23]. Waste combustion power generation offers another potential energy source if used as fuel instead of other forms. As an environmental indicator, they suggest considering energy consumption levels when measuring the environmental performance of information networks.

The analysis conducted in [24] provides a convincing argument for implementing circularity within China's traffic system. Using material flow analysis, researchers could thoroughly examine Direct Material Input (DMI) and Domestic Processed Output (DPO) about highway traffic infrastructure and vehicles. The results indicate significant room for improvement regarding efficiency, waste reduction, and resource utilization - all critical components of promoting sustainable practices throughout the transportation sector.

The article [25] explores resource duration as a tool for managers to assess how long resources last in the circular economy. This indicator considers material longevity, durability, and value retention over time. The argument put forth by this piece is that incorporating resource duration can provide valuable insights into efficiency, effectiveness, and environmental impact when it comes to managing resources. By using resource duration as an essential managerial metric, organizations can better evaluate their strategies related to circular economies while also identifying areas where improvements are needed.

The article [26] examines the recyclability benefit rate between closed-loop and open-loop systems in plastic recycling within Flanders. This study aims to show how different recycling methods can contribute towards a circular plastics economy while assessing their environmental impact. By conducting an extensive analysis focused solely on Flemish plastic recycling practices, this research determines both closed-loop and open-loop systems' respective recyclability benefit rates - defined as the ratio between achieved environmental benefits through recycling versus its ecological footprint during processing.

This analysis considers various factors, including energy consumption, greenhouse gas emissions, and resource use. It is possible to accurately measure the environmental benefits and impacts associated with each recycling system. The article outlines the methodology used to calculate recyclability benefit rates for plastic recycling in Flanders. It becomes clear that closed-loop systems are superior to open-loop systems as they have higher recyclability benefit rates. The research shows that using closed-loop systems results in greater environmental benefits per unit of recycled plastic due to reduced material losses and preserved quality of materials being reused or repurposed into similar products. This method reduces waste and has significant positive effects on our planet's environment by reducing carbon footprint through lower greenhouse gas emissions.

2.4 Stakeholders

Stakeholder analysis is an important step in any project or decision-making process, as it enables the identification and evaluation of individuals or groups who could be impacted. This tool allows for understanding the potential effect on various parties involved and provides insight into how to engage them effectively. The procedure entails pinpointing stakeholders, evaluating their level of interest and influence regarding the undertaking, then devising strategies that will best involve them in making decisions collaboratively.

The article [27] comprehensively overviews stakeholder analysis and management techniques. The first step involves identifying all potential project stakeholders, then prioritizing them based on their level of influence and interest using stakeholder categorization methods. Various techniques, such as interviews or surveys, are utilized to assess stakeholder needs and potential impacts effectively. Stakeholders must be engaged throughout the project's lifecycle to ensure successful outcomes through regular communication and consultation - an essential method known as Stakeholder engagement. Conflicts among stakeholders can arise at any point during this process. Hence conflict resolution is crucial for managing these conflicts successfully with the negotiation or mediation tactics.

A survey was conducted in Turkey in the article [28] to evaluate stakeholders' opinions regarding irrigation water management. The participants included farmers, cooperative irrigation members, and government officials. The findings showed that most farmers were content with the current system and had a favorable outlook. However, there are some improvements to Harran Plain's irrigation management process. To achieve this goal, all parties involved must work together by increasing communication channels while providing more support for modernized technologies such as government training sessions. It is crucial to understand that enhancing the existing infrastructure will benefit everyone involved from increased crop yields leading to higher profits for farmers and better economic growth overall.

This study [29] highlights the importance of involving all stakeholders in institutional decision-making. Carefully planning and implementing an inclusive approach ensures that everyone's perspectives are considered when making important decisions. To achieve this, it is essential to establish clear roles and responsibilities for each stakeholder group - including government agencies, water utilities, and members of the public. The transparent process ensures that data-related issues are collected accurately while providing opportunities for public participation through feedback mechanisms. Additionally, dispute-resolution techniques should be implemented during decision-making to address participant conflicts or disagreements. The benefits of such an effective decision-making procedure cannot be overstated, and urban water management improves significantly by considering input from all involved parties with diverse viewpoints, leading to better overall management practices based on well-rounded considerations from every perspective involved.

Article [30] emphasizes the significance of stakeholder analysis in comprehending the viewpoints and concerns of stakeholders engaged in river basin management. Conducting a thorough stakeholder analysis can aid in identifying crucial stakeholders, their preferences, and how they influence decision-making processes. This knowledge is essential for incorporating diverse perspectives into ecological planning procedures to ensure inclusivity during decision-making activities. By integrating spatial data with criteria evaluation and considering various stakeholder perspectives, we enable an informed participatory approach towards making sustainable land use decisions while promoting environmental integrity and addressing all interests involved within river basin management.

The complexities of river rehabilitation are many, from the intricate nature of river systems to the involvement of numerous stakeholders. Decision support systems (DSS) have been identified as valuable tools to address these challenges and ensure successful outcomes. The article [31] considers different concepts that can be used for DSS, such as multi-criteria decision analysis, adaptive management, and participatory approaches. These frameworks provide a structured approach to integrating scientific knowledge with stakeholder preferences to guide effective decisions during river rehabilitation efforts. Participatory approaches stand out by involving all relevant parties, including local communities, scientists, and policymakers, in making informed choices.

The importance of stakeholder attitudes in the effective execution of water management interventions is emphasized in the article [32]. It emphasizes that place meanings, personal and collective interpretations attached to specific places, play a crucial role in shaping people's perceptions and actions. The study utilizes qualitative research techniques such as interviews and focus group discussions to explore how these place meanings affect stakeholders' views on water management interventions. By analyzing participants' narratives and experiences thoroughly, this investigation identifies different aspects of place meaning dimensions and their impact on implementing successful water management programs.

The findings reveal that place meanings significantly affect stakeholders' attitudes and responses to water management interventions. Individuals' emotional attachment to a place, along with their historical, cultural, and ecological connections, influence their perceptions of the proposed interventions. Positive place meanings often lead to greater acceptance and support, while negative place meanings can generate resistance and opposition. The article also highlights the role of communication and engagement strategies in addressing the influence of place meanings. Water management practitioners can develop interventions that align with stakeholders' perceptions and enhance their acceptance by fostering meaningful dialogue, incorporating local knowledge, and acknowledging the value of place meanings.

It is crucial to consider stakeholders' goals when developing a strategic plan for urban water management, as highlighted in the article [33]. Participatory methods that acknowledge diverse perspectives must be employed to achieve optimal results and ensure sustainability. The study suggests adopting an inclusive framework that integrates stakeholder objectives throughout the planning process. This involves identifying key players and their priorities and comprehending their preferences thoroughly before incorporating them thoughtfully into decision-making processes.

Numerous methods and strategies are available to encourage stakeholder involvement and unbiased decision-making. These include workshops, surveys, and multi-criteria analyses that aid in understanding stakeholders' viewpoints while assessing various options based on multiple criteria. Incorporating the objectives of all parties involved is crucial for effective strategic planning since it allows for identifying areas where interests align or conflict with one another. This approach promotes transparency and accountability throughout the water management process by ensuring that everyone's needs are considered equally important when deciding on resource allocation or other critical issues related to water usage practices.

Ultimately, this leads to more relevant policies being developed, which will be accepted by a broader range of people within society due to its inclusive nature - benefiting both those who require access to clean drinking water sources without compromising environmental sustainability goals along with industry players seeking efficient ways towards achieving their business targets through responsible use of natural resources such as freshwater supplies.

Introducing the Stakeholder Circle in the article [34], a revolutionary tool that empowers them to manage their project stakeholders effectively. With its circular diagram representing stakeholder influence and interest levels, this innovative approach enables visualization and analyze everyone’s impact on the project. The Stakeholder Circle is designed for managers who want to prioritize their resources based on importance and potential impact. The comprehensive analysis evaluates different dimensions, such as the power/interest grid or power/influence grid which categorizes them according to their level of involvement to develop effective strategies explicitly tailored toward them.

2.5 Multi-Criteria Decision-Making (MCDM) Methods

To ensure the best decision is made, decision-makers must adopt a multi-criteria approach. This entails implementing diverse techniques that assist in selecting the most favorable option from multiple alternatives based on predetermined criteria and objectives. Multi-criteria decision-making has proven especially beneficial across various sectors, including supplier selection, water allocation, and project management, where complex decisions must be executed accurately. By incorporating this systematic process into their operations, companies can guarantee they are making informed choices that align with their aspirations and preferences [35].

There are two primary categories for Multi-Criteria Decision-Making techniques (MCDMs). MADM involves making decisions based on multiple attributes (MADM), while MODM involves considering various objectives as criteria to make a decision (MODM). Both approaches consider numerical and subjective factors when making choices; MADM is best utilized when there are limited choices with integer values. At the same time, MODM provides greater flexibility by accommodating infinite possibilities in an open decision space environment. There are various MCDM methods currently available [36].

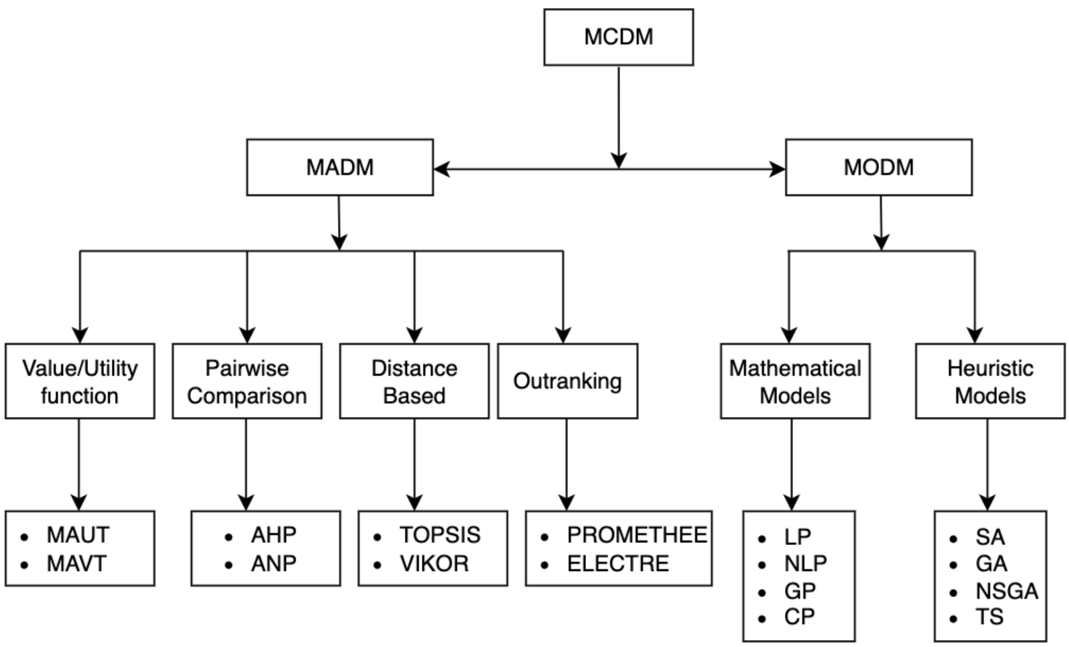

Figure 2.1 The MCDM methods [36]

The AHP method involves asking questions that compare pairs of options to construct a decision tree. At the same time, ANP builds upon this by considering interdependencies between criteria that structure a problem as a network rather than hierarchical [37]. The AHP method involves several steps that are outlined below.

Step 1: In this initial phase, it is crucial to identify and understand your challenge while setting objectives, criteria, and options in a hierarchical structure with goals at the highest level, criteria at the middle level, and possible solutions at lower levels.

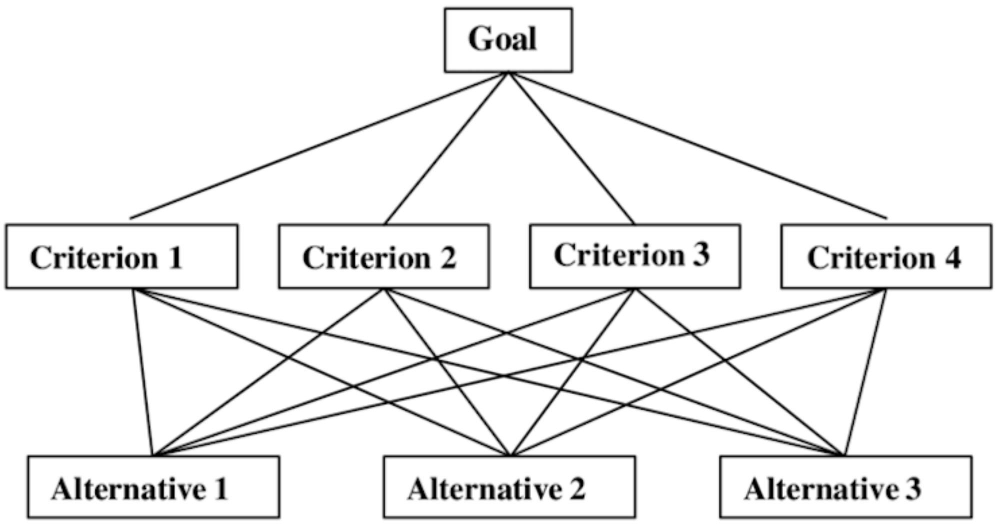

Figure 2.2 A typical AHP hierarchical structure (Source: based on [37])

Step 2: Determining the relative significance of components within a hierarchy involves pairwise comparisons conducted among decision-making groups using a 1–9 point scale, then creating comparison matrices representing relative importance between criteria. A matrix called A is created to demonstrate the significance of each criterion (i) relative to other criteria (j) when n criteria are evaluated. All elements along the diagonal of this matrix always equal 1 because (i) equals (j).

The importance index is determined by comparing each criterion against one another in Table 2.1. If one criterion is considered more significant than another one, that criterion's position at the intersection between the first row and third column (i=2, $j = 1$) in the comparison matrix will become 5. Values above the diagonal are direct comparisons that yield 1, while below diagonal calculations use the equation $a_{ji} = \frac{1}{a_{ij}}$.

Table 2.1 Pairwise comparison scale for AHP (Source: based on [37])

Importance Indices	Importance Definitions
1	Both factors are equally important
3	First factor is important relative to the second one
5	First factor is very important relative to the second one
7	First factor is much more important than the second one
9	First factor is absolutely dominant
2,4,6,8	Intermediate values

Step 3: To establish each criterion's priority and significance in shaping the overall decision, pairwise comparisons are conducted. These comparisons enable the determination of priority vectors represented by the W column vector. The W vector quantifies each criterion's relative importance or weight in the decision-making process using Equation 2.1.

$$w_i = \frac{\sum_{j=1}^{n} a_{ij} w_j}{n} \qquad 2.1$$

When the decision-makers have similar opinions regarding their evaluations, it is essential to mention that employing geometric means can reflect a criterion's weight. Nonetheless, this method does not consider the variations in judgments among different decision-makers. Therefore, it is crucial to conduct sensitivity analysis for precise and dependable outcomes or examine the weights assigned by groups of individuals with distinct preferences.

Step 4: The consistency of decisions made by groups can be evaluated through the eigenvector method, where the Consistency Ratio (CR) value determines if there are any inconsistencies or mistakes during calculations. If CR exceeds 0.10, then it implies reassessment should be done. The CR value is obtained by dividing the consistency index by the random index.

$$CR = \frac{CI}{RI} \tag{2.2}$$

For determining the consistency index:

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{2.3}$$

Step 5: The highest eigenvalue is symbolized as, λ_{max} represents n number of factors considered while calculating values obtained after multiplying vector A with vector w resulting in (E_i) set of values divided by w_i elements present in the D column vector summing up all these values gives us λ_{max} it is calculated further by dividing this sum by n.

$$E_i = \frac{d_i}{w_i}\ (i = 1,2,3, \dots, n) \tag{2.4}$$

$$\lambda_{max} = \frac{\sum_{i=1}^{n} E_i}{n} \tag{2.5}$$

Step 6: To determine the weights of criteria that affect decision-making, [37] design a method using n-dimensional matrices. It calculates the consistency values for these randomly generated matrices and names them the random index (RI). This crucial step enables us to evaluate alternatives by comparing them through matrices or incorporating criterion weights as inputs in other decision-making methods besides

AHP. Therefore, this process can significantly enhance our confidence to make informed decisions.

Table 2.2 Random index values for different numbers of elements matrix (Source: based on [37])

n	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

PROMETHEE assigns preference degree scores between 0 and 1 to each alternative, indicating their relative attractiveness compared to other options. The method involves pairwise comparisons of the alternatives for each criterion, allowing them, as the decision-maker, to assess which option is most important or preferred over another. With six available preference functions in PROMETHEE determining how these scores are calculated based on your pairwise comparisons, this innovative tool takes care of all complex calculations so that you can make informed choices quickly and efficiently [38].

TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) is a powerful approach that can help you rank alternatives based on their proximity to an ideal solution. This method was introduced in 1981 by Hwang and Yoon as part of complex decision-making scenarios [35]. TOPSIS starts with identifying the most pertinent criteria needed for making decisions - these may be qualitative or quantitative factors. Then it creates an "ideal solution" representing each criterion's optimal outcome. Using this benchmark against which all other options are evaluated, those closest to the ideal result will emerge as top choices worth further consideration.

They are introducing VIKOR, the ultimate solution for resolving multiple conflicting criteria simultaneously. Developed by [39], this powerful tool enables decision-makers to find a compromise that satisfies all stakeholders' demands while identifying levels of uncertainty and risks involved with each alternative. By considering relative importance across various criteria before making their final choice, VIKOR ensures equitable and balanced decision-making processes. The Extended VIKOR method is utilized to rank the alternatives in this thesis, and the next part will discuss this method.

2.5.1 The Extended VIKOR Method

The VIKOR method considers multiple criteria and conflicting factors. It determines the best compromise solution among various alternatives to ensure that all important aspects are considered before making a final choice.

However, the Extended VIKOR method is a version of the original technique that includes additional features such as handling imprecise or uncertain data and incorporating interval numbers to represent weights and scores. It also allows for different preferences from multiple decision-makers to be considered during the process.

As decision-makers, you are faced with the challenge of selecting from a variety of m alternatives A_1 , A_2,..., A_m. The evaluation process is based on n criteria such as C_1 , C_2 ...,C_n, which determine the suitability and effectiveness of each alternative. However, it's important to note that rating an alternative A_i against a specific criterion C_j isn't always straightforward since we can only estimate f_{ij} within $f_{ij} \in [f_{ij}^L, f_{ij}^U]$.

Table 2.3 A decision matrix for the Extended VIKOR method

	C_1	C_2	$\dots$	C_n
A_1	$[f_{11}^L, f_{11}^U]$	$[f_{12}^L, f_{12}^U]$	$\dots$	$[f_{1n}^L, f_{1n}^U]$
A_2	$[f_{21}^L, f_{21}^U]$	$[f_{22}^L, f_{22}^U]$	$\dots$	$[f_{2n}^L, f_{2n}^U]$
$\dots$	$\dots$	$\dots$	$\dots$	$\dots$
A_m	$[f_{m1}^L, f_{m1}^U]$	$[f_{m2}^L, f_{m2}^U]$	$\dots$	$[f_{mn}^L, f_{mn}^U]$

$$W = [w_1, w_2, \dots, w_n]$$

Making informed decisions despite this ambiguity requires careful consideration and weighting of these various criteria; w_j represents their importance relative to one another. Consider all relevant factors when assessing each option available before making final choices about what best suits your needs or goals. The steps of the Extended VIKOR method are explained below.

Step 1: To achieve the best possible outcome, it is essential to determine the positive ideal solution (PIS) and the negative ideal solution (NIS).

$$A^* = \{f_1^*, \dots, f_n^*\} = \{(max_i f_{ij}^U | j \in I) \; or \; (\{min f_{ij}^L | j \in J)\} \; j = 1,2,\dots,n \quad 2.6$$

$$A^- = \{f_1^-, \dots, f_n^-\} = \{(min f_{ij}^L | j \in I) \; or \; (\{max f_{ij}^U | j \in J)\} \; j = 1,2,\dots,n \quad 2.7$$

In this regard, I represents benefit criteria while J denotes cost criteria. A^* signifies PIS whereas A^- stands for NIS.

