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A Risk Assessment Model for Cyber-Physical Water and Wastewater Systems: Towards Sustainable Development

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Abstract: Cyber-physical systems (CPS) and their Supervisory Control and Data Acquisition (SCADA) have attracted great interest for automatic management of industrial infrastructures, such as water and wastewater systems. A range of technologies can be employed for wastewater treatment CPS to manage risks and protect the infrastructures of water systems and their wastewater against cyberattacks. In this paper, we develop a novel risk assessment framework, named RAF-CPWS, which perfectly estimates the risks of water and wastewater technologies. To do this, a multi-criteria group decision-making (MCGDM) approach is designed by neutrosophic theory to assess the risks of wastewater treatment technologies (WWTTs). The proposed approach evaluates the best WWTTs, considering various economic, environmental, technological and cybersecurity, and social factors. A decision-making trial and evaluation laboratory (DEMATEL) is employed to evaluate the significance of the adopted factors in a real testbed setting. The proposed approach contributes to a comprehensive measure of WWTTs through several factors, revealing its high sustainability and security in assessing the risks of cyber-physical water and wastewater systems.

Keywords: risk assessment; SCADA; wastewater treatment; reuse wastewater; sustainability

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1. Introduction

Cyber-physical systems (CPS) integrate industrial and technological elements to operate critical infrastructures, such as water/wastewater, oil/gas, and power systems. In CPS, Supervisory Control and Data Acquisition (SCADA) can remotely manage and control these industrial systems. With the focus on water/wastewater systems, there is an urgent need to effectively manage the use of available water and to reuse wastewater, such as sewage and industrial wastewater [1,2]. In other words, it is necessary to use water treatment and wastewater treatment CPS to remotely manage these systems and execute various automated operations, for example, the estimation of operational risks and discovery of cyber-attacks such as ransomware and botnets, and the assessment of the pollutants in the polluted water until it reaches to be reused. Most of the world's wastewater CPS that stems from human waste, industrial and agricultural waste, and other highly toxic materials are not treated, and their infrastructure could be hacked using various attacking techniques [3,4].

Water/wastewater systems can be automatically managed using SCADA technologies. Enhancing the integrity of those systems could ensure that pollutants and pathogens would not contaminate the drinking water supply and protect their critical infrastructure against cyber risks. Many countries have begun to invest in the automation of wastewater treatment using CPS and SCADA systems. Consequently, these systems will help to preserve the healthiness of ecologies and humans, securely achieving sustainable development, which is closely linked to the treatment of wastewater and recycled wastewater [5]. It is observed that 32% of the world's population still suffers from the absence of suitable sanitation facilities [6]. The United Nations have embraced a sustainable development approach to gain access to unpolluted water and sanitation. A wide range of sanitation-based CPS technologies are currently under development, but many are only prototypes or are not fully mature. Existing wastewater treatment technologies, in terms of their ability to treat water sustainably and preserve the environment and protect critical infrastructures against cyber threats, still need further investigation [7].

It is vital to use multi-criteria group decision-making (MCDM) methods; however, there is no uniquely standardized system for establishing the criteria and sub-criteria to support such an approach because decision-makers have different preferences [8]. Assessing the risks of CPS for developing effective water/wastewater systems is a multifaceted task that requires extensive experience. This is because decision-making is grounded on the consideration of several technological, economic, environmental, and cybersecurity factors to shore the appropriate selection process [9]. Further, the adoption of suitable wastewater treatment technologies (WWTT) requires a set of interrelated goals and multiple conflicting criteria, which depend on the predominant circumstances and user limitations [10].

All these aspects must be integrated to choose a sustainable solution regardless of the complications in a decision-making process [11]. To deal with this problem, MCDM methods are necessary to support the selection of the most sustainable WWTT from among the available alternatives. In this study, anaerobic anoxic oxic (AAO), Triple Oxidation Ditch (TOD), anaerobic single oxidation ditch (ASOD), and sequencing batch reactor activated sludge (SBRAS) have been adopted due to their ease of use. Each of which has its advantages and disadvantages. AAO is characterized by its ability to eliminate nitrogenous and phosphorous compounds, but it has a high cost. TOD is easy to operate, but cannot process the sludge or, at least, poor treatment of the sludge [12]. ASOD, like AAO, is also distinguished for being able to remove nitrogenous and phosphorous combinations, but needs very great areas of ground. SBRAS, which does not require a large area of land and is inexpensive, cannot remove phosphorous and nitrogenous compounds [12].