Step 2: To arrive at these solutions, calculate $[S_i^L, S_i^U]$ and $[R_i^L, R_i^U]$ intervals as described below:

The optimal result obtained by minS_i ensures maximum group utility through the "majority" rule; likewise, minR_i yields a minimum individual regret of the 'opponent.'

$$S_i^L = \sum_{j \in I} w_j \left(\frac{f_j^* - f_{ij}^U}{f_j^* - f_j^-}\right) + \sum_{j \in J} w_j \left(\frac{f_{ij}^L - f_j^*}{f_j^- - f_j^*}\right), i = 1, \dots, m \qquad 2.8$$

$$S_i^U = \sum_{j \in I} w_j \left(\frac{f_j^* - f_{ij}^L}{f_j^* - f_j^-}\right) + \sum_{j \in J} w_j \left(\frac{f_{ij}^U - f_j^*}{f_j^- - f_j^*}\right), i = 1, \dots m \qquad 2.9$$

$$R_i^L = \max \left(w_j \left(\frac{f_j^* - f_{ij}^U}{f_j^* - f_j^-}\right) | \, j \in I, \; w_j \left(\frac{f_{ij}^L - f_j^*}{f_j^- - f_j^*}\right) | \, j \in J\right) i = 1, \dots, m \qquad 2.10$$

$$R_i^U = \max \left(w_j \left(\frac{f_j^* - f_{ij}^L}{f_j^* - f_j^-}\right) | \, j \in I, \; w_j \left(\frac{f_{ij}^U - f_j^*}{f_j^- - f_j^*}\right) | \, j \in J\right) i = 1, \dots, m \qquad 2.11$$

Step 3: Compute the interval, $Q_i = [Q_i^L, Q_i^U]; i = 1, \dots, m$ by these relations:

$$Q_i^L = v \, \frac{(S_i^L - S^*)}{(S^- - S^*)} + (1 - v) \frac{(R_i^L - R^*)}{(R^- - R^*)} \qquad 2.12$$

$$Q_i^U = v \, \frac{(S_i^U - S^*)}{(S^- - S^*)} + (1 - v) \frac{(R_i^U - R^*)}{(R^- - R^*)} \qquad 2.13$$

Where,

$$S^* = minS_i^L, \; S^- = maxS_i^U \qquad 2.14$$

$$R^* = minR_i^L, \; R^- = maxR_i^U \qquad 2.15$$

Additionally, v serves as an indicator of strategy weightage in terms of either "maximum group utility" or "the majority of criteria," which we can assume here to be $v = 0.5$

Step 4: To select the most suitable alternative utilizing VIKOR methodology necessitates identifying minimal Q_i values. However, Q_i numbers are interval figures that require comparison before determining their least value. A novel method for comparing such interval numbers has been proposed to address this issue.

When selecting the minimum interval number between two given intervals, there are some possible scenarios to consider. Firstly, if these intervals do not intersect, we choose the one with lower values as our minimum interval number. Secondly, suppose both intervals are identical in value. In that case, they have equal priority for us, and there are some other situations in which we can refer to the article [40] for more information. Overall, it's important to carefully evaluate each scenario before deciding which minimal range will best suit your needs.

Introducing the concept of optimism level, denoted by $\propto$, is crucial in decision making. The value of $(0 < \propto \leq 1)$ represents how optimistic or pessimistic a decision-maker is with higher values indicating greater positivity. A rational individual has an $\propto$ value equal to 0.5 which serves as their baseline for objective analysis.

This method yields results like those derived from interval numbers based on means when used by a logical thinker during comparisons and evaluations. Therefore, incorporating optimism levels can enhance one's ability to make sound judgments while considering personal biases and outlooks toward various outcomes.

VIKOR provides enhanced flexibility and broader coverage compared to TOPSIS, which can be conveniently executed. As elaborated in article [41], VIKOR extension is particularly beneficial when criteria are presented as interval numbers rather than precise values. A decision matrix with interval numbers takes the following format in such cases.

By integrating stochastic data and subjective judgments, the VIKOR method has been enhanced in the article [42]. The novel approach employs a blend of probability distributions and personal opinions to assign significance to different decision-making criteria. Additionally, the authors introduced the Extended VIKOR algorithm for ranking alternatives with greater accuracy. This innovative technique offers an improved means of making informed decisions more aligned with individual preferences while considering unpredictable variables. Finally, when handling missing data values for certain aspects of the decision-making process, the Extended VIKOR is more flexible than other methods since it allows uncertain figures.

MCDM techniques are essential in the circular economy landscape, offering a reliable and systematic approach to evaluate performance, effectiveness, and progress toward achieving full circularity. Their role is essential in decision-making processes as they allow for multi-criteria assessment that leads to informed choices.

The use of MCDM methods within the context of circular economies enables consideration across various dimensions, such as resource efficiency, waste reduction strategies, product lifecycle management practices, eco-design approaches, and green innovation initiatives. This comprehensive evaluation considers environmental, economic, and social aspects simultaneously, resulting from multiple criteria analysis.

A significant advantage offered by these methods lies in their ability to handle the complexity inherent when making decisions about transitioning towards a more sustainable future through adopting Circular Economy principles. Conflicting objectives often present along with uncertainties surrounding outcomes require robust, flexible frameworks, which can be provided by incorporating Multi-Criteria Decision Making (MDMC) methodologies, transparently weighing different criteria, comparing alternatives, and identifying optimal solutions while maintaining transparency throughout this process, ensuring effective communication between stakeholders involved.

MCDM methods promote stakeholder engagement and participation in the circular economy decision-making process. These approaches incorporate diverse stakeholders' expert opinions, preferences, and values to ensure inclusivity and collaboration. By considering multiple perspectives, MCDM techniques capture the complexities of circular economy challenges while fostering stakeholder consensus-building.

Moreover, these methodologies enable continual measurement and monitoring of progress over time through composite indices or performance metrics that provide quantitative assessments of circulatory levels for benchmarking purposes. This information guides policy development and resource allocation towards continuous improvement in sustainable practices within the field.

In summary, MCDMs are essential tools for evaluating strategies with systematic robustness. They prioritize actions based on their ability to handle complexity while engaging various criteria simultaneously, advancing principles supporting sustainable development goals within Circular Economy initiatives.

The article [43] presents an innovative framework for developing an index that measures the circular economy performance of countries or regions. The authors utilize the multi-criteria decision-making (MCDM) approach and emphasize process-oriented aspects, which are crucial in achieving sustainable development. The circular economy is an economic model designed to minimize waste and resource consumption by promoting recycling, reusing, and reducing materials and energy usage. This new paradigm stresses closing product lifecycle's loops while prioritizing sustainability over profit maximization.

In this context, it is essential to develop comprehensive indicators capable of accurately measuring progress toward these goals. However, existing frameworks have limitations, such as not considering process-oriented aspects or capturing dynamic transitions within the system. To ensure accuracy and diversity of perspectives, Delphi surveys seek expert opinions to determine the weights of sub-criteria within each dimension and TOPSIS method is used to rank them. This rigorous process enhances reliability while quantitatively assessing countries' or regions' circular economy performance.

In another article [44], the authors thoroughly analyze the existing literature on multi-criteria methods for measuring circular economy performance. They aim to provide readers with an in-depth understanding of critical methodologies and indicators used in previous studies while highlighting the strengths and limitations of these approaches. The concept behind the circular economy is centered around minimizing resource consumption, waste generation, and environmental impact - all while maximizing efficiency and value creation. However, accurately measuring this type of economic model requires robust methodologies that consider multiple criteria.

The authors conducted a systematic review by analyzing relevant academic journal publications to achieve their objective. They identified several multi-criteria methods commonly utilized when evaluating circular economy performance, such as the analytic hierarchy process (AHP), analytic network process (ANP), multi-attribute utility theory (MAUT), and fuzzy logic. Through careful examination, they have presented valuable insights which can help researchers develop more effective measures for assessing progress toward achieving sustainable development goals related to circular economies

The research indicates that most studies assess circular economy performance at a country, regional or industry level. While there are variations in criteria and indicators utilized across these studies, specific themes emerge, such as resource efficiency, waste management, eco-design, and green innovation. However, subjectivity is also highlighted when determining weights for criteria, along with a lack of standardized indicators, which makes it challenging to capture the dynamic nature during transitions towards circular economies.

The article [45] presents an approach to multi-criteria decision-making (MCDM) modeling that this model aims to capture all essential dynamics and interactions within intricate waste management systems while minimizing complexity. By adopting circular economy principles, prioritizing resource recovery and recycling over waste generation, they can revolutionize the current practices toward sustainability.

This methodology has been successfully applied in waste management with promising results. Several critical criteria, including environmental impact, economic feasibility, technological feasibility, and social acceptance, influence the adoption of circular economy principles in waste management. When making decisions using the model that captures their interrelationships and feedback loops, these factors are considered.

To effectively implement this parsimonious MCDM model, the authors combine system dynamics with fuzzy cognitive mapping. System dynamics helps to understand complex systems, while fuzzy cognitive mapping analyzes causal relationships among variables.

To ensure the accuracy and reliability of the model for practical use, it was validated through data from a case study on waste management practices in a specific region which helped calibrate its parameters against historical data points. The modeling exercise has uncovered valuable insights into adopting circular economy principles in waste management. The factors and feedback mechanisms that significantly influence this process are now clear, providing decision-makers with a roadmap for developing effective strategies and policies to promote sustainable practices.

2.6 MCDM Methods in Water Circular Economy

Water scarcity, as defined by the Food and Agriculture Organization [46], is a critical issue when there is an imbalance between water demand and availability. This discrepancy can vary depending on location, climate conditions, or seasons. Furthermore, this phenomenon can be classified into two types: physical scarcity - which refers to limited access in specific places- and economic scarcity, caused by financial constraints limiting individuals' or communities' ability to obtain accessible water resources. We must address these challenges since they threaten our planet's sustainability.

According to this article [47], implementing the multi-criteria analysis is essential in determining the best strategies for managing water resources in a Greek farming economy facing severe water scarcity. This study evaluated seven approaches using four distinct techniques to ensure hydrological and economic factors were considered. To establish accurate evaluation weights, decision-makers and experts on water management participated in surveys.

The results reveal significant obstacles when effectively managing these precious natural resources while highlighting the need for collaboration between authorities and professionals toward more sustainable practices. By adopting innovative solutions such as multi-criteria analysis, we can achieve efficient resource management that benefits our environment and society.

MCDM techniques are an effective means to address concerns regarding water quality. Water quality pertains to the physical, chemical, and biological attributes determining its fitness for human consumption (for drinking), agriculture, or industrial purposes. Various parameters need consideration to evaluate this aspect of water resources, such as dissolved oxygen levels in aquatic bodies, salt content concentrations, presence of heavy metals like lead or mercury, and nutrients, including phosphorus and nitrate ammonia microorganisms. Factors like pH, temperature, and suspended solid count must also be considered [48].

It is an undeniable fact that human actions, including domestic, agricultural, and industrial activities, are the primary reason behind water quality degradation worldwide. The pollution caused by these activities poses a significant threat to aquatic environments today. Fortunately, Water Quality Indices (WQIs) provide valuable data for assessing water sources that decision-makers and the public can easily comprehend. By utilizing multi-criteria decision-making techniques in resource allocation efforts, we may help mitigate issues related to the equitable distribution of resources towards improving our planet's precious water supply [49].

The AHP method is applied in this article [50] to evaluate nonmarket monetary value changes associated with water quality modifications based on Water Framework Directive (WFD) principles. WFD is an EU directive designed to improve and protect European water bodies. Non-market monetary value refers to the economic worth of goods or services not traded directly on the market, such as clean water for recreational activities or healthy ecosystems that provide ecological benefits. They utilized a case study to demonstrate how multi-criteria analysis can be used to estimate non-market monetary values associated with changes to water quality under WFD. Researchers used data gleaned from various water quality indicators - biological, chemical, and physical parameters - to calculate the value of changes to water quality over time. Their investigation demonstrated that non-market monetary values of changes varied considerably based on each indicator and where they occurred along the Guadalquivir River basin in southern Spain.

By implementing MCDM techniques, the authors of this case study [51] analyzed various factors contributing to Korea's hydrological vulnerability. This included topography, land use, and soil type, among others. The results revealed an accurate map highlighting areas with higher levels of exposure ranked at the top. This approach proved highly effective in determining spatial ranking for water-related hazards across Korea. As such, it is recommended as a valuable tool for identifying regions with more pronounced risks than others.

The article [52] presents a hybrid approach to selecting the optimal wastewater treatment technology for a given application. The approach combines multiple criteria decision-making (MCDM) methods with a life cycle assessment (LCA) framework to evaluate the environmental, economic, and social impacts of different wastewater treatment technologies. The authors present a compelling case study showcasing the effectiveness of their proposed approach in selecting the optimal wastewater treatment technology for residential development in Malaysia. The study involved comparing three distinct technologies: conventional activated sludge, membrane bioreactor, and sequencing batch reactor based on various evaluation criteria such as environmental impact, cost-effectiveness, social implications, and technical feasibility. Their findings suggest that this hybrid approach can be applied to other settings with similar success rates. Integrating MCDM methods with life cycle assessment frameworks into one comprehensive system enables an accurate analysis of different treatment options' economic viability while considering their environmental impacts alongside social factors.

2.7 Mixture Design of Experiments

Mixture design of experiments (DOE) is a statistical technique for optimizing mixtures containing multiple ingredients or compounds that comprise products. DOE helps identify optimal levels for each element within a mixture to produce maximum effectiveness based on specific performance criteria [53].

Mixture DOE is about finding combinations of component proportions that deliver desired performance characteristics of mixtures; in particular $x_1, x_2, \dots, x_p$ represent different proportions within a specific mixture that cannot be considered independent variables. The goal is to find optimal solutions that result in desired responses - for instance, proportions related together; therefore, they cannot be treated independently.

$$0 \leq x_i \leq 1 \quad i = 1,2, \dots\dots, p \tag{2.16}$$

$$x_1 + x_2 + \cdots + x_p = 1 \quad (i.e.,\ 100\ percent) \tag{2.17}$$

There are various mixture designs, such as full factorials, fractional factorials, response surface designs, simplex centroid, simplex lattice, and Box-Behnken designs. When selecting one for use in experiments, the choice will depend upon both available ingredients and resources available in an experiment. Full factorial designs involve testing all possible combinations of component levels, while fractional factorial designs employ only selected subsets. Response surface designs use mathematical models to analyze data to find combinations of component proportions that produce optimal responses from an experiment. Choosing this form of mixture design depends on its ingredients and available resources [54].

Extreme Vertices Design (EVD) [55] is an approach to designing mixture experiments. This method harnesses the power of extreme vertices in the design space, optimizing the experiment for maximum efficiency and accuracy. Unlike traditional methods such as full factorial designs, EVD selects only a few critical points near these crucial areas before analyzing response data and fitting statistical models that can predict results with unparalleled precision.

The benefits are clear: by using EVD, we get more accurate estimations of model parameters than ever before while improving prediction accuracy across all combinations of components tested. Numerous simulation studies have repeatedly shown how effective this technique is.

[56] provides an in-depth introduction to the design and analysis of mixture experiments. The authors present various methodologies for designing mixture experiments, such as full factorial design, fractional factorial design, Response Surface Methodology (RSM), Central Composite Design (CCD), and Box-Behnken design. Furthermore, the authors cover methods of analyzing these mixture experiments, such as statistical models to predict response for various combinations of components, while emphasizing validation techniques and practical guidance, such as data transformation for more efficient data processing or selecting suitable designs that might help overcome challenges related to mixture experiments.

2.8 Sensitivity Analysis

Sensitivity analysis is an approach employed in finance, engineering, and other disciplines that allows analysts to establish how much of any variation in the output of a model or system can be traced back to variations in its inputs. It serves as an instrument for studying how changing inputs affect output while identifying major drivers or risk factors with the most significant influence. Sensitivity analysis may involve repeatedly altering input parameters while holding all other inputs constant for comparison purposes.

Sensitivity analysis in Multi-Criteria Decision Making (MCDM) techniques involves manipulating weight values assigned to criteria and monitoring how these change the final ranking of materials. Many prominent companies around the globe employ this practice in making more calculated decisions and understanding which variables affect them most significantly. In summary, sensitivity analysis remains crucial throughout every stage involved when making informed choices about anything- ensuring reliability and resilience against unforeseen circumstances is paramount, no matter the context being considered.

A sensitivity analysis was conducted in the article [53] to select the best material for structural concrete repair. The authors utilized the VIKOR method as an evaluation criterion and assessed how changes in weight values assigned to criteria impacted the final rankings of alternative materials. To ensure accuracy, they compared their results with those obtained using other multi-criteria decision-making approaches such as AHP and SMART. Their findings revealed that VIKOR is more reliable and provides a consistent ranking of materials compared to other methods. This approach is its robustness and reliability during material selection processes for structural concrete repairs projects - it remains unaffected by any fluctuations or adjustments made on weight values.

Several key steps are followed to perform a thorough sensitivity analysis using the Extended VIKOR method. First, choosing a range of values for the criteria weights is essential - these represent how important each criterion is in making your decision. By varying these weightings, we can gain valuable insight into how different factors impact our results. Running an Extended VIKOR analysis with both the original criteria weights and those modified allows us to compare the results side-by-side to identify any patterns or trends emerging from changes made. Ultimately, we need to determine the most sensitive aspects when considering future decisions, pinpointing areas where small tweaks could lead to significant differences.

The article [57] provides valuable insights into the performance of various decision-making methods and runs sensitivity analysis; the authors thoroughly evaluated both Extended VIKOR (EVIKOR) and several outranking techniques using real-world data from an actual case study. To truly understand the impact of various weightings, conducting a sensitivity analysis on the Extended VIKOR is essential. Examining equal and modified weights results in valuable results for different weighting settings.

The Extended VIKOR method employs sensitivity analysis to assess the impact of varying decision criteria and weightings on the outcome. The aim is to evaluate the strength of our choices and pinpoint which factors hold significant sway over results. This evaluation ensures that our decisions remain sound despite changing circumstances while understanding what drives success in our chosen field.

CHAPTER 3

GENERATION OF CIRCULAR ECONOMY ALTERNATIVES

Water scarcity is a critical problem that emerges when the supply of this vital resource becomes insufficient in an area, causing severe difficulties for individuals to obtain clean drinking water or use it effectively for agriculture and industry. This creates intense competition among people leading to reduced agricultural output and excellent transmission rates of diseases through contaminated sources.

To confront this challenge head-on in Eskisehir City, we developed a circular economy model that considers economic and environmental factors. We aim to offer comprehensive insights on the issue by providing up-to-date details about its current state while outlining our approach towards developing sustainable solutions using advanced mathematical modeling techniques during analysis.

Implementing circular economy principles for water allocation is a challenging task, and it is crucial to emphasize its significance. The unequal distribution of water resources across different regions poses an obstacle to allocating them equitably among various sectors with varying demands, such as agriculture, industry, and households. Conflicting request further complicates the matter; while agriculture consumes most of the available water supply, industries require significant amounts too. Additionally, households need clean drinking water daily. Overcoming these challenges requires advanced technologies and infrastructure development like wastewater treatment plants or desalination facilities that are expensive to build but necessary for effective management practices. Recycling high-quality industrial-grade waters also presents difficulties due to their specific requirements. Therefore, we must prioritize implementing circular economy principles by investing in research and development alongside adequate funding for building sustainable infrastructures capable of meeting current and future demand levels.

3.1 Current System

Current systems involve taking water from rivers and treating it at treatment plants before discharging it to households for domestic consumption. Wastewater from homes and industries has the potential to negatively affect aquatic environments due to organic matter, nutrients, and hazardous substances it contains; most urban wastewater collection systems divert it to wastewater treatment plants before release back into aquatic systems; the level of treatment before release will determine its effect. To simplify this model, we assume certain boundaries, including starting and ending points within the system. This has granted us a deeper understanding, allowing for more effective streamlining.

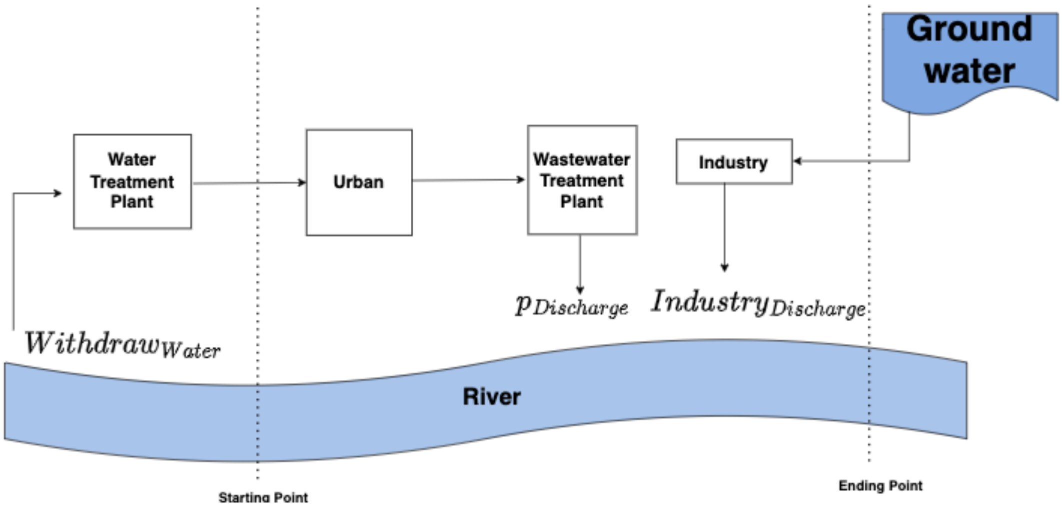

Figure 3.1 The current system

Current systems use surface water (river) for daily consumption. At the same time, agriculture and industries draw groundwater as their source of pure water supply, so in some alternatives, they might not require treated wastewater due to groundwater use. Therefore, analyzing the impact of this system from a broader perspective becomes imperative. Once used, wastewater must then be processed until reaching an acceptable quality standard before being discharged back into rivers or oceans for disposal.

Distributing treated wastewater can bring numerous advantages to various individuals and entities. Farmers can decrease their dependence on freshwater resources by utilizing treated wastewater for irrigation while ensuring a dependable water source for crops. This will not only benefit the farming community but also enhance overall productivity. Numerous industries require substantial amounts of water to operate effectively; however, using treated wastewater as an alternative could prove cost-effective compared with using freshwater sources alone - thus conserving valuable natural resources while simultaneously reducing companies' expenses related to utility bills. The proposed system (circular model) in section 3.2 aims not to discharge all treated wastewater into rivers but instead recycle part of it within its internal system, thus keeping river levels from decreasing further. Some treated waste will still be released into rivers to fulfill downstream water demands.

3.2 The Circular Economy Model

This thesis examines the Porsuk Basin and how its various water users, such as agriculture, industry, and urbanization, affect its resources within its boundaries. We have four key components within this boundary to focus on; however, it's important to note that future studies may reveal additional users. Our four components include agriculture, industry, and parks for recreational activities. A portion of this water will also be discharged into the river to provide water demand for the remaining water users.

We generate multiple options to determine how much water should be allocated for each user group. We aim to utilize experimental designs that cater specifically to fulfilling our users' unique requirements while ensuring maximum efficiency across all fronts. Instead of simply discharging treated wastewater into rivers, this model suggests other stakeholders purchase this treated waste instead of using freshwater for non-portable uses; an example is shown below in Figure 3.2.

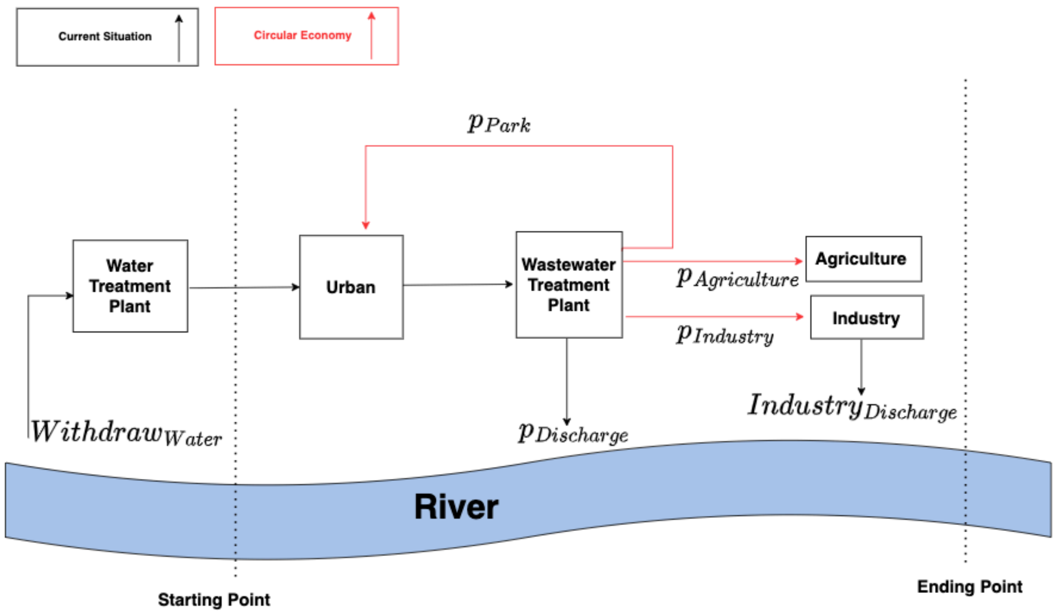

Figure 3.2 The circular economy model

A wastewater allocation model is used to predict the movement of wastewater within municipal or industrial wastewater collection and treatment systems. Such models help designers optimize new systems and evaluate existing ones' performance more efficiently. They consider factors like population density and infrastructure layout to analyze how wastewater travels through a system comprehensively. These models allow utility managers to identify capacity issues and areas requiring further treatment, providing informed guidance about improving system efficiency and effectiveness.

Municipalities can gain advantages by utilizing treated wastewater for multiple purposes, such as maintaining landscapes, cleaning streets, and operating fire hydrants. This approach curbs their reliance on freshwater and liberates these resources for other essential requirements. Additionally, it contributes positively to the environment by reducing the quantity of discharged wastewater into rivers and water bodies which ultimately safeguards aquatic ecosystems from harm's way.

A significant portion must be allocated for agricultural purposes, as it can be a valuable resource for crops and sustainable farming practices. Additionally, manufacturing companies should receive their fair share to aid production processes while minimizing water waste. Moreover, parks and recreational areas require water to maintain healthy greenery; therefore, allocating an appropriate proportion will benefit our communities greatly. Releasing untreated or poorly treated wastewater into rivers poses severe risks to aquatic life and ecosystems. We must minimize such actions by closely monitoring the proportions discharged into these bodies of water.

3.3 Generation of Alternatives for the Circular Economy Model

The Experiment Mixture Design technique is a tool that can help to identify the perfect combination of factors for creating a circular economy model. In Eskisehir, we have identified four key elements - agriculture, industry, parks, and discharging into rivers (current situation) - vital in establishing an effective wastewater allocation system. By creatively combining these components during our design process while ensuring all percentages add up to 100%, we aim to determine the optimal ratio by evaluating various options based on their economic and environmental aspects.

However, it is essential not to overlook social and cultural criteria when developing water allocation projects, as this could lead to unjustifiable outcomes. Incorporating such considerations into decision-making processes will result in more equitable results regarding sustainable water management practices that benefit communities and ecosystems.

Therefore, we must strive towards including all relevant parameters while allocating precious resources like wastewater management solutions. We will rank them accordingly after considering several factors, such as numerical values utilized in calculations or evaluation criteria used during assessments, so our approach creates sustainable solutions with minimal negative impacts on society or nature.

$P_{Agriculture}$	A significant portion will be allocated for agricultural purposes
$P_{Industry}$	A significant portion will be supplied to the manufacturing companies
P_{Park}	A significant portion will be allocated to the parks
$P_{Dishcharge}$	A significant proportion of wastewater released into the river

Constraints:

$$P_{Agriculture} + P_{Industry} + P_{Park} + P_{Discharge} = 1 \tag{3.1}$$

$$0 \leq P_{Agriculture} \leq 1 \tag{3.2}$$
$$0 \leq P_{Industry} \leq 1 \tag{3.3}$$
$$0 \leq P_{Park} \leq 1 \tag{3.4}$$
$$0 \leq P_{Discharge} \leq 1 \tag{3.5}$$
$$P_{Agriculture} + P_{Park} \geq 0.1 \tag{3.6}$$

By applying the formulas outlined in sections (3.1) to (3.5), we can produce a range of options that will undergo thorough evaluation using advanced decision-making methods. It is imperative to follow strict guidelines regarding proportion constraints - minimum and maximum limits must be observed for effective experiment planning. To determine what percentage of the total water should go towards each sector, we divided each sector's water demand by the quantity of treated wastewater available. Equation (3.6) determines at least 10% of their treated wastewater from urban treatment facilities is allocated for various purposes, including agricultural irrigation and recreational activities.

Circular economy indicators serve as measurable parameters that evaluate the effectiveness and progress of a circular economic model. These metrics accurately assess how well resources are utilized, waste is minimized, materials are recycled, and products are designed for reusability and sustainability while highlighting significant environmental and financial benefits.

3.4 The Selection of Indicators

Circular economy indicators encompass various factors such as recycling percentages in production processes, amount of landfill diversion achieved to reduce waste accumulation, reduction in greenhouse gas emissions through sustainable practices, and new business opportunities created by adopting these approaches.

For our project, we focus on Porsuk Basin in Eskisehir with its unique environmental conditions and data availability constraints - we choose four indicators out of many possible options from literature sources: River Flow Rate, Water Quality Index, Withdrawing Water (amount), and Net Cost. As mentioned, these are our criteria for evaluating the alternatives to reach the desired outcomes.

The River Flow Rate is essential in determining the water available for various purposes. These include irrigation, electricity generation, and providing drinking water to communities. It also plays a crucial role in maintaining aquatic ecosystems by ensuring specific flow conditions for certain species' survival. Moreover, it is vital to consider the quality of water flowing through rivers as this directly affects its ability to support aquatic life and ensure safety for human consumption or recreational activities. Pollutants such as chemicals and bacteria can harm or kill marine creatures, making the waters unsafe for humans. To promote healthy environments and sustainable use of resources, local communities must prioritize monitoring their nearby rivers' flow rates regularly while protecting them from harmful pollutants like never before.

The river flow rate changes due to different water management alternatives can significantly impact downstream water users, aquatic ecosystems, and other ecological functions. It is crucial to consider these impacts to ensure a balanced and sustainable approach to water management in the Porsuk Basin. The following potential effects should be addressed: decreased river flow rate can affect irrigation availability for agricultural activities downstream. Reduced water availability may lead to lower crop yields, economic losses for farmers, and potential conflicts over water allocation between agricultural and other sectors.

Reduced river flow can impact freshwater availability for municipal water supply systems downstream. This may necessitate alternative water sources, increased treatment costs, or stricter water conservation measures to meet the demands of the population. Industries relying on river water may face challenges maintaining their operations if the reduced flow rate affects their water intake capabilities. This can potentially impact production capacities and economic output in the industrial sector. Changes in the river flow rate can disrupt aquatic habitats, affecting the biodiversity and ecological balance of the Porsuk Basin. Decreased flow may alter various aquatic species' migration patterns, breeding grounds, and survival rates, leading to a decline in biodiversity and potential ecological imbalances.

Maintaining a sustainable river flow rate requires balancing the needs of various sectors while ensuring the ecological integrity of the Porsuk Basin. It is essential to address potential conflicts and trade-offs that may arise, such as: allocating water resources among sectors to meet their respective demands while considering environmental needs and sustainability goals or promoting water-efficient practices and technologies in different sectors to reduce overall water demand and mitigate the impact of reduced river flow rates and encouraging stakeholder engagement and collaboration among water users, policymakers, and environmental organizations to develop integrated water management strategies that consider the needs of all stakeholders.

By addressing these potential impacts and trade-offs, the evaluation of water management alternatives can identify solutions that optimize the river flow rate while meeting the water needs of different sectors and maintaining the ecological health of the Porsuk Basin

The Water Quality Index (WQI) is crucial in evaluating water quality within specific regions. This metric considers various factors such as dissolved oxygen levels, pH balance, and the presence of pollutants to determine overall water health. The circular economy model emphasizes responsible resource use while minimizing waste. Incorporating WQI into this economic framework allows companies to assess their impact on local bodies of water from industrial or agricultural activities. By monitoring these metrics, businesses can identify areas where they can reduce environmental harm through changes in production processes that promote sustainability.

Advanced treatment processes can be utilized as alternative options to enhance treated wastewater quality significantly. These methods can reduce levels of pollutants, pathogens, and other contaminants, ultimately leading to improved water quality downstream. By implementing these specific alternatives, we can minimize pollution input into our bodies of water.

However, any chosen method must have robust treatment processes and proper monitoring and maintenance procedures. Without this attention, there is potential for insufficient removals resulting in degraded water quality downstream or poorly managed storage systems leading to accidental spills or leaks causing cross-contamination between different sources - both scenarios compromising the integrity and safety standards set forth by governing agencies responsible for maintaining clean drinking supplies across all regions.

Changes in water quality can impact crop productivity, irrigation practices, and soil health. Assess the suitability of treated wastewater for agricultural use, considering the presence of nutrients, salts, and potential contaminants. By analyzing the possible improvements or degradation in water quality resulting from each alternative and considering the implications for various water users, ecological systems, regulatory compliance, and additional treatment requirements or monitoring efforts, the evaluation process can account for the crucial aspect of water quality management in the Porsuk Basin.

For instance, implementing closed-loop systems for recycling wastewater reduces consumption rates during manufacturing procedures, ultimately decreasing pollution output. Similarly, adopting sustainable agriculture practices minimizes chemical usage, reducing contamination potential for nearby sources.

Embracing the circular economy means optimizing our resources while minimizing waste. A critical aspect of this strategy is reducing water intake from natural sources such as rivers, lakes, and aquifers. We can effectively safeguard valuable water reserves for future generations to come through inventive methods like precision irrigation systems or drought-resistant crops in agriculture.

In a circular economy, withdrawing water means taking what is necessary for human consumption while leaving enough for nature to thrive. This requires efficiently using available resources through recycling wastewater or capturing rainwater whenever possible. Sustainable management practices ensure that current and future generations can access clean drinking water without harming the environment.

Withdrawing large quantities of water from rivers, lakes, or aquifers can adversely affect the natural environment and aquatic ecosystems. Reduced water flow and depleted water levels can disrupt habitats, harm biodiversity, and jeopardize the survival of sensitive species. This trade-off involves balancing the water needs of human activities with the ecological requirements for maintaining healthy and functioning ecosystems.

Embracing sustainable and efficient practices in water allocation management can significantly reduce the Net Cost in a circular economy. These include repairing leaks, utilizing effective irrigation systems, and recycling water to minimize freshwater demand for non-potable purposes such as industrial processes or flushing toilets. Additionally, adopting modern infrastructure like intelligent irrigation systems, automated monitoring tools, and energy-efficient appliances will lower maintenance costs and decrease energy consumption while promoting sustainability and resilience within the ecosystem. By implementing these measures effectively, we can achieve both economic benefits through reduced operating expenses while ensuring environmental conservation by reducing the wastage of our precious natural resources.

An approach that considers all aspects of water management in the region is necessary to calculate circular economy indicators accurately. Firstly, we define our study area by identifying the specific section of the river we analyze. We gather data on water use within this area, including withdrawals made for agriculture, industry, and domestic purposes. By incorporating the parameters and constraints set by our project team after several meetings- we evaluate the equilibrium between outflow and inflow levels of water, considering both withdrawal and river flow rates. By thoroughly analyzing all the criteria, we have established specific limitations and their corresponding variables. This has enabled us to gain an in-depth understanding and accurate measurement of circular economy indicators within the scope of this study. We must consider these crucial factors for effective implementation toward achieving sustainable economic growth.

In summary, the criteria of River Flow Rate, Water Quality Index, Withdrawing Water (amount), and Net Costs are interconnected in evaluating and ranking circular economy water management alternatives. Balancing these criteria is essential to ensure sustainable water management practices that consider the ecological, water quality and financial aspects of the Porsuk Basin project.

3.4.1 Calculation of The Indicators

Analyzing the information collected regarding water consumption patterns in this particular river section is imperative. Using the constraints the experts designed, we calculate a representation of the overall balance between what is flowing out and what is coming in concerning withdrawal rates and natural inflow levels. Our system's design faces certain limitations that cannot be ignored; one such restriction is the water extracted from the city's supply but never returned to the system via sewer or other channels. This can arise due to multiple factors, including pipe leaks, unsanctioned connections to the water source, and improper disposal of greywater or non-potable water.

The impact of this “unaccounted” water on overall supplies and treatment systems cannot be overstated - it leads to higher costs for treating such water. At the same time, residents may face shortages as well. Moreover, these practices contribute heavily towards general urban consumption patterns causing harm to our environment too. A portion of water consumed and not returned in the system is known as "non-revenue" wastewater after reaching end users.

The primary purpose of this system is to guarantee adequate wastewater treatment in a facility before releasing it back into nature. This operation necessitates various expenses linked with pipes, pumping stations, and machinery for gathering and transporting sewage efficiently to diverse facilities. In certain instances, localized treatments are mandatory before transferring them further to central sites.

However, our aim here is to reduce wastewater proficiently and safeguard public health by averting any environmental hazards associated with untreated waste disposal methods. Furthermore, we aspire to substantially contribute to sustainable development objectives while promoting economic growth opportunities. To evaluate these criteria effectively, parameters and constraints have been established to help us measure progress accurately while ensuring optimal outcomes.

Index:

A: Agriculture

I: Industry

P: Park

D: Discharge

Parameters:

$Demand_{Agriculture}$	The water demand for the Agriculture
$Demand_{Industry}$	The water demand for Industries
$Demand_{Urban}$	The water demand for daily use in Urban
$Demand_{Park}$	The water demand for irrigation Recreational/Parks
$Withdraw_{Water}$	The amount of withdrawn water at the starting point
$Wastewater$	The amount of wastewater in the wastewater treatment plant
$Quality_{Start}$	Quality of the water at the starting point in the river
$Quality_{End}$	Quality of the water at the ending point of the river after it has been affected by the release of wastewater from cities and industries
$Industry_{Discharge}$	The flow rate of wastewater discharging into the river from industries
$FlowRate_{Start}$	The flow rate of water in the river at the starting point
$FlowRate_{End}$	The flow rate of water in the river at the ending point

$Unreturn_{Urban}$	The flow rate of water that is consumed and not returned to the system
$Unaccountable_{Start}$	The flow rate of lost water while withdrawing from the river at the starting point
$NetCost$	The net expense of designing a circular economy framework
$InvestCost_{WWTP}$	The expense of building and installing a new wastewater treatment plant (WWTP) (if required)
$TreatmentCost_{A}$	The cost of investing in filtration/ultra-filtration in Agriculture
$OMCost_{A}$	The operation and maintenance costs related to treatment processes for Agricultural
$PipeCost_{I}$	The pipe and excavation cost for Industry
$Distance_{I}$	The distance from the wastewater treatment plant to the Industry
$PumpCost_{I}$	The cost of investing in pumping the treated wastewater into the Industry
$OMCost_{I}$	The operation and maintenance cost related to piping and pumping the treated wastewater for Industry
$PipeCost_{P}$	The pipe and excavation cost for Parks/Recreational irrigation uses

$Distance_P$	The distance from the treated wastewater treatment plant to the Parks/Recreational irrigation uses
$PumpCost_P$	The cost of investing in pumping the treated wastewater to Parks/Recreational irrigation uses
$OMCost_P$	The operation and maintenance cost related to piping and pumping the wastewater to the Parks/Recreational irrigation
StorageCost_P	The cost of investing in tanks to store the treated wastewater for Parks/Recreational irrigation uses
$QualityUrban_D$	The quality of the wastewater from urban that will be released into the river
$QualityIndustry_D$	The quality of the wastewater from industries that will be released into the river
$Revenue_A$	The revenue from market demand and prices, water availability, irrigation costs
$Revenue_I$	The income from selling the treated wastewater, enhanced operational efficiency
$Environmental_{Benefit}$	Conserving water, reducing pollution levels, recycling nutrients, and saving energy, etc.