In this study, to evaluate sustainable and secure WWTT alternatives, we conducted a literature review and selected various factors, including economic, environmental, technological and cybersecurity, and social-political. Within these factors, fifteen sub-factors were identified: construction cost, implementation and maintenance costs, occupied land, nitrogen and phosphorous disposal efficiency, organic matter and suspended solids disposal efficiency, sludge removal effect, carbon footprint, maturity, reliability, operability and simplicity, public acceptance, employment, governmental policy, odors, and noise.

The main contributions of this study include:

- An extensive index that offers a functional archive of risk assessment factors to compare WWTTs in their future studies.
- A proposal of a hybrid MCDM model to help stakeholders (such as wastewater engineers and policymakers) adopt the most sustainable and secure WWTTs.
- A demonstration of the ability of neutrosophic DEMATEL-TOPSIS to efficiently handle linguistic uncertainty.
- The establishment of a mechanism and common reference point for the concerned institutions, ministries, decision-makers, and local communities when establishing such plants to achieve the best-expected results.
- Clarification of a key aspect of CPS operation in assessing the risks of wastewater treatment technologies.

The rest of this article is organized in the following manner. Section 2 introduces the fundamentals of SCADA and water/wastewater systems. Assessment factors and sub-factors for sustainable WWTTs selection are explored in Section 3. Section 4 shows a review of neutrosophic theory, the DEMATEL, and the TOPSIS methods. A novel framework for evaluating the WWTTs is explained in Section 5. Section 6 provides a case study and outlines the results obtained. Section 7 introduces comparisons with various MCDM techniques, followed by Section 8 which indicates a sensitivity analysis of the obtained outcomes. Section 9 notes some interesting managerial implications for WWT and Section 10 concludes the article.

2. Extant Literature

This section explains the fundamentals of SCADA and water/wastewater CPS, as well as the background and related studies related to risk assessment and multi-decision-making approaches.

2.1. SCADA and Water Systems

SCADA acts as the remote automation control system that comprises kernel functions for monitoring, configuring, assessing, and controlling various physical components, such as breakers and tap alters [13]. It uses computerized models, especially human-machine interfaces (HMI), for controlling its functions [14]. In a water/wastewater CPS, SCADA is the technology that operates a large number of measurements collected by sensors and sends commands to control other system devices [15]. Its main components are programmable logic controllers (PLCs) and remote terminal units (RTUs) that serve as a gateway for processing acquired data [13].

Current SCADA systems can use the functionalities of network connections using Ethernet connectivity and protocols [13], for example, IEC 61850 and DNP3, which are adjusted to operate over the Modbus TCP/IP model [16]. The intercommunication among SCADA, substation automation systems, and information technology (IT) through network systems is shown in Figure 1 [13]. Water systems within SCADA become more vulnerable to exposure by attackers due to their remote monitor via the Internet. To improve their security and privacy, privacy-preservation firewalls, authentication methods, and cyber-attack approaches have been widely utilized [13,14].

2.2. Risk Assessment & Multi-Decision-Making Approaches

A risk assessment is defined as a systematic process that includes defining, inspecting, and managing hazards and risks [2]. In water/wastewater CPS, it is essential to measure environmental, economic, and cyber risks to effectively treat wasted waters, as well as achieve the survival and safety of human beings. To develop efficient risk assessment methods, a combined MCDM method, grounded on the judgments of different decision-makers regarding all aspects of a decision problem, has been proposed in several studies [17,18]. MCDM has been advanced for the MCGDM technique to avoid problems related to individual decision-makers, such as imperfect knowledge and individual judgments [19,20].

Collective decision allows for the arrangement of alternates in various decision circumstances. When making decisions based on multi-criteria, it is preferable to collect opinions from different specialists in various fields such as academics, investigators, and local inhabitants, when making decisions regarding the choice of the most appropriate sustainable WWTT. It is advisable in MCDM methods for decision-makers to conduct pairwise comparisons when selecting one alternative over another in the evaluation process [21]. Nevertheless, some intangible features mean that the evaluation process of the alternatives is difficult because decision-makers are frequently unable to offer real ratios [22]. To reduce the burden of decision-makers and to allow them to readily express their preferences, linguistic terms were introduced [23]. Uncertainty can affect the process of assessing risks and adopting the best alternative. To overcome this problem, Florentine suggested the neutrosophic set as a popularization of the fuzzy set (FS) and the intuitionistic fuzzy set (IFS), for treating with vagueness and unreliability [24]. The neutrosophic theory has attracted the interest of researchers in a range of fields [25,26].