Constraints:

$$Withdraw_{Water} = Demand_{Urban} + Demand_{Park} - (P_{Park} \times Wastewater) \tag{3.7}$$

$$FlowRate_{End} = FlowRate_{Start} - Withdraw_{Water} - Unaccountable_{Start} - Unreturn_{Urban} + \left(P_{Discharge} \times Wastewater\right) + Industry_{Discharge} \tag{3.8}$$

$$Quality_{End} = \frac{(Quality_{Start} \times FlowRate_{Start}) + \left(QualityUrban_{D} \times P_{Discharge} \times Watewater\right) + (QualityIndustry_{D} \times Industry_{Discharge})}{FlowRate_{End}} \tag{3.9}$$

$$NetCost = +(InvestCost_{WWTP}) + (TreatmentCost_{A}) + (OMCost_{A}) - (Revenue_{A}) + (PipeCost_{I} \times Distance_{I}) + (PumpCost_{I}) + (OMCost_{I}) - (Revenue_{I}) + (PipeCost_{P} \times Distance_{P}) + (PumpCost_{P}) + \left(OMCost_{p}\right) + (StorageCost_{P}) - (Environmental_{Benefit}) \tag{3.10}$$

Equation (3.7) can be used to calculate how much freshwater will be extracted from rivers at their initial source for various options based on daily urban consumption, recreational park use, and irrigation requirements. We apply circular economy principles to decrease our total use by redirecting purified wastewater towards parks or non-consumable processes, thereby decreasing our river water takes.

The river's flow at its destination, including water released by industries and wastewater treatment plants, and unutilized or lost water due to consumer preferences is assessed in Constraint (3.8). Meanwhile, Constraint (3.9) evaluates the quality of the final point by accounting for treated industrial wastewater discharged into it.

Climate change can significantly impact our precious water resources and make managing them more challenging than ever before. Changes like the reduced availability of freshwater sources could lead to difficulties treating and distributing enough clean drinking water while increasing pollutants' concentration levels or salinity rates that affect overall quality standards.

These changes may necessitate alternative approaches towards sourcing or treating available waters, such as using treated wastewater in agriculture, industry settings, parks, etc., depending upon their suitability under new climate conditions - making sustainable management practices crucial.

Climate fluctuations can impact water demand by altering rainfall patterns and raising temperatures, affecting irrigation needs, industrial requirements for water, and park usage. Furthermore, climate change-induced shifts in the availability of freshwater resources could put pressure on existing allocation systems necessitating adjustments to management strategies.

To address these challenges related to global warmings, such as dwindling supplies or concerns about quality control over time, governments may introduce new regulations that are more stringent than before. These changes will undoubtedly affect stakeholders who must adapt their practices accordingly while considering how vulnerable they are given different scenarios posed by climatic events like droughts or floods impacting economic viability productivity sustainability operations requiring alternative sources adaptation measures be considered when planning projects with an eye towards resilience against future impacts from changing weather conditions. Given all this uncertainty surrounding climate change, any project must include provisions designed specifically around enhancing its ability to withstand environmental pressures brought forth through risk assessment projections.

Equation (3.10) shows the elements of the total cost of implementing a circular economy within any system. Each alternative model comes at its costs and benefits, and we must aim to minimize the alternatives' costs and adverse environmental impacts as much as possible while striving to maximize the benefits. Cost constraints can also help us decide and determine the most cost-effective solutions by comparing costs against benefits for different options. Total cost is the summation of all costs (in the present value) associated with a project or system. In the project context, it would involve considering the costs of implementing a water management alternative in the Porsuk Basin. These costs include infrastructure investment, operational expenses, maintenance and repair costs, personnel costs, and any other expenses incurred throughout the project's lifecycle. On the other hand, the alternatives may involve revenue generation mechanisms such as those that require the beneficiaries paying a price for the treated wastewater. In addition, the alternative may create environmental benefits which can possibly be converted into monetary terms.

The Net Cost refers explicitly to the expenses associated with operating and maintaining the water management alternatives chosen for the Porsuk Basin. It includes regular operational costs such as energy consumption, chemical usage, labor costs, and routine maintenance activities required to ensure the proper functioning of the water management systems. A cash flow analysis helps to assess the financial implications of different alternatives and provides essential information for decision-making.

By applying the time value of money and discounting, we can transform the annual cost into its present worth. The current value reflects future cash flows considering how much money is worth over time [1].

$$Present\ Value = \frac{Annual\ Cost}{(1 + Discount\ Rate)^n}$$

The amount you pay or receive every year represents the yearly expenses known as annual costs, while the rate at which future cash flows are discounted to their present values refers to Discount Rate. This rate reflects what it would have been like if you had invested or borrowed funds instead - an opportunity cost.

To calculate this formula, n denotes years in advance for determining today's net monetary gain/loss from these payments made annually and calculating each expense's actual impact on our finances by bringing back those upcoming expenditures' equivalent amounts down to their respective Present Values (PVs).

A perpetuity formula is a mathematical tool that enables investors to calculate the present value of an investment with perpetual cash flows or infinite time horizons. It's beneficial when dealing with financial instruments generating never-ending future cash inflows. Perpetuity rests on the assumption that investments will continue producing steady and unending income without any termination date in sight, making it ideal for valuing assets like those offering long-term dividends or interest payments. We can accurately determine the investment's worth by utilizing this specialized formula.

$$Present\ Value = \frac{Annual\ Cost}{Discount\ Rate}$$

The agriculture industry incurs an annual cost for operation and maintenance, which can be calculated using the present value formula. The discount rate used in this calculation represents how future cash flows are discounted to their current worth. It is important to note that perpetuity formulas are typically only applicable in theoretical scenarios. Most projects have finite lifetimes or expected termination dates with various factors affecting cash flow, such as inflation, market conditions, and operational changes.

Conducting a cash flow analysis is crucial when it comes to evaluating the financial viability of any project or investment. It involves scrutinizing all incoming and outgoing cash flows within a specified period to determine profitability. Regarding water management alternatives for the Porsuk Basin, conducting such an assessment would be essential in deciding which option offers the most favorable investment returns.

This comprehensive evaluation will consider various factors that affect revenue generation and cost savings associated with each alternative. These include operational expenses incurred during implementation, income generated from treated wastewater sales, and reduced freshwater usage costs, among other relevant aspects. Therefore, performing this critical exercise can provide valuable insights for making informed decisions regarding your water management options while maximizing profits at every stage of operation.

When considering costs with this approach in Equation (3.10), we must consider both economic factors alongside its associated ecological values that translate directly into tangible benefits such as cleaner air and waterways, etc. This thesis is essential for stating a necessity for further research and analysis to quantify environmental benefits. If such benefits are hard to quantify, then these can be taken out of the cost term, and the benefits can be considered as a separate criterion to be assessed subjectively.

Quantifying environmental benefits is a challenging task that requires certain assumptions to be made in this thesis regarding the absence of revenue. These assumptions deviate from realistic scenarios, so we focus on methodology without incorporating complex considerations into our analysis.

To accurately assess the financial impact of a project, it is crucial to consider any positive environmental benefits. By subtracting their monetary value from the overall cost, we can ensure that these benefits are properly accounted for. However, determining this monetary value may not always be straightforward and objective. It often involves subjective judgments and uncertainties which need careful consideration by experts in consultation with stakeholders or environmental economists.

When allocating treated wastewater between different sectors or reducing groundwater usage, various factors must be analyzed before assigning potential monetary values to associated environmental benefits. This complex task requires a thorough examination to avoid significant contributions towards sustainability goals such as conserving natural resources and reducing carbon footprint, among others.

Imagine being able to save costs for your business while also contributing positively towards the environment. Allocating treated wastewater instead of relying on groundwater can do just that. By comparing the cost of treating and distributing groundwater versus wastewater, we will see a significant difference in potential savings achieved through reduced groundwater usage.

Reducing the reliance on extracting from underground water sources has far-reaching environmental benefits too. With less need for extraction comes fewer risks associated with land subsidence, depletion of water tables, or even contamination issues which could lead to costly remediation measures down the line.

Allocating treated wastewater to different sectors can significantly improve water quality by reducing pollution and nutrient discharge. This, in turn, leads to a plethora of benefits, such as enhanced recreational opportunities, improved ecological health, and increased aesthetic value. By estimating the willingness of people to pay for cleaner water or evaluating economic advantages like tourism growth or fisheries expansion due to better-quality water bodies, we can determine its monetary worth.

Reducing groundwater usage helps conserve this precious resource and contributes to mitigating greenhouse gas emissions associated with energy consumption. We could estimate its financial value by applying carbon pricing mechanisms or assessing social costs incurred per ton of emitted greenhouse gases that cause environmental damage.

Determining these values requires data availability and expert judgment based on specific project contexts' local conditions - consulting with environmental economists specializing in valuation techniques would help provide more accurate estimations tailored according to each unique circumstance surrounding the allocation project's needs.

To ensure precise evaluation outcomes while considering multiple aspects of alternative management options effectively, researchers will identify critical environmental elements such as habitat disruption levels and ecosystem health status indicators like pollution level measurements or carbon footprint assessments before proceeding further toward decision-making processes.

It is recommended to perform cash flow and cost-benefit analyses when evaluating water management alternatives or any project with financial implications. Cost-benefit analysis is a systematic approach used to assess a project or investment's economic viability and potential benefits. It involves comparing the costs and benefits of different alternatives to determine which option provides the most significant net benefit. In the project context, a cost-benefit analysis would help evaluate the economic feasibility of the circular economy water management alternatives for the Porsuk Basin. It would consider the costs (investment, operation, maintenance) and benefits (revenue, cost savings, environmental benefits) associated with each alternative to determine the most advantageous option.

In summary, cash flow and cost-benefit analyses are valuable tools in project evaluation. Cash flow analysis provides insights into the financial feasibility and performance of the project. In contrast, cost-benefit analysis takes a more comprehensive approach, considering both financial and non-financial factors to assess the overall value and desirability of the project. For each sector (agriculture, industry, parks, river discharge), the analysis would involve considering sector-specific factors and evaluating the costs, benefits, and financial implications within their requirements and objectives. The multi-criteria evaluation and ranking process would consider various criteria, such as economic feasibility, environmental impact, social considerations, and regulatory requirements, to comprehensively assess and compare the different water management alternatives for the Porsuk Basin.

Finally, to determine what percentage of the total supply should go towards each sector, we utilize software like Minitab or Design Expert to generate various alternative allocation scenarios based on our identified ranges per sector. In this thesis, we use the mixture design of experiments with the Minitab software to generate the circular economy alternatives.

CHAPTER 4

THE PROPOSED METHOD FOR EVALUATING THE CIRCULAR ECONOMY ALTERNATIVES

This section covers the proposed method for assessing circular economy alternatives to evaluate the possible advantages and disadvantages of adopting the circular economy model for allocating treated wastewater. With this approach, key decision-makers can weigh various alternatives within their unique circumstances and select one that best aligns with their goals. After analyzing relevant literature, we chose the Extended VIKOR method to rank the alternatives we generated for this system. The several steps of the proposed method are mentioned below.

4.1 Steps of The Proposed Method

The proposed method for assessing circular economy options involves a series of steps. The first step is generating various alternatives, as mentioned in Chapter 3. The next step is to develop an interval-based decision matrix and determine the criteria weights; we assume equal weights for all the criteria in this thesis. However, the AHP method is a much better way to ensure that all decision-makers are considered and find common ground between differing viewpoints to arrive at acceptable solutions for everyone involved. The Extended VIKOR technique is then used to rank these alternatives. Finally, a sensitivity analysis is applied with different criteria weights; Figure 4.1 outlines all necessary steps in our proposed process.

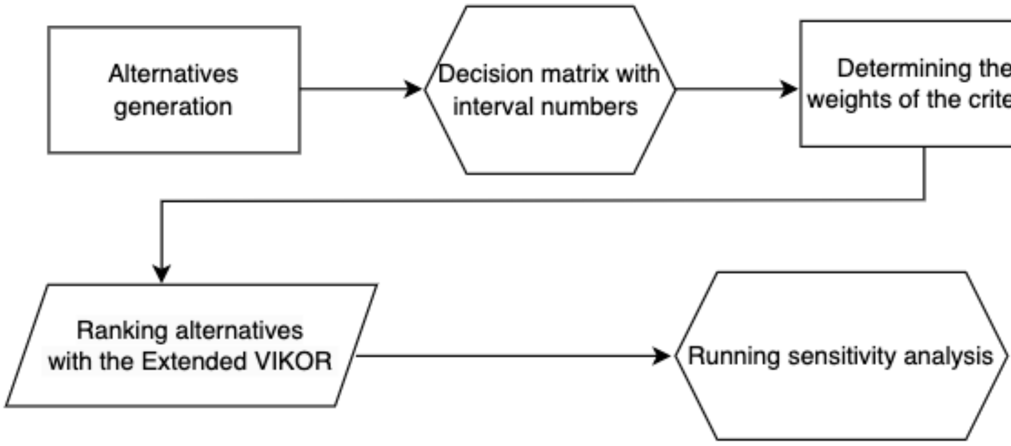

Figure 4.1 Flowchart of the proposed method

Step 1: Alternatives generation: The generation of the alternatives was mentioned in Chapter 3; it is imperative to establish the range of values that can be allocated for each sector. Take agriculture, for instance; it could receive anywhere between 0% and 100% of the total water supply. To determine how much water should be delivered, we calculated each sector's requirements by dividing them by treated wastewater quantities. We then identified possible amounts based on these calculations and created several alternatives.

Step 2: Decision matrix with interval numbers: Experts and professionals determine the ranges of criteria values corresponding to each circular economy alternative under uncertainty. One way of determining the range is to find the best estimate of a criterion value and introduce an error margin around it, such as $\pm 20\%$. However, certain industries and applications may have specific regulations that dictate an acceptable level of deviation. Sometimes, determining a suitable range involves analyzing historical data or the best guess. The statistical analysis estimated the mean and standard deviation, and twice the standard deviation around the mean covers 95% of the distribution. Selecting the appropriate criterion value range depends on the application requirements and expert advice from industry standards and guideline sources. We consult with experts before deciding on any approach to ensure acceptable results.

Step 3: Determining the weights of the criteria: To ensure a well-rounded perspective from all parties involved, conducting an AHP survey utilizing multi-criteria approaches is crucial. Implementing such methods guarantees effective participation and input from multiple decision-makers. Chapter 2 outlines the steps of the AHP method, which allows each participant to express their preferences regarding criteria and alternatives. In doing so, we create a comprehensive overview of everyone's viewpoints while identifying significant criteria with different weights through sensitivity analysis in our final step. Incorporating these techniques into our approach will ultimately lead us towards making more informed decisions as they provide insight into various perspectives while highlighting key factors necessary for successful outcomes. In this study, we assume that every criterion holds equal importance.

Step 4: Ranking alternatives with Extended VIKOR: In Chapter 2, we mention the steps of the Extended VIKOR and how this technique ranks alternatives based on various factors and considers uncertainty and imprecision. The VIKOR method has been extended to handle situations where criterion values are expressed using interval numbers, indicating data uncertainty or imprecision. These numerical ranges do not provide exact figures but signify a range of possible parameters within the given interval, along with an acceptable range they could possess. As our project involves real-world data and calculations that may contain errors, we employ interval data for complete assurance. Utilizing the Extended VIKOR is one effective way to analyze such uncertain information accurately and efficiently in this system.

Step 5: Running sensitivity analysis: We have taken inspiration from [57] in adopting a similar weighting strategy. To ensure accuracy in our calculations, let w_p denote the original weight of criterion C_p and this modified weight may be expressed as $w'_p = \lambda w_p$. In addition, sensitivity analysis of weightings can be conducted by changing the λ between 0 and 1 to anticipate the confidence level of the evaluation.

As all weights must add up to 1 when combined with other criteria factors under consideration, this method allows us to calculate the remaining weights accordingly:

$$w'_p = \lambda w_p \,, 0 \leq \lambda \leq 1 \qquad 4.1$$

$$w'_j = \varphi w_j \,, j = 1,2, \ldots .n \,, j \neq p \qquad 4.2$$

The significance of each criterion is measured by its w_j value, except for w_p which undergoes modification to conduct sensitivity analysis. The function $\varphi(\lambda)$, crucial in determining the weightage, can be derived from this equation: $\lambda w_p + \varphi \sum_{j \neq p} w_j = 1$ and takes on a specific format:

$$\varphi = \frac{1 - \lambda w_p}{1 - w_p} \qquad 4.3$$

For example, let $w_1 = w_2 = w_3 = w_4 = 0.25$ and $\lambda = 0.1$. Then,

$$w'_1 = 0.1 \times 0.25 = 0.025$$

$$\varphi = \frac{1 - 0.025}{1 - 0.25} = 1.3 \qquad w'_2 = w'_3 = w'_4 = 0.325$$

The significance of sensitivity analysis lies in its ability to evaluate the influence of different decision criteria and weightings on the outcome. The goal is to determine which factors affect our choices more, enabling us to make informed decisions that stand firm even amidst changing scenarios. In essence, this evaluation helps solidify our decision-making process by identifying key areas where we need to focus attention for optimal results. Moving forward, Chapter 5 will show how we apply these findings using a proposed method and showcase the outcomes achieved through such an approach.

CHAPTER 5

APPLICATION OF THE METHOD AND RESULTS

Our model is designed to analyze and address the environmental and economic impacts within the Eskisehir Porsuk basin. This region, encompassing a vital river basin and its surrounding areas, requires careful consideration of ecological health and financial implications when making decisions that could affect it.

By narrowing our focus exclusively on this area, we can understand all the unique challenges such an intricate system presents. Our approach considers various factors like water quality, ecosystem health, and economic considerations for a complete picture.

Our analysis stays strictly within the boundaries of Eskisehir Porsuk Basin; any external factors do not come under scrutiny to concentrate entirely on local dynamics specific only to this particular environment. Such tailored recommendations ensure effective solutions based solely upon contextualized data gathered from extensive research efforts made through precise parameters defined.

Our model is designed to specifically address the effects of discharging treated wastewater into the river, which has significant environmental implications. While we acknowledge that other factors, such as groundwater considerations, may also impact the basin, our current analysis does not include them.

It is important to note that our research currently prioritizes environmental and ecological aspects over financial ones. We haven't assigned any costs related to implementing a new system for treating wastewater discharge yet so that we can evaluate potential benefits and drawbacks without being influenced by financial constraints.

Ultimately, our goal is to comprehensively understand economic and environmental impacts within the Eskisehir Porsuk basin. Focusing on this region's unique challenges and opportunities, we aim to offer tailored insights and recommendations based on thorough analysis.

5.1 Demands and River Flow Rates

Water is an invaluable asset that holds an essential place in households, factories, businesses, and farmers' lives. Each group's water needs differ depending on location, weather conditions, and population size. Effective management strategies can play a crucial role in reducing the overall demand for this precious resource.

In this section specifically designed to meet our needs in the Eskishehir region, we analyze the requirements of diverse consumers and monitor the river's flow rate from its starting point while examining unreturned and unaccounted rates concerning processed wastewater reuse across sectors. The amount of wastewater produced depends upon numerous factors, including population size and activity types being conducted, efficient use of water usage practices, and availability of technologies designed to conserve it.

Residential wastewater mainly stems from household activities like cooking, bathing, and laundry, while industrial areas typically generate wastewater through manufacturing processes, cooling systems, and other industrial activities. Weather conditions also influence wastewater production; periods of heavy rainfall can increase runoff volumes of wastewater production.