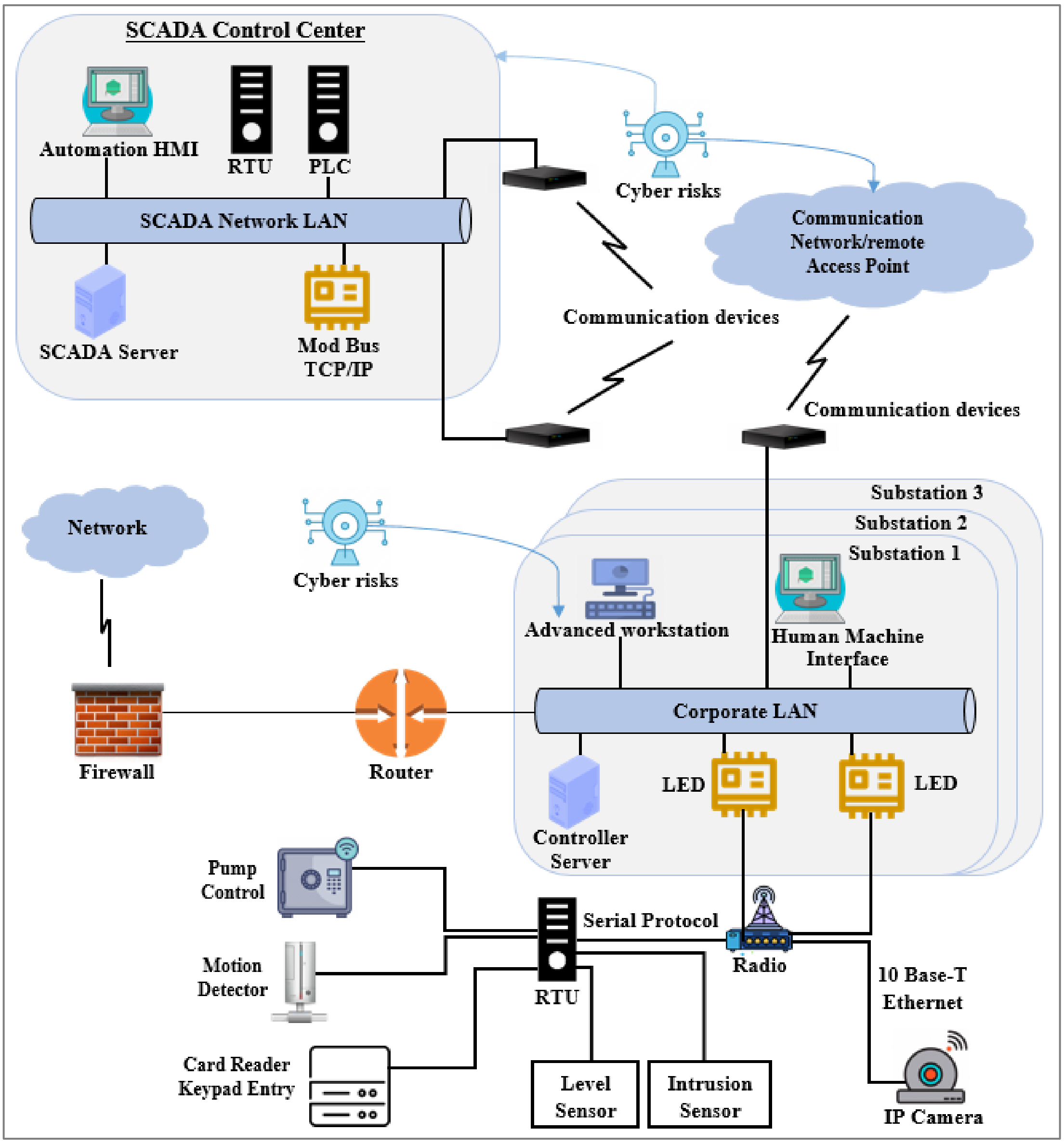

Figure 1. Systematic architecture of water/wastewater CPS-SCAD.