Leakage, illegal connections, and operation and maintenance practices all affect how much-unaccounted water exists - leakages within distribution systems cause water loss, contributing to this total amount. Overall, its production depends on many technical, operational, and administrative considerations that combine to create unaccounted volumes of unaccounted water.

Table 5.1 Demands and river flow rates [58], [59]

	Model Parameters
$Demand_{Agriculture}$	3.16 (m^3/s)
$Demand_{Industry}$	0.185 (m^3/s)
$Demand_{Urban}$	1.35 (m^3/s)
$Demand_{Park}$	0.76 (m^3/s)
$FlowRate_{Start}$	6.41 (m^3/s)
$Unreturn_{Urban}$	0.2 (m^3/s)
$Unaccountable_{Start}$	0.25 (m^3/s)
$Wastewater$	1.21 (m^3/s)

5.2 Water Quality Index

The water quality index is a crucial indicator that enables us to assess the condition and standard of our precious resources. The criteria for establishing these benchmarks are multifaceted, encompassing biological markers, habitat excellence, land usage practices, and overall water status. Determining such standards requires a range of data sources, including pH levels, temperature readings, or nutrient concentrations; in addition to this, information on pollutants present within the body of water being evaluated may also be considered.

Furthermore, other variables like species diversity or riverbed physical integrity might be during this evaluation process. We must consistently monitor our rivers by collecting relevant data that can help identify potential problems requiring attention while assessing their health status. Doing so ensures proper management and protection measures are put in place, thus safeguarding one of nature's most valuable resources.

Chemical Oxygen Demand (COD) measures the indicated pollution and helps determine the quality of wastewater treatment processes' quality. As recommended by World Health Organization (WHO) for drinking water applications and the US Environmental Protection Agency discharge into surface waters. The World Health Organization recommends an acceptable COD value not exceeding 125 mg/L, while U.S.EPA sets its maximum acceptable limit at 250 mg/L, respectively.

Total Phosphorus (TP) and Total Nitrogen (TN), essential plant nutrients, are regularly measured to monitor aquatic ecosystem health. Total TP refers to all forms of phosphate present in water samples, while Total Nitrogen refers to all forms of nitrogen present; both serve as important indicators of whether an aquatic body has become polluted with excess nutrients that lead to problems like increased aquatic plant growth, and reduced levels of dissolved oxygen in its ecosystems.

Dissolved oxygen (DO) is a crucial factor in maintaining the health and vitality of aquatic life. Without sufficient dissolved oxygen levels, plants and animals that rely on it to survive will struggle to grow and thrive.

According to WHO recommendations, at least 6 mg/L levels should be maintained to ensure good quality drinking water with minimal pipe corrosion concerns. Inadequate amounts could lead to harmful bacteria growth, which may cause illnesses if consumed by humans. It's essential not only for human consumption but also when discharging wastewater into rivers where different sectors have established their standards regarding acceptable levels depending on their specific needs.

Table 5.2 Water Quality Index [58], [59]

	$Quality_{Start}$	$QualityIndustry_D$	$QualityUrban_D$	$Quality_{End}$
Chemical Oxygen Demand (COD)	50 (mg/L)	250 (mg/L)	125 (mg/L)	>50 (mg/L)
Total Phosphorus (TP)	0.2 (mg/L)	2 (mg/L)	1 (mg/L)	>0.2 (mg/L)
Total Nitrogen (TN)	11.5 (mg/L)	37.5 (mg/L)	10 (mg/L)	>11.5(mg/L)
Dissolved Oxygen (DO)	6 (mg/L)	2 (mg/L)	2 (mg/L)	<6 (mg/L)

5.3 The Net Cost

The expenses for water distribution with operation and upkeep extend beyond simply building and maintaining infrastructure such as reservoirs, pipelines, and treatment plants. It also encompasses staffing these facilities and procuring water from external sources through means like purchasing or transporting rights. The costs can fluctuate based on various factors, including location, size of management systems involved in the process, and accessibility of available water resources, not forgetting government funding.

To accurately determine the Net Costs, assessing all ongoing expenses related to managing and preserving your project or asset is crucial. This entails identifying each O&M expense and breaking it into yearly expenditures while accounting for inflationary factors and price fluctuations. We must also consider your project's and asset's lifespan when calculating its present value over time. Accurately determining operational and maintenance expenses requires careful consideration regarding various aspects, such as annual costing breakdowns adjusted for inflation rates and pricing shifts throughout periods spanning from initiation to completion date- while keeping track via regular reviews, ensuring estimates always remain relevant.

It is important to note that excluding agricultural and industrial revenues and environmental benefits from Equation (3.10) was a deliberate decision made for illustrative purposes only. This reflects the inherent complexities involved in accurately measuring these values within our system. We acknowledge that precise calculation is challenging given their unique nature by explicitly stating zero revenue from these sources in the equation. Therefore, it should not be seen as a weakness but rather an acknowledgment of reality - one which underscores how we take precision when quantifying data related to agriculture and industry while also recognizing limitations associated with such calculations.

It is imperative to conduct a cost-benefit analysis when considering implementing circular economy practices for wastewater allocation across various sectors. This entails evaluating the expenses and advantages associated with different treatment and reuse options and assessing their potential economic and environmental impacts.

The costs involved may comprise capital investments required to upgrade or maintain existing wastewater infrastructure, operational expenditures incurred in treating water effectively, and transportation charges related to distributing treated wastewater among multiple industries. Meanwhile, benefits could include reducing freshwater demand by utilizing recycled resources efficiently and increasing access to non-potable water sources. Moreover, some opportunities can be explored concerning generating revenue streams from selling treated effluent waste products generated during industrial processes, which would otherwise go unused into other markets such as agriculture or energy production facilities - making it an economically viable option.

When considering implementing circular economy practices in wastewater treatment systems, conducting a comprehensive cost-benefit analysis that considers potential environmental impacts is crucial. This includes examining energy consumption and emissions associated with wastewater distribution and treatment and evaluating any possible effects on water quality or ecosystem health. In addition to these factors, social implications such as public acceptance, community involvement, and stakeholder participation must also be considered.

To accurately assess costs related to implementing circular economy principles for treated wastewater management within sewage plants, initial capital expenses like equipment purchases and labor charges should be considered along with operating expenditures, including chemical usage fees and utility bills required for daily operations. In contrast, maintenance costs will cover repairs and replacements needed over time.

Wastewater treatment systems offer many advantages, including enhanced water quality, reduced environmental pollution, and improved public health. These systems are designed to eliminate harmful pollutants and pathogens that could otherwise contaminate our precious water sources or harm aquatic ecosystems. By treating wastewater before discharging, it into the environment, we can ensure clean drinking water for human consumption and agricultural use while reducing the risk of potentially deadly illnesses. Furthermore, investing in wastewater treatment facilities can create jobs within local communities, supporting economic development. Industries such as fisheries and tourism rely on clean waters, which these facilities help provide by minimizing pollution levels.

To determine whether an investment in a new system is economically feasible or whether upgrading existing ones would be more beneficial, decision-makers should employ cost-benefit analysis methods when assessing potential projects related to waste-water management solutions. This approach allows them to weigh costs against benefits to make informed decisions about sustainable investments with positive returns, contributing towards long-term growth strategies for their region's prosperity.

Several things will impact the total cost of the treated wastewater pipes: material used in construction (such as PVC), pipe size needed based on project requirements, and installation method chosen by contractors and engineers working alongside local regulations, which may affect pricing too. To get an accurate estimate tailored directly towards our needs, we recommend consulting experts, whether a contractor or engineer familiar with your area's specific rules around piping projects.

Installing a pump and excavating the site for its installation are critical steps in ensuring the optimal performance of the pump. The process involves various stages, including preparing the site, excavation work, footing preparation, and installing the pump itself, followed by backfilling and grading before testing it to ensure proper functioning. Properly installed pumps operate efficiently, while safe excavation provides stability during operation.

As part of our data collection process, we conduct numerous meetings to gather crucial information on the distance between wastewater treatment plants and their end users. This factor is influenced by various elements, such as local regulations and environmental considerations, that impact the safe and efficient use of treated wastewater in agricultural or industrial settings. To ensure adherence to relevant laws and best practices, we must consult with key stakeholders, including local authorities, environmental agencies, and industry experts.

To account solely for the earning power of money without being affected by inflation or other external forces on cash flow projections, we use a discount rate (i) free from any inflationary influences when evaluating project feasibility based purely on the time value of money principles.

It is imperative to acknowledge that the future purchasing power of money can be drastically impacted by inflation, which is often present in real-world scenarios.

Unfortunately, many individuals solely focus on the time value of money and the expected return on investment without considering this crucial factor. However, it is essential to recognize that ignoring inflation could lead to inaccurate evaluations regarding a project's earning potential and profitability.

Therefore, when analyzing investments or projects where inflation isn't significant or explicitly excluded from consideration, an "inflation-free" discount rate may suffice for evaluating its earning capacity based purely on the concept of the time value of money. Nonetheless, one must not overlook how vital accounting for possible changes in currency values over time is as they play a pivotal role in determining long-term processes.

Example:

$$PV_A = \frac{(OMCost_A)}{0.25}$$

When it comes to our system for distributing treated wastewater among different sectors, it the importance to consider the discount rate used in estimating project value. This crucial number represents the minimum required to return or opportunity cost of capital when investing in wastewater treatment and allocation.

Choosing an appropriate discount rate requires careful thought regarding factors such as investment risk profile, market conditions, and expected investor returns. Our analysis has settled on a 25% arbitrary figure within our designed system for illustration purposes.

While some subjectivity is involved with selecting a specific discount rate, this percentage reflects what's assumed to be necessary for achieving desired rates of return on investments made into water distribution projects like ours. It is difficult to give an exact discount rate for any project since it varies based on multiple factors unique to each situation.

The risk profile of the project, current interest rates, inflation expectations, market conditions, and the opportunity cost of capital all significantly impact determining the appropriate discount rate. Individual circumstances can affect which exact figures are chosen; therefore, seeking advice from domain experts alongside financial analysts could provide valuable insights into determining applicable discount rates tailored explicitly toward a unique situation. We have collated all findings from these multiple meetings and some recourses, which are outlined below:

Table 5.3 Different pipes and pumps and their prices [60], [61]

	Agriculture	**Organized Industrial Zone**	**Recreational irrigation**
Pipe Type	Corrugated Drainage Pipes (HDPE)*	Corrugated Drainage Pipes (HDPE)*	Corrugated Drainage Pipes (HDPE)*
Pipe Cost (EUR/KM)	4.750	1.890	4.750
Distance (KM)	3	5.3	12
Pump/Installation Price (EUR)	990	680	1100
Excavation (EUR)	5434.14	1015.41	5016.15

*(HDPE: High Density Polyethylene)

To ensure the safety of our water sources, we must follow recommended guidelines when using treated wastewater in agriculture. Experts suggest a minimum distance of 50 to 100 meters from treatment plants and nearby wells or streams. However, for optimal protection against contamination, this study recommends sending treated wastewater at least three kilometers away from agricultural regions.

Our data collection may not provide exact figures, but it offers a reliable estimate based on meticulous calculations. Our estimations result from an analysis considering regulatory requirements, environmental factors, infrastructure availability, and end-user need. These guidelines are valuable tools to promote sustainable practices when managing wastewater resources.

Following these recommendations, we can encourage responsible farming techniques that optimize treated wastewater usage while maintaining public health standards. Sustainable agriculture is all about utilizing natural resources efficiently and responsibly - water being one of them. The distance between treatment plants and agricultural users must be carefully balanced so that irrigation with treated wastewater benefits crops without harming our environment's well-being.

Recommended distances may vary depending on industry type and the nature of wastewater being produced; a minimum distance of 200 meters from a treatment plant and 100 meters from any water source should always be observed.

It is important to note that regulations regarding these distances can differ between jurisdictions. Local health or environmental agencies may regulate minimum distances in some areas - compliance with such restrictions must not be overlooked as they are put in place precisely to minimize potential negative impacts on our surroundings.

5.4 Alternatives Generated Using Mixture Design of Experiments

Our objective is to identify the ideal distribution of treated wastewater across all four components linked together. To accomplish this, we have developed 16 alternatives, as depicted in Table 5.4, utilizing a combination design experiment incorporating extreme vertices methodology.

This approach enables us to make decisions for resource allocation based on sustainability goals while simultaneously considering economic and environmental impacts. By optimizing our resources through this method, we can achieve long-term sustainability objectives without sacrificing quality or quantity requirements throughout each stage of the process chain. Therefore, it is essential to adopt such an innovative technique to efficiently utilize available resources while ensuring sustainable management practices at every level possible.

Table 5.4 Generated Alternatives

Alternatives	Agriculture	Industries	Parks	Discharge
1	0	0	0.6	0.4
2	0	0.15	0.6	0.25
3	0.9	0	0	0.1
4	0.75	0.15	0	0.1
5	0.3	0	0.6	0.1
6	0.15	0.15	0.6	0.1
7	0	0	0.1	0.9
8	0.1	0	0	0.9
9	0	0.15	0.1	0.75
10	0.1	0.15	0	0.75
11	0.23	0.075	0.26	0.435
12	0.115	0.1125	0.43	0.3425
13	0.565	0.0375	0.13	0.2675
14	0.19	0.1125	0.43	0.2675
15	0.115	0.0375	0.18	0.6675
16	0.165	0.1125	0.13	0.5925

We must assess the outcomes of various alternatives generated by our mixture design experiment to determine the optimal water allocation between sectors following our objectives. We must thoroughly evaluate each option's feasibility once a range of alternatives has been produced. For example, if only a tiny amount of water is discharged into a river within one alternative, it may eventually dry up. We create 21 distinct alternatives by concluding through Chapter 3 constraints calculations that five alternatives were not feasible for achieving desired results within this project. Table 5.1 shows agriculture demand is 3.16 $\left(m^3/_s\right)$, which exceeds treated wastewater capacity at just $1.21\ (m^3/_s)$. We can send 100% of the available treated wastewater. We determine the demand for water required by each sector and the amount of treated wastewater from Table 5.1. Now we have the maximum range of sending the treated wastewater to these sectors according to their demands and the available treated wastewater in the wastewater treatment plant in Eskisehir.

Acknowledging that groundwater has already been utilized as a freshwater source in certain industrial and agricultural settings is essential. Therefore, diverting treated wastewater for alternative uses in these cases may not be necessary. However, when deciding which sectors should receive the allocated treated wastewater, careful consideration must be given to existing groundwater usage and its potential impact on future studies and allocation ratios.

A comprehensive evaluation of this matter is crucial to ensure effective resource management. By considering each sector's respective ranges of utilization along with environmental protection concerns and public health considerations, stakeholders can make informed decisions regarding the allocation of treated wastewater while striking an optimal balance between sustainable resource use. Our four sectors and their ranges are:

$$0 \leq P_{Agriculture} \leq 1$$
$$0 \leq P_{Industry} \leq 0.15$$
$$0 \leq P_{Park} \leq 0.62$$
$$0.1 \leq P_{Discharge} \leq 1$$

In every industry, specific acceptable values determine how treated wastewater is allocated and released. When discharging this water into rivers, a minimum of 0.1 percent must be released to maintain the river's flow rate at its endpoint. This release is crucial as severe environmental damage would occur without it, leading to an inability for downstream communities' water demands.

Releasing a small percentage of treated wastewater into the river system using Minitab software helps sustain aquatic life while maintaining proper ecosystem health levels by preventing stagnation in these watersheds. The program also optimizes allocation based on identified sector ranges, so we make decisions about resource management with thorough analysis considering various factors such as infrastructure limitations or stakeholder needs.

Chapter 3 of the resource provided is invaluable for those seeking to generate alternatives and make informed decisions. It offers a comprehensive guide on utilizing Design of Experiments (DOE) techniques in conjunction with extreme vertices methodology, enabling decision-makers to create alternative scenarios tailored towards effective resource management.

One critical element when making essential decisions involves determining the flow rate at the river's endpoint while considering allocated percentages of treated wastewater across various sectors. Equation (3.8) comes into play to assess this vital aspect effectively as it takes specific percentage allocations into account and calculates resulting flow rates accurately. By manipulating these values using different input data sets through calculations based on this equation, one can evaluate multiple scenarios' impact on water quality levels within rivers before implementation. Moreover, another tool used by decision-makers includes Equation (3.9), designed explicitly for assessing discharging treated wastewater impacts onto a given body of water- including its composition capacity limits -and environmental standards compliance considerations such as regulatory requirements or other relevant factors affecting overall outcomes positively or negatively depending upon their inputs.

5.5 The Decision Matrix

To determine the most suitable option in a decision matrix, assessing how effectively each alternative fulfills every criterion is imperative. To construct the decision matrix, we must evaluate all criteria for each available option. This will enable us to assign a value indicating which alternative performs optimally based on its relative importance and adherence to established standards. After generating the 16 alternatives, we calculate each criterion for all alternatives using the defined constraints in Chapter 3. An example is shown below.

To calculate the value of Water Withdraws for alternative 1, we use the values as given in Table 5.1; we know the $Demand_{Urban} = 1.35\ (m^3/s)$, $Demand_{Park}$= $0.76\ (m^3/s)$, and $Wastewater = 1.21\ (m^3/s)$.

After generating the alternatives, in alternative 1, we observe that 0.6 % of the treated wastewater will be sent to the parks for recreational purposes. Using Equation (3.7), we have the withdrawal amount for the first alternative.

$$Withdraw_{Water} =$$

$$Demand_{Urban} + Demand_{Park} - (P_{Park} * Wastewater)$$

For Alternative 1:

$$1.35 + 0.76 - (0.6 \times 1.21) = 1.384$$

To properly evaluate the effectiveness of our options, we conduct calculations for all criteria identified in the decision-making process. These equations can be found in Chapter 3 of our resource and are used to assess each criterion individually. Utilizing these results creates a comprehensive decision matrix that allows us to compare and rank alternatives based on their suitability towards achieving desired outcomes. This tool provides an overview across multiple criteria so that informed decisions can be made confidently.

Table 5.5 provides additional details about generated alternatives and necessary equations from Chapter 3 for calculating performance metrics associated with each evaluated criterion. This table ensures clarity throughout the assessment process, with columns representing different choices and rows outlining specific evaluation factors.

Table 5.5 The Decision Matrix

Alternatives	Withdraw	Flowrate	Quality	Cost(K)
1	1.384	5.244	7.625	61,593
2	1.384	5.062	7.827	63,274
3	2.115	3.973	9.880	30,673
4	2.115	3.973	9.880	32,819
5	1.384	4.881	8.043	92,936
6	1.384	4.881	8.043	96,425
7	1.989	5.092	8.089	61,593
8	2.117	4.941	8.337	30,673
9	1.989	4.911	8.314	96,425
10	2.117	4.763	8.578	32,819
11	1.795	4.772	8.397	96,425
12	1.589	4.917	8.103	96,425
13	1.952	4.372	9.071	96,425
14	1,589	4.826	8.218	96,425
15	1.892	4.932	8.238	96,425
16	1.952	4.766	8.487	96,425

Once the decision matrix has been generated and performance values have been obtained for each alternative across various criteria, it is crucial to assign numerical values that accurately reflect how well each option meets its corresponding criterion. These numeric indicators serve as a means of quantifying satisfaction or alignment with desired outcomes.

An interval decision matrix is used to account for uncertainties and variations in evaluating alternatives based on different criteria. This analytical tool incorporates uncertainty by considering ranges or intervals instead of precise figures when assessing options against individual standards. The interval decision matrix helps address potential uncertainties from incomplete data sets, subjective judgments made during evaluations, or inherent variability associated with complex systems.

Utilizing intervals rather than fixed numbers throughout assessments using this model allows those responsible for making choices to capture all possible results related to specific benchmarks under consideration. Such an approach acknowledges existing ambiguities while enabling more robust evaluation methods leading toward comprehensive solutions being identified efficiently.