Even though there is various actual research to determine the efficiency and evaluation of WWTT, very little literature has considered a systematic approach for helping decision-makers in selecting WWTT [27]. Further, those systems that have been developed tend to be complex and difficult to use, so that they are not widely used [28]. In addition, some systems depend on the experts' judgment, which leads to a difference in the arrangement of alternatives according to the level of expertise, which does not always end with the best decision.

We review several studies and applications of wastewater treatment CPSs and MCDM methods related to choosing the most sustainable alternatives. Ren and Liang developed the IFS theory-based group multi-attribute decision analysis (MADA) for ranking the determined WWTTs that achieve the conditions of sustainability [8].

Yao et al. introduced an incomplete interval type-2 fuzzy (IT2F) methodology grounded on an MCGDM approach for the evaluation and ranking of four WWTTs using four key factors and eight sub-factors in the assessment process [12]. In this regard, AAO had recognized as the most optimal followed by TOD, ASOD, and SBRAS. The limitation of the approach was that the consistency standard did not reach 100% and the number of experts was limited. Arroyo and Molinos-Senante presented a choosing-by-advantages

(CBA) framework for ranking the seven WWTTs [5]. They compared CBA results with results obtained by the analytical hierarchy process (AHP) method. Molinos-Senante et al. presented an analytic network process (ANP) method for the evaluation and ranking of seven WWTT arrangements for secondary treatment: Constructed Wetland (CW), Extended Aeration (EA), Membrane Bioreactor (MBR), Pond System (PS), Rotating Biological Contactor (RBC), Sequencing Batch Reactor (SBR), and Trickling Filter (TF) [29]. They used three main factors (economic, environmental, and social) and fourteen sub-factors in the evaluation process. Their results showed that extensive technologies, CWs, and PSs are the most favored options by WWT experts.

Ullah et al. introduced a decision support system (DSS) to evaluate and select WWTT, and they implemented it by utilizing Microsoft Visual Studio software and authenticated it out of real-time case studies [6]. They took into account several factors related to sustainability in the evaluation process: technological, social, economic, regulatory, constitutional, and ecological. The proposed system of WWTT is divided into four treatment phases; namely, preliminary, primary, secondary, and tertiary. Grounded on all the above constraints, the sustainable WWTT option is selected. Ibrahim and Ali proposed an approach based on MCD analysis (MCDA) to assess three sustainable wastewater management (WWM) alternates for Khartoum State including central, cluster, and onsite schemes using four main factors and twenty-eight sub-factors [30]. Three WWM schemes were inspected, centralized, and decentralized WWM schemes, using MCDA to assess their appropriateness and sustainability for fast-extending cities. Their results identified that the decentralized onsite and decentralized cluster WWM schemes were more sustainable because such schemes are more suitable for planning and can be applied in the cities of Sudan. Kanchanamala Delanka-Pedige et al. introduced a multi-criteria comparison of algal-based and activated sludge-based wastewater infrastructure systems based on 30 process parameters derived from the UN Sustainable Development Goals (SDGs) to assess their environmental, economic, social, and overall sustainability [31]. They used four alternatives: the classical high-rate algal ponds (HRAP) and an emerging mixotrophic algal system (A-WWT) were selected as algal-based systems; and the conventional activated sludge (CAS) system and the membrane bioreactor (MBR) system as activated sludge-based systems. Their results indicate that the mixotrophic A-WWT is considered the preferred technology in environmental, economic, and overall sustainability aspects.

Some researchers have utilized fuzzy MCDM for WWTTs selection, while there have been no discussions about neutrosophic MCDM in this field. Additionally, there was at least no implementation study that combined the features of the DEMATEL technique and the TOPSIS technique in this regard to dealing with ambiguity and minimizing the uncertainties. Further, we have considered caught uncertainties in all stages that were ignored in former studies. In this work, triangular neutrosophic numbers (TNNs) have been utilized for decreasing data unsureness collected by specialists, and an integrated MCDM method has been utilized to set the unsureness regarded in the assessment model. In general, an integration of various evaluation techniques can aid scholars in achieving more precise consequences [32].