It is important to mention that in this study we recognizes the discount rate as an essential factor with potential sensitivity implications. Our research objectives and constraints require us to focus our analysis on other identified variables. By narrowing down the scope of our sensitivity analysis in this way, we can effectively explore how these selected parameters influence the outcomes of our research. However, it's worth noting that conducting a comprehensive sensitivity analysis that encompasses all uncertain factors - including the discount rate - could provide us with even more valuable insights into variations in these parameters and their impact on findings.

Despite its limitations compared to broader analyses, such an approach allows for deeper examination within defined contexts while contributing significant value toward understanding specific variables' sensitivities. Future studies should consider expanding upon what was done here by broadening their range of analyzed parameter sets (including those previously mentioned) so they can achieve greater comprehensiveness and robustness when interpreting results.

5.6 The Decision Matrix with Interval Numbers

The interval decision matrix incorporates interval data with lower and upper limits, allowing you to evaluate alternatives based on a range of values rather than just one point estimate. This approach systematically explores multiple possibilities instead of just one option by quantifying uncertainty through tolerance of error limits for each criterion.

Error limits have been established to ensure accuracy and account for any uncertainties or variations in the evaluation process. These limits indicate an acceptable deviation range from best estimates for each criterion and can be expressed as a percentage, range, or specific value depending on the research needs. To maintain consistency with these guidelines, experts have determined that all criteria should allow for a potential deviation of up to 20% from their best estimate values. This margin provides ample flexibility while acknowledging inherent uncertainties within evaluations.

The interval decision matrix is calculated using these error margins across all generated alternatives. By incorporating such measures into our analysis, we can reflect uncertainty accurately throughout our findings. Table 5.6 displays this information clearly by illustrating how each alternative performs against defined criteria while remaining within set boundaries.

Table 5.6 The decision matrix with interval numbers

Alternatives	**Withdraw**	**Flowrate**	**Quality**	**Cost(K)**
1	[1.11,1.66]	[4.20,6.29]	[6.10,9.15]	[49,73]
2	[1.11,1.66]	[4.05,6.08]	[6.26,9.39]	[50,75]
3	[1.69,2.53]	[3.18,4.77]	[7.90,11.86]	[24,36]
4	[1.69,2.53]	[3.18,4.77]	[7.90,11.86]	[26,39]
5	[1.11,1.66]	[3.90,5.86]	[6.44,9.65]	[74,111]
6	[1.11,1.66]	[3.90,5.86]	[6.44,9.65]	[77,115]
7	[1.59,2.39]	[4.07,6.11]	[6.47,9.71]	[49,73]
8	[1.69,2.53]	[3.95,5.93]	[6.67,10]	[24,36]
9	[1.59,2.39]	[3.93,5.89]	[6.65,9.98]	[77,115]
10	[1.69,2.53]	[3.81,5.71]	[6.86,10.29]	[26,39]
11	[1.44,2.15]	[3.82,5.73]	[6.72,10.08]	[77,115]
12	[1.27,1.91]	[3.93,5.90]	[6.48,9.72]	[77,115]
13	[1.56,2.34]	[3.50,5.25]	[7.26,10.89]	[77,115]
14	[1.27,1.91]	[3.86,5.79]	[6.57,9.86]	[77,115]
15	[1.51,2.27]	[3.95,5.92]	[6.59,9.89]	[77,115]
16	[1,56,2.34]	[3.81,5.72]	[6.79,10.19]	[77,115]

It is imperative to prioritize alternatives using a decision matrix that integrates interval values. We employ the Extended VIKOR method to achieve this and assign equal weightage to each criterion. This approach enables us to rank our options effectively and make informed decisions while ensuring optimal outcomes are consistently achieved.

5.7 The Extended VIKOR Method

First, we define our four criteria and generate different alternatives. Then we create the decision matrix with an interval number. The step of the Extended VIKOR method is mentioned in Chapter 2. Briefly, we normalize our decision matrix to ensure the value of all criteria in our decision-making process and divide each matrix element by its corresponding column's maximum value. Then we assign weights to criteria to determine the relative importance of every criterion using various methods such as expert judgment or pairwise comparison. In this thesis, we prefer to assign equal weights. The next step is to calculate the weighted normalized decision matrix; we multiply each element with its respective weight. The detailed calculation is given in Appendix A. The Extended VIKOR is applied; the results are shown in Table 5.7.

Table 5.7 Results of Extended VIKOR

Alternatives	$[S^L, S^U]$	$[R^L, R^U]$	$[Q^L, Q^U]$	Ranking
1	[0.07,0.48]	[0.07,0.15]	[0.00,0.47]	**1**
2	[0.10,0.51]	[0.07,0.16]	[0.03,0.53]	**2**
3	[0.37,0.78]	[0.15,0.25]	[0.41,0.94]	**8**
4	[0.37,0.79]	[0.15,0.25]	[0.42,0.94]	**10**
5	[0.19,0.63]	[0.15,0.25]	[0.26,0.81]	**6**
6	[0.20,0.65]	[0.14,0.24]	[0.29,0.85]	**7**
7	[0.23,0.67]	[0.13,0.22]	[0.26,0.78]	**3**
8	[0.21,0.63]	[0.15,0.25]	[0.32,0.84]	**4**
9	[0.33,0.81]	[0.14,0.25]	[0.37,0.96]	**13**
10	[0.24,0.66]	[0.15,0.22]	[0.34,0.86]	**5**
11	[0.31,0.78]	[0.14,0.25]	[0.36,0.93]	**12**
12	[0.24,0.70]	[0.14,0.25]	[0.31,0.89]	**9**
13	[0.41,0.89]	[0.14,0.25]	[0.42,1.00]	**15**
14	[0.25,0.71]	[0.14,0.25]	[0.32,0.89]	**11**
15	[0.31,0.78]	[0.14,0.25]	[0.36,0.94]	**12**
16	[0.34,0.82]	[0.14,0.25]	[0.38,0.96]	**14**

Based on the analysis using equal weights for all criteria, Table 5.7 reveals that alternatives one, two, and seven are the most favorable options. Upon further examination of Table 5.4, it was discovered that these three alternatives share a commonality, they involve sending treated wastewater to parks with discharge into rivers as their destination point. However, alternative seven stands out because only a fraction of water is directed toward industries.

We explored various options to manage treated wastewater, and it appears that alternative 13 is not preferred, which involves sending the highest percentage of water to agriculture and industries. This could be attributed to many factors, such as increased transportation costs, pre-treatment requirements for the water, and potential environmental consequences leading to decreased river flow rates.

However, we identify alternatives that may prove more cost-effective or environmentally sound. These include discharging the wastewater into the river or repurposing it for different uses. Our ranking system considers operational expenses like maintenance costs associated with pumping and piping systems required for pre-treatment procedures and construction work transporting waste products to agricultural areas.

The VIKOR method provides a formula for calculating individual regret values, which involves determining each alternative's distance from the ideal and anti-ideal solutions. This has been done by computing the absolute difference between an alternative's performance score and its best or worst criterion.

We conducted a sensitivity analysis to identify potential weaknesses and limitations in decision-making by testing them under different scenarios. Consequently, incorporating a sensitivity analysis into the Extended VIKOR method enhances its effectiveness as a decision-making tool by providing more insights into how other inputs might affect outcomes under various circumstances.

5.8 Sensitivity Analysis

A sensitivity analysis is applied to the Extended VIKOR for equal and modified weights to see the effect of different weightings. Results are obtained for different weight settings. A similar weighting strategy is adopted from [57], which is mentioned in Chapter 4 with details.

We modified the weights as given in Equation (4.3); we have equal weights for our four criteria. $w_1 = w_2 = w_3 = w_4 = 0.25$ and $\lambda = 0.2$. Then,

$$w_1' = 0.2 \times 0.25 = 0.05$$

$$\varphi = \frac{1 - 0.5}{1 - 0.25} = 1.27 \quad w_2' = w_3' = w_4' = 1.27 \times 0.25 = 0.32$$

Table 5.8 displays the modified weights for the Withdrawal criterion while maintaining the other three criteria as equally weighted. This calculation is applied to all four criteria to conduct a sensitivity analysis.

Table 5.8 The Modified Weights

λ	Withdraw	Flow rate	Quality	Cost	φ
0	0.00	0.33	0.33	0.33	1.33
0.1	0.03	0.33	0.33	0.33	1.30
0.2	0.05	0.32	0.32	0.32	1.27
0.3	0.08	0.31	0.31	0.31	1.23
0.4	0.10	0.30	0.30	0.30	1.20
0.5	0.13	0.29	0.29	0.29	1.17
0.6	0.15	0.28	0.28	0.28	1.13
0.7	0.18	0.28	0.28	0.28	1.10
0.8	0.20	0.27	0.27	0.27	1.07
0.9	0.23	0.26	0.26	0.26	1.03
1	0.25	0.25	0.25	0.25	1.00

To determine the relative importance of each criterion in decision-making, one-way sensitivity analysis is utilized by changing the weight of a single criterion while keeping all others constant. This method allows for identifying which criteria impact outcomes most. It is possible to determine how much each factor contributes to overall decisions and highlight those with more significant influence over results [62].

Despite using four criteria in the decision-making process, altering the weights for River Flow Rate, Water Quality Index, and Cost of Operation and Maintenance did not affect the ranking of the alternatives. However, changing the weight of the criterion for Withdrawing Water (amount) did impact the ranking. Alternative 8 became the most favorable option for lower weights, which involved discharging 0.9% of treated wastewater into the river and sending 0.1% for agriculture. Alternative 1 was the best option for higher weights for Withdrawing Water which involved withdrawing less water from the river and sending the treated wastewater for recreational and irrigation purposes in parks. This indicates that Withdrawing Water (amount) is an important criterion affecting the ranking of alternatives. For those criteria that didn't affect the ranking of the alternative, it may indicate that the differences in performance between the alternatives are significant enough that the relative ranking remains consistent even if the weights are varied.

One-at-a-time sensitivity analysis has limitations, as it does not account for potential interactions between criteria or capture every possible outcome. More advanced techniques like multi-dimensional or probabilistic sensitivity analyses can be used to overcome these limitations. The factorial design of experiments is a statistical tool that allows for the simultaneous variation of multiple factors to determine their individual and interactive effects on the response variable. This method proves especially useful in sensitivity analysis, where it can evaluate how changes in several input parameters impact the response variable.

Conducting sensitivity analysis is essential for ensuring the robustness and reliability of decision-making processes. This can be achieved through various approaches, such as modifying discount rates, adjusting criteria weights, or including environmental benefits in the evaluation process. These analyses allow one to examine subjective sensitivities and other factors influencing outcomes. By conducting sensitivity analysis, we can gain valuable insights into potential risks and uncertainties associated with the decisions while also identifying opportunities for improvement in future evaluations.

Utilizing such comprehensive methods when conducting scientific research studies involving sensitive variables with numerous contributing factors simultaneously, we can gain invaluable insight into complex systems' behavior patterns while minimizing errors caused by oversimplification or incomplete data sets. It is crucial to consider the preferences of stakeholders and decision-makers in determining the importance of each criterion, and it may be necessary for different groups of decision-makers to have different weights for each criterion based on their desired outcomes.

Incorporating the preferences of all stakeholders is a step in any decision-making process. To ensure fairness and inclusivity, it is crucial to consider input from various groups with different perspectives and priorities. We can assign appropriate weights to each criterion based on their relative significance according to stakeholder opinions. Other groups may have varying levels of expertise or desired outcomes that influence how they view specific criteria. Incorporating these diverse viewpoints leads to more comprehensive evaluations that account for broader considerations.

Assigning unique weights allows us to evaluate alternatives more thoroughly while considering the needs and perspectives of everyone involved in the decision-making process. And even if some criteria don't significantly affect rankings, this observation highlights substantial performance differences between options, ensuring consistency regardless of weight variations.

CHAPTER 6

CONCLUSION AND FUTURE WORK

This research project aimed to create a circular economy model for allocating the treated wastewater in a specific area of the Porsuk basin in Eskisehir. The study analyzed various circular economy indicators from existing literature before beginning fieldwork with a project team. Four indicators were chosen for evaluation based on the availability of data and the situation in the study region, River Flow Rate, Water Quality Index, Withdrawing Water (amount), and Net Cost. A mixture design of experiments generates different alternatives for allocating water to four sectors: agriculture, industry, parks, and discharging into the river. The study also included constraints to evaluate the feasibility of each alternative, using data obtained from wastewater treatment plants, the agriculture sector, the municipality, literature research, and different reports.

The Extended VIKOR method is a powerful tool for evaluating multiple criteria simultaneously, enabling decision-makers to make informed choices that balance competing interests. This approach considers both the benefits and drawbacks of different water allocation options to achieve optimal sustainability outcomes.

By incorporating various factors such as water availability, sector-specific needs, environmental impacts, and economic considerations into its analysis framework - The Extended VIKOR Method provides an all-encompassing view of allocating resources across sectors while ensuring equitable distribution among stakeholders. Moreover, critical elements that significantly influence alternative selection can be identified through sensitivity analyses conducted during the decision-making process. This allows for valuable insights into potential trade-offs associated with different strategies, which ultimately lead to achieving sustainable solutions aligned with overall goals.

To ensure the reliability and robustness of research findings, conducting a more comprehensive sensitivity analysis is imperative. This critical process involves systematically varying inputs such as criteria weights, discount rates, and environmental benefits, including evaluating potential outcome variations. A thorough approach would require multiple scenarios that assess different parameter values' impact on overall results. Identifying critical drivers through this method will gain insights into the degree of uncertainty associated with the findings while demonstrating stability across plausible scenarios. It is also crucial to consider context-specific factors like economic or political influences that may affect criteria weightings or interpretations of environmental benefits for an accurate assessment. These external factors ensure a reliable evaluation of system performance implications under various circumstances.

Analyzing the treated wastewater management alternatives resulted in identifying alternatives one, two, and seven as the top-performing options. These alternatives involve directing the treated wastewater towards parks and discharging it into the river, with only a small portion allocated for industries in alternative seven. On the other hand, alternative 13, which involves sending the highest percentage of water to agriculture and industries, is considered the least desirable option due to several factors, such as increased transportation costs, additional pre-treatment requirements, and potential negative environmental impacts.

Among the 16 alternatives considered, the first and second options focus on environmental factors by discharging most of the water into the river and using a small portion for recreational purposes in parks. The stakeholders impacted by these decisions should be carefully considered. Currently, the industry and agriculture sectors will likely accept this decision, as they can quickly meet their water demands from groundwater. However, climate change will make this decision unfavorable for them, and they may need to look for different water sources. It's essential to assess the stakeholders impacted by these decisions.

If we allocate treated wastewater for parks, we can reduce the water taken from the river, which requires less treatment, and reduce the cost. These alternatives can enhance the ecosystem and bring about economic benefits regarding the environmental economy. While we did not consider these non-intangible criteria during our evaluation, their inclusion could result in more favorable outcomes for these alternatives.

Apart from the benefits mentioned, it is also essential to acknowledge some drawbacks. Increasing water allocation to agriculture may lead to higher agricultural production, positively impacting the country's economy. Similarly, industries may benefit from increased water allocation by exporting more. However, these two sectors require pre-treatment and additional costs and rely on groundwater as their primary source. Considering the current situation, giving greater importance to environmental factors may be more beneficial.

As mentioned, effectively allocating treated wastewater resources to different sectors requires immediate attention. Once this problem is solved, we use the same approach in various ways to optimize allocation ratios for water resources. Firstly, it is essential to update our criteria regularly based on changes in water availability, demand, or policy priorities to allocate these precious resources effectively and efficiently. For instance, conservation efforts should be prioritized over non-essential uses during droughts or other emergencies with limited clean drinking water supplies.

We propose allocating treated wastewater by integrating environmental benefits as an evaluation criterion. This innovative method enables us to consider the positive impact of reducing groundwater dependence, which is critical for preserving our environment. Proper allocation can significantly benefit the ecosystem and contribute towards sustainable management practices.

By decreasing reliance on groundwater through appropriate water distribution among sectors, we can conserve this valuable resource while mitigating ecological and socio-economic consequences such as land subsidence, water scarcity, or ecosystem degradation. Groundwater depletion has become a growing concern worldwide; hence we must take proactive measures before irreversible damage occurs.

In conclusion, incorporating new criteria into evaluating wastewater treatment projects will help promote environmentally friendly policies leading to long-term sustainability goals. Allocating treated wastewater appropriately amongst different sectors conserves precious resources and ensures their availability for future generations' needs- making it imperative that everyone plays their part in protecting our planet.

We can achieve many positive environmental impacts by using treated wastewater in different sectors. Not only does it provide an alternative water source for irrigation or industrial processes, but it also reduces pollution and nutrient discharge into our precious water bodies. This ultimately leads to improved water quality and aquatic ecosystem protection- all contributing to the overall environmental betterment. Incorporating these environmental benefits when deciding how to allocate treated wastewater is crucial as it highlights our dedication to holistic and sustainable management practices. It showcases our commitment to safeguarding the environment and promoting resource efficiency while striving for long-term balance.

As a future study environmental benefits can be employed as a new criterion in our system to allow its subjective assessment. We recommend the use of Fuzzy VIKOR method to evaluate its impact. By adopting structured frameworks like this, decision-makers can address uncertainties and complexities arising during subjective judgments and environmental assessments.

These methodologies balance multiple criteria while accommodating vagueness and imprecision commonly encountered when evaluating the environment's benefits. It allows for a more comprehensive approach by including revenue and ecological considerations; hence, informed decisions are made toward economic prosperity without compromising sustainability.

It is imperative to assess the potential effects of new policy proposals before implementing them. This approach can save time and money while ensuring that all stakeholders involved in critical infrastructure projects, such as providing access points into public utility systems like municipal sewage treatment plants, achieve optimal outcomes.

To effectively enhance allocation ratios for water resources management, this thesis proposes a technique that continuously updates criteria and monitors performance. By modifying allocation ratios when necessary and evaluating the impacts of any policy changes made along the way - we can efficiently allocate our precious natural resources with sustainability and equity at its core. By adopting these measures moving forward, we can significantly streamline resource distribution processes while safeguarding against negative consequences.

There are numerous ways to enhance this thesis. It would be highly advantageous to explore the involvement of stakeholders such as government entities, industries, and consumers in making pivotal decisions regarding a sustainable future. Furthermore, social and cultural factors significantly impact the adoption of new practices related to circular economies; hence studying them could help integrate those aspects into our decision-making procedures. This can be accomplished through educational programs, public gatherings, and other communication channels that ensure everyone comprehends the significance of this approach while being eager to participate in its implementation process.

The process of establishing criteria weights is a crucial step toward developing circular economy alternatives and maximizing the utilization of wastewater resources. These weightings are essential in determining the significance of various factors or criteria that must be considered while assessing and selecting alternative options. To ensure a comprehensive, unbiased approach to this decision-making process, involving diverse stakeholders is imperative.

Government bodies, industries, and consumers are all critical players who can offer valuable input when deciding on these criterion weights. Government experts bring their policy-making skills to bear on ensuring alignment with environmental objectives as well as public health goals; meanwhile, industry insiders have practical knowledge about specific requirements for operations which enables them to provide insights regarding feasibility and viability considerations such as resource availability, etc. Finally, consumer perspectives cannot be ignored since they represent end-users whose preferences matter incredibly - understanding what drives demand among users helps shape final decisions made by policymakers during selection processes.

Finally, assessing groundwater's influence requires a comprehensive evaluation encompassing its quantity, quality, and recharge rate. Moreover, it is crucial to comprehend the interrelations between surface water and groundwater to utilizing this precious resource efficiently within our water allocation system. Considering this information, investing time and resources into researching these aspects can pave the way for better implementation strategies that will bring us closer to achieving sustainability goals while simultaneously promoting economic growth on a grand scale.

REFERENCES

[1] K. Winans, A. Kendall, and H. Deng, ‘The history and current applications of the circular economy concept’, *Renewable and Sustainable Energy Reviews*, vol. 68. Elsevier Ltd, pp. 825–833, Feb. 01, 2017. doi: 10.1016/j.rser.2016.09.123.

[2] ‘Boulding, K. (1966) The Economics of the Coming Spaceship Earth. In Jarrett, H., Ed., Environmental Quality in a Growing Economy, Resources for the Future/Johns Hopkins University Press, Baltimore, 3-14. - References - Scientific Research Publishing’. https://www.scirp.org/(S(czeh2tfqyw2orz553k1w0r45))/reference/referencespapers.aspx?referenceid=1673862 (accessed Dec. 26, 2022).

[3] ‘Product-Life Factor (Mitchell Prize Winning Paper 1982) | The Product-Life Institute’. http://www.product-life.org/en/major-publications/the-product-life-factor (accessed Jan. 06, 2023).

[4] J. Z. Chen, ‘Material flow and circular economy’, *Syst Res Behav Sci*, vol. 26, no. 2, pp. 269–278, Mar. 2009, doi: 10.1002/sres.968.

[5] B. Su, A. Heshmati, Y. Geng, and X. Yu, ‘A review of the circular economy in China: Moving from rhetoric to implementation’, *J Clean Prod*, vol. 42, pp. 215–227, 2013, doi: 10.1016/j.jclepro.2012.11.020.

[6] Y. Geng, Q. Zhu, B. Doberstein, and T. Fujita, ‘Implementing China’s circular economy concept at the regional level: A review of progress in Dalian, China’, *Waste Management*, vol. 29, no. 2, pp. 996–1002, Feb. 2009, doi: 10.1016/j.wasman.2008.06.036.

[7] L. Becerra, S. Carenzo, and P. Juarez, ‘When circular economy meets inclusive development. Insights from urban recycling and rural water access in Argentina’, *Sustainability (Switzerland)*, vol. 12, no. 23, pp. 1–21, Dec. 2020, doi: 10.3390/su12239809.

[8] F. Zhang, Y. Ju, P. Dong, A. Wang, and E. D. R. Santibanez Gonzalez, ‘Multi-period evaluation and selection of rural wastewater treatment technologies: a case study’, *Environmental Science and Pollution Research*, vol. 27, no. 36, pp. 45897–45910, Dec. 2020, doi: 10.1007/s11356-020-10307-z.

[9] A. De Pascale, R. Arbolino, K. Szopik-Depczyńska, M. Limosani, and G. Ioppolo, ‘A systematic review for measuring circular economy: The 61 indicators’, *J Clean Prod*, vol. 281, Jan. 2021, doi: 10.1016/j.jclepro.2020.124942.

[10] A. J. Balkema, H. A. Preisig, R. Otterpohl, and F. J. D. Lambert, ‘Indicators for the sustainability assessment of wastewater treatment systems’. [Online]. Available: www.elsevier.com/locate/urbwat

[11] M. Preisner *et al.*, ‘Indicators for resource recovery monitoring within the circular economy model implementation in the wastewater sector’, *Journal of Environmental Management*, vol. 304. Academic Press, Feb. 15, 2022. doi: 10.1016/j.jenvman.2021.114261.

[12] S. Poponi, G. Arcese, F. Pacchera, and O. Martucci, ‘Evaluating the transition to the circular economy in the agri-food sector: Selection of indicators’, *Resour Conserv Recycl*, vol. 176, Jan. 2022, doi: 10.1016/j.resconrec.2021.105916.

[13] P. Kerdlap and S. Cornago, ‘Life Cycle Costing: Methodology and Applications in a Circular Economy’, *An Introduction to Circular Economy*, pp. 499–525, 2021, doi: 10.1007/978-981-15-8510-4_25.

[14] M. Ilyas, F. M. Kassa, and M. R. Darun, ‘Life cycle cost analysis of wastewater treatment: A systematic review of literature’, *Journal of Cleaner Production*, vol. 310. Elsevier Ltd, Aug. 10, 2021. doi: 10.1016/j.jclepro.2021.127549.

[15] M. Smol and R. Koneczna, ‘Economic Indicators in Water and Wastewater Sector Contributing to a Circular Economy (CE)’, *Resources*, vol. 10, no. 12, Dec. 2021, doi: 10.3390/resources10120129.

[16] P. Vanegas *et al.*, ‘Ease of disassembly of products to support circular economy strategies’, *Resour Conserv Recycl*, vol. 135, pp. 323–334, Aug. 2018, doi: 10.1016/j.resconrec.2017.06.022.

[17] M. Marconi, M. Germani, M. Mandolini, and C. Favi, ‘Applying data mining technique to disassembly sequence planning: a method to assess effective disassembly time of industrial products’, *Int J Prod Res*, vol. 57, no. 2, pp. 599–623, Jan. 2019, doi: 10.1080/00207543.2018.1472404.

[18] M. Smol and R. Koneczna, ‘Economic Indicators in Water and Wastewater Sector Contributing to a Circular Economy (CE)’, *Resources*, vol. 10, no. 12, Dec. 2021, doi: 10.3390/resources10120129.

[19] M. Ghafourian, C. E. Nika, A. Mousavi, E. Mino, M. Al-Salehi, and E. Katsou, ‘Economic impact assessment indicators of circular economy in a decentralised circular water system — Case of eco-touristic facility’, *Science of the Total Environment*, vol. 822, May 2022, doi: 10.1016/j.scitotenv.2022.153602.

[20] M. Djukic, I. Jovanoski, O. M. Ivanovic, M. Lazic, and D. Bodroza, ‘Cost-benefit analysis of an infrastructure project and a cost-reflective tariff: A case study for investment in wastewater treatment plant in Serbia’, *Renewable and Sustainable Energy Reviews*, vol. 59. Elsevier Ltd, pp. 1419–1425, Jun. 01, 2016. doi: 10.1016/j.rser.2016.01.050.

[21] S. Gigli, D. Landi, and M. Germani, ‘Cost-benefit analysis of a circular economy project: a study on a recycling system for end-of-life tyres’, *J Clean Prod*, vol. 229, pp. 680–694, Aug. 2019, doi: 10.1016/j.jclepro.2019.03.223.

[22] G. Moraga *et al.*, 'Circular economy indicators: What do they measure?', *Resour Conserv Recycl*, vol. 146, pp. 452–461, Jul. 2019, doi: 10.1016/j.resconrec.2019.03.045.

[23] H. A. Verfaillie, 'World Business Council for Sustainable Development eco-efficiency measuring a guide to reporting company performance'.

[24] Z. Wen and R. Li, 'Materials metabolism analysis of China's highway traffic system (HTS) for promoting circular economy', *J Ind Ecol*, vol. 14, no. 4, pp. 641–649, Aug. 2010, doi: 10.1111/j.1530-9290.2010.00263.x.

[25] E. Franklin-Johnson, F. Figge, and L. Canning, 'Resource duration as a managerial indicator for Circular Economy performance', *J Clean Prod*, vol. 133, pp. 589–598, Oct. 2016, doi: 10.1016/j.jclepro.2016.05.023.

[26] S. Huysman *et al.*, 'The recyclability benefit rate of closed-loop and open-loop systems: A case study on plastic recycling in Flanders', *Resour Conserv Recycl*, vol. 101, pp. 53–60, Jun. 2015, doi: 10.1016/j.resconrec.2015.05.014.

[27] Y. Riahi, 'Project Stakeholders: Analysis and Management Processes', 2017. [Online]. Available: www.internationaljournalssrg.org

[28] M. H. Aydogdu, B. Karli, M. Aydogdu, and M. H. Aydogdu, 'Evaluation of attitudes of stakeholders for irrigation water management: A case study of Harran Plain, Turkey', 2015.

[29] M. Starkl, N. Brunner, W. Flögl, and J. Wimmer, 'Design of an institutional decision-making process: The case of urban water management', *J Environ Manage*, vol. 90, no. 2, pp. 1030–1042, Feb. 2009, doi: 10.1016/j.jenvman.2008.03.012.

[30] E. Comino, M. Bottero, S. Pomarico, and M. Rosso, 'The combined use of Spatial Multicriteria Evaluation and stakeholders analysis for supporting the ecological planning of a river basin', *Land use policy*, vol. 58, pp. 183–195, Dec. 2016, doi: 10.1016/j.landusepol.2016.07.026.

[31] P. Reichert *et al.*, 'Concepts of decision support for river rehabilitation', *Environmental Modelling and Software*, vol. 22, no. 2, pp. 188–201, Feb. 2007, doi: 10.1016/j.envsoft.2005.07.017.

[32] M. H. Jacobs and A. E. Buijs, 'Understanding stakeholders' attitudes toward water management interventions: Role of place meanings', *Water Resour Res*, vol. 47, no. 1, 2011, doi: 10.1029/2009WR008366.

[33] J. Skrydstrup, H. M. Madsen, R. Löwe, I. B. Gregersen, A. N. Pedersen, and K. Arnbjerg-Nielsen, 'Incorporating objectives of stakeholders in strategic planning of urban water management', *Urban Water J*, vol. 17, no. 2, pp. 87–99, Feb. 2020, doi: 10.1080/1573062X.2020.1748204.

[34] L. Bourne and D. H. T. Walker, 'Project relationship management and the Stakeholder Circle^{TM}', *International Journal of Managing Projects in*

Business, vol. 1, no. 1, pp. 125–130, Jan. 2008, doi: 10.1108/17538370810846450.

[35] Alessio. Ishizaka and Philippe. Nemery, *Multi-criteria decision analysis : methods and software*.

[36] S. L. Gebre, D. Cattrysse, and J. Van Orshoven, 'Multi-criteria decision-making methods to address water allocation problems: A systematic review', *Water (Switzerland)*, vol. 13, no. 2. MDPI AG, Jan. 02, 2021. doi: 10.3390/w13020125.

[37] 'Saaty, T.L. (1980) The Analytic Hierarchy Process. McGraw-Hill, New York. - References - Scientific Research Publishing'. https://www.scirp.org/(S(lz5mqp453edsnp55rrgjct55))/reference/ReferencesPapers.aspx?ReferenceID=1943982 (accessed Dec. 27, 2022).

[38] 'Brans, J.P. and Vincke, P. (1985) A Preference Ranking Organisation Method (The PROMETHEE Method for Multiple Criteria. Decision-Making). Management Science, 31, 647-656. - References - Scientific Research Publishing'. https://www.scirp.org/(S(i43dyn45teexjx455qlt3d2q))/reference/ReferencesPapers.aspx?ReferenceID=1733804 (accessed Dec. 29, 2022).

[39] 'Opricovic, S. (1998) Multicriteria Optimization of Civil Engineering Systems. PhD Thesis, Faculty of Civil Engineering, Belgrade, 302 p. - References - Scientific Research Publishing'. https://www.scirp.org/(S(351jmbntvnsjt1aadkposzje))/reference/ReferencesPapers.aspx?ReferenceID=1600129 (accessed Jan. 04, 2023).

[40] M. K. Sayadi, M. Heydari, and K. Shahanaghi, 'Extension of VIKOR method for decision making problem with interval numbers', *Appl Math Model*, vol. 33, no. 5, pp. 2257–2262, May 2009, doi: 10.1016/j.apm.2008.06.002.

[41] M. K. Sayadi, M. Heydari, and K. Shahanaghi, 'Extension of VIKOR method for decision making problem with interval numbers', *Appl Math Model*, vol. 33, no. 5, pp. 2257–2262, May 2009, doi: 10.1016/j.apm.2008.06.002.

[42] M. Tavana, R. Kiani Mavi, F. J. Santos-Arteaga, and E. Rasti Doust, 'An extended VIKOR method using stochastic data and subjective judgments', *Comput Ind Eng*, vol. 97, pp. 240–247, Jul. 2016, doi: 10.1016/j.cie.2016.05.013.

[43] A. Garcia-Bernabeu, A. Hilario-Caballero, D. Pla-Santamaria, and F. Salas-Molina, 'A process oriented MCDM approach to construct a circular economy composite index', *Sustainability (Switzerland)*, vol. 12, no. 2, Jan. 2020, doi: 10.3390/su12020618.

[44] P. V. dos Santos Gonçalves and L. M. S. Campos, 'A systemic review for measuring circular economy with multi-criteria methods', *Environmental Science and Pollution Research*, vol. 29, no. 21, pp. 31597–31611, May 2022, doi: 10.1007/s11356-022-18580-w.

[45] K. Kabirifar, M. Ashour, M. Yazdani, A. Mahdiyar, and M. Malekjafarian, ‘Cybernetic-parsimonious MCDM modeling with application to the adoption of Circular Economy in waste management’, *Appl Soft Comput*, vol. 139, May 2023, doi: 10.1016/j.asoc.2023.110186.

[46] P. Steduto, J.-Marc. Faurès, Jippe. Hoogeveen, J. T. Winpenny, and J. J. Burke, *Coping with water scarcity : an action framework for agriculture and food security*. Food and Agriculture Organization of the United Nations, 2012.

[47] A. Alamanos, N. Mylopoulos, A. Loukas, and D. Gaitanaros, ‘An integrated multicriteria analysis tool for evaluating water resource management strategies’, *Water (Switzerland)*, vol. 10, no. 12, Dec. 2018, doi: 10.3390/w10121795.

[48] R. Bhateria and D. Jain, ‘Water quality assessment of lake water: a review’, *Sustain Water Resour Manag*, vol. 2, no. 2, pp. 161–173, Jun. 2016, doi: 10.1007/s40899-015-0014-7.

[49] A. M. Dunca, ‘Water pollution and water quality assessment of major transboundary rivers from Banat (Romania)’, *J Chem*, vol. 2018, 2018, doi: 10.1155/2018/9073763.

[50] J. Martin-Ortega and J. Berbel, ‘Using multi-criteria analysis to explore non-market monetary values of water quality changes in the context of the Water Framework Directive’, *Science of the Total Environment*, vol. 408, no. 19, pp. 3990–3997, Sep. 2010, doi: 10.1016/j.scitotenv.2010.03.048.

[51] E. S. Chung and K. S. Lee, ‘Identification of spatial ranking of hydrological vulnerability using multi-criteria decision making techniques: Case study of Korea’, *Water Resources Management*, vol. 23, no. 12, pp. 2395–2416, 2009, doi: 10.1007/s11269-008-9387-9.

[52] M. Ilangkumaran *et al.*, ‘Optimization of wastewater treatment technology selection using hybrid MCDM’, *Management of Environmental Quality: An International Journal*, vol. 24, no. 5, pp. 619–641, 2013, doi: 10.1108/MEQ-07-2012-0053.

[53] D. C. Montgomery, *Design and analysis of experiments*.

[54] J. A. Cornell, *Experiments with mixtures : designs, models, and the analysis of mixture data*. Wiley, 2002.

[55] R. A. McLean and V. L. Anderson, ‘Extreme vertices design of mixture experiments’, *Technometrics*, vol. 8, no. 3, pp. 447–454, 1966.

[56] R. D. Snee, ‘Design and analysis of mixture experiments’, *Journal of Quality Technology*, vol. 3, no. 4, pp. 159–169, 1971.

[57] S. Opricovic and G. H. Tzeng, ‘Extended VIKOR method in comparison with outranking methods’, *Eur J Oper Res*, vol. 178, no. 2, pp. 514–529, Apr. 2007, doi: 10.1016/j.ejor.2006.01.020.

[58] ‘Wastewater Characteristics, Treatment and Disposal’.

[59] 'WastewaterEngbyMecalfandEddy2003'.

[60] 'ilbank-5-2022-3-altyapi-tesisleri-birim-fiyatlari'.

[61] G. Tchobanoglous, F. L. Burton, and H. D. Stensel, 'Wastewater engineering: treatment and reuse, Metcalf & Eddy Inc', *McGraw-Hill, Inc., New York. doi*, vol. 10, p. 0070418780, 2003.

[62] S. Zakeri, P. Chatterjee, D. Konstantas, and F. Ecer, 'A decision analysis model for material selection using simple ranking process', *Sci Rep*, vol. 13, no. 1, p. 8631, May 2023, doi: 10.1038/s41598-023-35405-z.

APPENDICES

A. THE EXTENDED VIKOR METHOD

Withdraw	Withdraw	Flow rate	Flow rate	Quality	Quality	Cost	Cost
0,00	0,10	0,00	0,17	0,00	0,13	0,07	0,14
0,00	0,10	0,02	0,18	0,01	0,14	0,08	0,15
0,10	0,25	0,12	0,25	0,08	0,25	0,00	0,03
0,10	0,25	0,12	0,25	0,08	0,25	0,01	0,05
0,00	0,10	0,03	0,19	0,01	0,15	0,14	0,24
0,00	0,10	0,03	0,19	0,01	0,15	0,14	0,25
0,08	0,22	0,01	0,18	0,02	0,16	0,07	0,14
0,10	0,25	0,03	0,19	0,02	0,17	0,00	0,03
0,08	0,22	0,03	0,19	0,02	0,17	0,14	0,25
0,10	0,25	0,05	0,20	0,03	0,18	0,01	0,05
0,06	0,18	0,05	0,20	0,03	0,17	0,14	0,25
0,03	0,14	0,03	0,19	0,02	0,16	0,14	0,25
0,08	0,22	0,08	0,22	0,05	0,21	0,14	0,25
0,03	0,14	0,04	0,20	0,02	0,16	0,14	0,25
0,07	0,20	0,03	0,19	0,02	0,16	0,14	0,25
0,08	0,22	0,05	0,20	0,03	0,18	0,14	0,25

S_L	S_U	R_L	R_U	S*	S-	R*	R-		Q_L	Q_U
0,07	0,53	0,07	0,17	0,07	0,90	0,07	0,25		0,00	0,56
0,10	0,57	0,08	0,18						0,04	0,61
0,30	0,78	0,12	0,25						0,29	0,93
0,31	0,80	0,12	0,25		V	0,50			0,30	0,94
0,19	0,68	0,14	0,24		1-V	0,50			0,26	0,84
0,19	0,69	0,14	0,25						0,28	0,88
0,18	0,70	0,08	0,22						0,12	0,81
0,16	0,64	0,10	0,25						0,15	0,85
0,28	0,83	0,14	0,25						0,34	0,96
0,19	0,68	0,10	0,25						0,17	0,87
0,27	0,81	0,14	0,25						0,33	0,94
0,22	0,74	0,14	0,25						0,30	0,90
0,36	0,90	0,14	0,25						0,38	1,00
0,23	0,75	0,14	0,25						0,31	0,91
0,27	0,81	0,14	0,25						0,33	0,94
0,30	0,84	0,14	0,25						0,35	0,97

$$S_i^L = \sum_{j\in I} w_j\left(\frac{f_j^* - f_{ij}^U}{f_j^* - f_j^-}\right) + \sum_{j\in J} w_j\left(\frac{f_{ij}^L - f_j^*}{f_j^- - f_j^*}\right), \text{ i=1,…,m}$$

$$S_i^U = \sum_{j\in I} w_j\left(\frac{f_j^* - f_{ij}^L}{f_j^* - f_j^-}\right) + \sum_{j\in J} w_j\left(\frac{f_{ij}^U - f_j^*}{f_j^- - f_j^*}\right), \text{ i=1,…,m}$$

$$R_i^L = \max\left(w_j\left(\frac{f_j^* - f_{ij}^U}{f_j^* - f_j^-}\right) \mid j \in I,\ w_j\left(\frac{f_{ij}^L - f_j^*}{f_j^- - f_j^*}\right) \mid j \in J\right) i = 1, \dots, m$$

$$R_i^U = \max\left(w_j\left(\frac{f_j^* - f_{ij}^L}{f_i^* - f_i^-}\right) \mid j \in I,\ w_j\left(\frac{f_{ij}^U - f_j^*}{f_i^- - f_i^*}\right) \mid j \in J\right) i = 1, \dots, m$$

$$Q_i^L = v\ \frac{(S_i^L - S^*)}{(S^- - S^*)} + (1 - v)\frac{(R_i^L - R^*)}{(R^- - R^*)}$$

$$Q_i^U = v\ \frac{(S_i^U - S^*)}{(S^- - S^*)} + (1 - v)\frac{(R_i^U - R^*)}{(R^- - R^*)}$$

$$S^* = minS_i^L,\ S^- = maxS_i^U$$

$$R^* = minR_i^L,\ R^- = maxR_i^U$$

Figure A.1 The Extended VIKOR Method Results

The Extended VIKOR method is an effective tool for making informed decisions by evaluating multiple alternatives based on various criteria. In this study, we utilized the Extended VIKOR method to assess 16 options across four distinct performance indicators to identify the most suitable alternative that meets our pre-defined standards. To ensure fairness in our analysis, each criterion was given equal weightage at first. The evaluation focused on beneficial factors such as Withdrawal, River Flow Rate, and Water Quality while also considering non-beneficial ones like Net Cost.

After careful consideration using these parameters, we identified ideal solutions for our favorable criteria, which were rated respectively as 1.11 (Withdrawal), 6.29 (River Flow Rate), and 6.10 (Water Quality). On the other hand, non-ideal solutions emerged from those same categories, scoring values of 2.53 (Withdrawal), 3.18

(River flow rate), and 11.86 (Water quality). Therefore, it is evident that employing the extended VIORK methodology provides us with valuable insights into complex decision-making processes allowing us to make well-informed choices backed up by data-driven evidence rather than mere intuition or guesswork alone.

To achieve maximum benefits, it is crucial for the alternative that scores highest on all criteria. Conversely, selecting an option with a low score on any criterion would be non-ideal. When considering factors such as Net Cost, which do not directly translate into benefits, aim for alternatives scoring lowest across all aspects, $A^{-} = 24{,}981$ being the ideal solution in this case. On the other hand, choosing an alternative with high scores $A^{*} = 116{,}708$ will prove disadvantageous in terms of net cost management and upkeep expenses. Therefore, making informed choices based on these guidelines can lead to optimal outcomes while minimizing unnecessary expenditures.

We must find a solution that strikes a balance that closely resembles our ideal outcome while being as far away from an unfavorable result. To achieve this, we evaluate each alternative by calculating two essential values: $[S_i^L, S_i^U]$. This involves weighing the distances between every criterion and determining how close or distant it is to our desired and undesired outcomes. You can refer to Figure A.1 for detailed results.

Furthermore, we consider another set of intervals known as $[R_i^L,\ R_i^U]$, which are calculated based on the maximum weighted distance between any given alternative i with respect to its proximity towards either favorable or non-favorable solutions across all criteria under consideration. It is also important to note these ranges have been normalized using range scores and weights assigned per criterion so that they remain fair throughout the evaluation process without bias towards factors over others.

Using the Extended VIKOR method, we could accurately rank each alternative based on its performance against predetermined criteria. This approach involves several crucial steps, such as normalizing data and determining a decision matrix outlined in Table 5.6. From there, calculating individual VIKOR scores for every option listed in Table 5.7 was necessary before applying the Extended VIKOR technique resulting in Figure A.1 revealing results.

To make informed decisions, it is crucial to consider multiple criteria. The method involves using a preference threshold set by the decision-maker themselves. This determines how much compromise they're willing to accept between different factors - with we assume that this level is 0.5. A moderate compromise of 0.5 means that while the decision-maker may not select an alternative performing best in every criterion, they'll choose one to achieve balance across all aspects instead. This approach ensures appropriate and well-rounded choices are made based on careful consideration of various factors rather than focusing solely on individual elements without regard for others' importance or impact.

After a thorough analysis, it was evident that Alternative 1 emerged as the most favorable option, closely followed by Alternatives 2 and 7. These alternatives demonstrated exceptional performance across all four criteria and held the immense potential to meet the decision-makers requirements. Interestingly, their shared feature of discharging treated wastewater into the river sets these three options apart - an approach that has proven effective in achieving desired results.

On the other hand, Alternative 13 failed to make its mark due to several reasons, such as high net costs for pre-treatments and construction involved in sending large amounts of water toward agriculture. It was subsequently making this alternative less desirable compared with others mentioned above, which have shown promising outcomes without any significant drawbacks or concerns over the environmental impact on our ecosystem's health.

B. SENSITIVITY ANALYSIS

Alternatives	Q_L	Q_U	Q_L	Q_U	Q_L	Q_U	Q_L	Q_U	Q_L	Q_U
1	0,10	0,62	0,09	0,62	0,09	0,61	0,09	0,61	0,08	0,60
2	0,14	0,67	0,14	0,67	0,13	0,66	0,13	0,66	0,12	0,66
3	0,33	0,88	0,33	0,89	0,33	0,89	0,33	0,90	0,33	0,90
4	0,33	0,89	0,33	0,90	0,33	0,90	0,34	0,90	0,33	0,91
5	0,35	0,89	0,34	0,89	0,33	0,88	0,33	0,88	0,32	0,87
6	0,37	0,93	0,36	0,93	0,36	0,92	0,35	0,91	0,35	0,91
7	0,12	0,67	0,12	0,67	0,12	0,68	0,13	0,68	0,12	0,68
8	0,00	0,63	0,00	0,63	0,00	0,64	0,01	0,65	0,01	0,65
9	0,38	0,94	0,37	0,94	0,37	0,94	0,37	0,95	0,37	0,95
10	0,07	0,68	0,07	0,69	0,07	0,69	0,07	0,70	0,07	0,71
11	0,39	0,95	0,38	0,95	0,38	0,95	0,38	0,95	0,38	0,95
12	0,37	0,93	0,36	0,93	0,36	0,92	0,36	0,92	0,35	0,92
13	0,44	1,00	0,43	1,00	0,43	1,00	0,43	1,00	0,43	1,00
14	0,38	0,94	0,37	0,94	0,37	0,93	0,37	0,93	0,36	0,93
15	0,37	0,94	0,37	0,94	0,37	0,94	0,37	0,94	0,36	0,94
16	0,39	0,96	0,39	0,96	0,39	0,96	0,39	0,96	0,38	0,96

Alternatives	Q_L	Q_U	Q_L	Q_U	Q_L	Q_U	Q_L	Q_U	Q_L	Q_U
1	0,06	0,59	0,04	0,58	0,01	0,57	0,00	0,56	0,00	0,56
2	0,10	0,64	0,08	0,63	0,05	0,62	0,04	0,61	0,04	0,61
3	0,32	0,91	0,30	0,91	0,29	0,92	0,29	0,93	0,29	0,93
4	0,32	0,91	0,31	0,92	0,29	0,92	0,29	0,93	0,30	0,94
5	0,31	0,86	0,29	0,86	0,27	0,85	0,26	0,84	0,26	0,84
6	0,33	0,90	0,32	0,90	0,30	0,89	0,29	0,88	0,28	0,88
7	0,11	0,68	0,09	0,67	0,06	0,67	0,08	0,72	0,12	0,81
8	0,02	0,65	0,03	0,65	0,03	0,65	0,10	0,75	0,15	0,85
9	0,36	0,95	0,35	0,95	0,34	0,95	0,34	0,96	0,34	0,96
10	0,05	0,71	0,05	0,71	0,06	0,71	0,13	0,77	0,17	0,87
11	0,37	0,95	0,35	0,95	0,34	0,95	0,33	0,94	0,33	0,94
12	0,34	0,92	0,33	0,91	0,31	0,91	0,30	0,91	0,30	0,90
13	0,42	1,00	0,40	1,00	0,39	1,00	0,38	1,00	0,38	1,00
14	0,35	0,92	0,33	0,92	0,32	0,92	0,31	0,91	0,31	0,91
15	0,35	0,94	0,34	0,94	0,33	0,94	0,33	0,94	0,33	0,94
16	0,37	0,96	0,36	0,96	0,35	0,96	0,35	0,97	0,35	0,97

Figure B.1 The Sensitivity Analysis for Withdrawing Water Criteria

Furthermore, it can be discussed that Withdrawing Water (amount) was a critical criterion in determining the ranking of alternatives. The results of this study suggest that when the weight for Withdrawing Water is low, Alternative 8 is the most favorable option. However, when the weight of Withdrawing Water is high, Alternative 1 becomes the best option shown in Figure B.1. This indicates that the amount of water that needs to be withdrawn is an essential factor to consider when evaluating alternatives for the management of treated wastewater.

Let's consider how the weights assigned to criteria can significantly influence the ranking of alternatives in decision-making. It is worth mentioning that it is a widely accepted practice in multicriteria decision-making to assign different weights, accurately reflecting each criterion's significance. In this study, we have adjusted these weightings and analyzed their impact on alternative rankings for every criterion under consideration.

Alternatives	Q_L	Q_U	Q_L	Q_U	Q_L	Q_U	Q_L	Q_U	Q_L	Q_U
1	0,00	0,43	0,00	0,44	0,00	0,44	0,00	0,44	0,00	0,45
2	0,03	0,48	0,04	0,49	0,04	0,49	0,04	0,49	0,04	0,50
3	0,19	0,88	0,19	0,89	0,20	0,89	0,20	0,90	0,21	0,90
4	0,19	0,89	0,20	0,90	0,20	0,90	0,21	0,91	0,21	0,91
5	0,25	0,81	0,26	0,82	0,26	0,82	0,26	0,82	0,26	0,82
6	0,28	0,86	0,28	0,86	0,28	0,86	0,28	0,86	0,28	0,86
7	0,13	0,80	0,13	0,80	0,13	0,80	0,13	0,80	0,12	0,80
8	0,14	0,82	0,14	0,82	0,14	0,82	0,14	0,83	0,14	0,83
9	0,36	0,97	0,36	0,97	0,36	0,97	0,35	0,97	0,35	0,97
10	0,16	0,84	0,16	0,84	0,16	0,84	0,16	0,85	0,16	0,85
11	0,34	0,94	0,34	0,94	0,34	0,94	0,34	0,94	0,34	0,94
12	0,31	0,90	0,31	0,90	0,31	0,90	0,31	0,90	0,31	0,90
13	0,38	1,00	0,38	1,00	0,38	1,00	0,38	1,00	0,38	1,00
14	0,31	0,90	0,31	0,90	0,31	0,90	0,31	0,90	0,31	0,90
15	0,35	0,95	0,35	0,95	0,34	0,95	0,34	0,95	0,34	0,95
16	0,36	0,97	0,36	0,97	0,36	0,97	0,36	0,97	0,36	0,97

Alternatives	Q_L	Q_U	Q_L	Q_U	Q_L	Q_U	Q_L	Q_U	Q_L	Q_U
1	0,00	0,45	0,00	0,46	0,00	0,46	0,00	0,49	0,00	0,56
2	0,04	0,50	0,04	0,51	0,04	0,51	0,04	0,54	0,04	0,61
3	0,21	0,91	0,22	0,92	0,23	0,92	0,24	0,93	0,29	0,93
4	0,22	0,92	0,23	0,93	0,23	0,93	0,25	0,93	0,30	0,94
5	0,26	0,83	0,26	0,83	0,26	0,83	0,26	0,83	0,26	0,84
6	0,28	0,87	0,28	0,87	0,28	0,87	0,28	0,87	0,28	0,88
7	0,12	0,80	0,12	0,81	0,12	0,81	0,12	0,81	0,12	0,81
8	0,14	0,83	0,15	0,84	0,15	0,84	0,15	0,84	0,15	0,85
9	0,35	0,97	0,35	0,96	0,34	0,96	0,34	0,96	0,34	0,96
10	0,16	0,85	0,16	0,86	0,16	0,86	0,17	0,86	0,17	0,87
11	0,34	0,94	0,34	0,94	0,33	0,94	0,33	0,94	0,33	0,94
12	0,31	0,90	0,30	0,90	0,30	0,90	0,30	0,90	0,30	0,90
13	0,38	1,00	0,38	1,00	0,38	1,00	0,38	1,00	0,38	1,00
14	0,31	0,91	0,31	0,91	0,31	0,91	0,31	0,91	0,31	0,91
15	0,34	0,95	0,33	0,95	0,33	0,95	0,33	0,95	0,33	0,94
16	0,36	0,97	0,35	0,97	0,35	0,97	0,35	0,97	0,35	0,97

Figure B.2 The Sensitivity Analysis for River Flow Rate Criteria

The evidence presented in Figure B.1, Figure B.2, and Figure B.4 strongly suggests that the River Flow Rate, Water Quality Index, and Net Cost were not significant factors influencing the ranking of alternatives during decision-making processes. However, it is essential to acknowledge that these results may be limited by potential discrepancies between stakeholder preferences and criteria weighting used within this study's framework. To ensure accurate representation of stakeholders' priorities throughout future decision-making procedures for similar projects or initiatives, we must prioritize consultation with all relevant parties involved to obtain a comprehensive understanding of their perspectives on critical issues, ultimately resulting in more effective outcomes.

Alternatives	Q_L	Q_U	Q_L	Q_U	Q_L	Q_U	Q_L	Q_U	Q_L	Q_U
1	0,00	0,54	0,00	0,54	0,00	0,55	0,00	0,55	0,00	0,55
2	0,04	0,59	0,04	0,60	0,04	0,60	0,04	0,60	0,04	0,60
3	0,28	0,87	0,28	0,88	0,28	0,89	0,28	0,89	0,28	0,90
4	0,28	0,88	0,28	0,89	0,28	0,89	0,29	0,90	0,29	0,91
5	0,27	0,83	0,27	0,84	0,27	0,84	0,27	0,84	0,26	0,84
6	0,30	0,88	0,30	0,88	0,30	0,88	0,29	0,88	0,29	0,88
7	0,13	0,81	0,13	0,81	0,12	0,81	0,12	0,81	0,12	0,81
8	0,14	0,82	0,14	0,83	0,14	0,83	0,14	0,83	0,15	0,83
9	0,36	0,98	0,36	0,98	0,36	0,97	0,36	0,97	0,35	0,97
10	0,16	0,84	0,16	0,85	0,17	0,85	0,17	0,85	0,17	0,85
11	0,35	0,95	0,35	0,95	0,35	0,95	0,35	0,95	0,34	0,95
12	0,32	0,91	0,32	0,91	0,31	0,91	0,31	0,91	0,31	0,91
13	0,40	1,00	0,40	1,00	0,40	1,00	0,40	1,00	0,39	1,00
14	0,33	0,92	0,32	0,91	0,32	0,91	0,32	0,91	0,32	0,91
15	0,35	0,96	0,35	0,96	0,35	0,96	0,34	0,96	0,34	0,95
16	0,37	0,98	0,37	0,98	0,37	0,98	0,36	0,98	0,36	0,97

Alternatives	Q_L	Q_U	Q_L	Q_U	Q_L	Q_U	Q_L	Q_U	Q_L	Q_U
1	0,00	0,55	0,00	0,55	0,00	0,55	0,00	0,55	0,00	0,56
2	0,04	0,60	0,04	0,60	0,04	0,60	0,04	0,61	0,04	0,61
3	0,28	0,90	0,28	0,91	0,29	0,91	0,29	0,92	0,29	0,93
4	0,29	0,91	0,29	0,92	0,29	0,92	0,29	0,93	0,29	0,93
5	0,26	0,84	0,26	0,84	0,26	0,84	0,26	0,84	0,26	0,84
6	0,29	0,88	0,29	0,88	0,29	0,88	0,29	0,88	0,29	0,88
7	0,12	0,81	0,12	0,81	0,12	0,81	0,12	0,81	0,12	0,81
8	0,15	0,83	0,15	0,84	0,15	0,84	0,15	0,84	0,15	0,84
9	0,35	0,97	0,35	0,97	0,35	0,97	0,34	0,96	0,34	0,96
10	0,17	0,85	0,17	0,86	0,17	0,86	0,17	0,86	0,17	0,86
11	0,34	0,95	0,34	0,95	0,34	0,95	0,34	0,95	0,33	0,94
12	0,31	0,91	0,31	0,91	0,31	0,91	0,30	0,90	0,30	0,90
13	0,39	1,00	0,39	1,00	0,39	1,00	0,39	1,00	0,39	1,00
14	0,32	0,91	0,32	0,91	0,31	0,91	0,31	0,91	0,31	0,91
15	0,34	0,95	0,34	0,95	0,34	0,95	0,33	0,95	0,33	0,95
16	0,36	0,97	0,36	0,97	0,36	0,97	0,35	0,97	0,35	0,97

Figure B.3 The Sensitivity Analysis for Water Quality Criteria

Alternatives	Q_L	Q_U	Q_L	Q_U	Q_L	Q_U	Q_L	Q_U	Q_L	Q_U
1	0,00	0,60	0,00	0,60	0,00	0,60	0,00	0,60	0,00	0,60
2	0,05	0,64	0,04	0,64	0,03	0,64	0,02	0,65	0,02	0,65
3	0,45	1,00	0,44	1,00	0,43	1,00	0,42	1,00	0,41	1,00
4	0,45	1,00	0,44	1,00	0,43	1,00	0,42	1,00	0,41	1,00
5	0,10	0,68	0,10	0,69	0,09	0,69	0,08	0,70	0,10	0,71
6	0,10	0,68	0,10	0,69	0,09	0,69	0,09	0,70	0,11	0,71
7	0,25	0,82	0,24	0,83	0,23	0,83	0,22	0,83	0,21	0,84
8	0,31	0,90	0,30	0,90	0,29	0,90	0,28	0,90	0,26	0,90
9	0,26	0,84	0,26	0,85	0,26	0,86	0,25	0,87	0,25	0,88
10	0,32	0,92	0,32	0,92	0,31	0,92	0,30	0,92	0,28	0,92
11	0,20	0,77	0,20	0,78	0,19	0,78	0,19	0,79	0,18	0,80
12	0,11	0,70	0,11	0,71	0,10	0,72	0,10	0,73	0,12	0,74
13	0,31	0,88	0,31	0,89	0,30	0,90	0,30	0,91	0,30	0,92
14	0,14	0,72	0,14	0,73	0,13	0,74	0,12	0,75	0,13	0,76
15	0,22	0,78	0,22	0,79	0,22	0,80	0,21	0,81	0,21	0,81
16	0,26	0,83	0,26	0,84	0,26	0,85	0,25	0,86	0,25	0,87

Alternatives	Q_L	Q_U	Q_L	Q_U	Q_L	Q_U	Q_L	Q_U	Q_L	Q_U
1	0,00	0,60	0,00	0,60	0,00	0,58	0,00	0,57	0,00	0,56
2	0,03	0,65	0,03	0,65	0,03	0,63	0,04	0,62	0,04	0,61
3	0,40	1,00	0,38	0,99	0,34	0,96	0,32	0,95	0,29	0,93
4	0,40	1,00	0,38	1,00	0,34	0,97	0,32	0,95	0,30	0,94
5	0,12	0,72	0,14	0,72	0,19	0,72	0,22	0,75	0,26	0,84
6	0,13	0,72	0,15	0,73	0,21	0,72	0,25	0,79	0,28	0,88
7	0,20	0,84	0,19	0,84	0,16	0,82	0,14	0,82	0,12	0,81
8	0,25	0,90	0,23	0,90	0,19	0,87	0,17	0,86	0,15	0,85
9	0,24	0,89	0,24	0,90	0,27	0,89	0,30	0,89	0,34	0,96
10	0,27	0,92	0,25	0,92	0,22	0,89	0,19	0,88	0,17	0,87
11	0,18	0,81	0,21	0,82	0,26	0,81	0,30	0,86	0,33	0,94
12	0,15	0,74	0,17	0,75	0,23	0,74	0,26	0,82	0,30	0,90
13	0,29	0,93	0,28	0,94	0,32	0,94	0,35	0,93	0,38	1,00
14	0,16	0,77	0,18	0,77	0,24	0,77	0,27	0,82	0,31	0,91
15	0,20	0,82	0,20	0,83	0,26	0,83	0,29	0,86	0,33	0,94
16	0,24	0,88	0,23	0,89	0,28	0,88	0,31	0,88	0,35	0,97

Figure B.4 The Sensitivity Analysis for Cost Criteria

It is imperative to remember that when using the Extended VIKOR method for water allocation analysis, some criteria may not significantly impact alternative rankings. Nevertheless, this does not necessarily indicate no discernible differences in performance among alternatives regarding those specific criteria. Even if changes were made to weight assignments and ranking remained unchanged, significant variations could still exist within actual performance values.

The lack of substantial influence on ranking implies that these criteria do not significantly differentiate one alternative from another. This means their relative positions remain relatively stable during decision-making processes; however, it should be noted that noteworthy variances can still occur about individual performances themselves.