3. Evaluation Factors of Sustainable and Secure WWTT CPS

The sustainability and security factors utilized in the assessment process are a combination of those selected from the literature (see Table 1) and others that were proposed by the experts participating in this paper. The main factors that are always used for assessing sustainability and security are the economy, environment, society, and cybersecurity. There is, however, no standardized approach to measuring the sustainability and security of WWTT CPS because each problem has a significant number of unique attributes, and the associated decision-makers need to account for unique requirements. In addition to the three main sustainability factors, other widely used factors include such aspects as technological and political aspects, depending on the nature of the problem.

Table 1. Factors used for assessing WWTT CPS.

Factors	Sub-Factors	Acronym	References
Economic ECF (F_1)	Construction cost	COC (F_{1-1})	[8]
	Implementation and maintenance costs	OMC (F_{1-2})	[8]
Environmental ENF (F_2)	Occupied land	OCL (F_{2-1})	[8,33]
	Nitrogen and phosphorous disposal efficiency	NPD (F_{2-2})	[12]
	Organic matter and suspended solids efficiency disposal	OSD (F_{2-3})	[29]
	Sludge removal effect	SRE (F_{2-4})	[12]
	Carbon footprint	CAF (F_{2-5})	[29]
Technological and Cybersecurity TEF (F_3)	Maturity	MAT (F_{3-1})	[8]
	Reliability	REL (F_{3-2})	[33]
	Operability and simplicity	OST (F_{3-3})	[8]
Social-Political SOF (F_4)	Public acceptance	PAC (F_{4-1})	[33]
	Employment	EMP (F_{4-2})	Proposed
	Governmental policy	GOP (F_{4-3})	[8]
	Odors	ODS (F_{4-4})	Proposed
	Noise	NOS (F_{4-5})	Proposed

3.1. Economic Factor ECF (F_1)

This factor deals with the economic factors of the WWT processes and includes two sub-factors: construction costs and operation and maintenance costs.

3.1.1. Construction Cost COC (F_{1-1})

The construction cost factor indicates the total expenditure required to construct a WWT plant, including many expensive elements that must be taken into account when establishing the project, such as the purchase of land, equipment, and facilities [34]. The principal cost greatly affects decision-makers when considering the implementation of projects related to WWT.

3.1.2. Operation and Maintenance Costs OMC (F_{1-2})

The operating and conservation costs factor comprises all the expenses associated with operating and maintaining the WWT procedures. Such costs include energy use, maintenance costs, personnel, and waste management.

3.2. Environmental Factor ENF (F_2)

This factor includes the environmental factors related to the construction of a WWT plant, its operations, and the extent of its impact on the environment that are related to harmful wastes and consumed resources. Five sub-factors have been defined to measure the environmental efficiency of WWT processes: occupied land, nitrogen and phosphorous disposal efficiency, organic matter and suspended solids efficiency disposal, sludge removal effect, and carbon footprint.

3.2.1. Occupied Land OCL (F_{2-1})

This factor refers to the terrestrial resources used to construct the WWT projects and the land to construct the supplementary infrastructure.

3.2.2. Nitrogen and Phosphorous Disposal Efficiency NPD ($F_{2–2}$)

This factor indicates the percentage of removal from wastewater of some nutrients with high concentrations, such as phosphorous and nitrogen.

3.2.3. Organic Matter and Suspended Solids Efficiency Disposal OSD ($F_{2–3}$)

This factor indicates the efficiency of disposal of suspended solids and organic matter solids from wastewater.

3.2.4. Sludge Removal Effect SRE ($F_{2–4}$)

This factor indicates the disposal efficiency of sludge that is a byproduct during municipal or industrial wastewater treatment. It also indicates the extent to which sludge can be used and treated since it is one of the biggest problems facing the WWT sectors.

3.2.5. Carbon Footprint CAF ($F_{2–5}$)

This factor refers to the greenhouse gas emissions that result from WWT processes and is divided into two types of emissions: direct and indirect. Biological processes in WWT plants result in direct emissions such as carbon dioxide, methane, and nitrous oxide. In addition, indirect emissions are those that may be generated from the energy used to operate the WWT plant and associated facilities.

3.3. Technological and Cybersecurity Factor TEF (F_3)

This factor includes several sub-factors to measure the technological and cybersecurity performance of WWTT: maturity, reliability, and operability and simplicity.

3.3.1. Maturity MAT ($F_{3–1}$)

This factor refers to the stage at which WWT plants are well-adapted to modern technologies and operate efficiently.

3.3.2. Reliability REL ($F_{3–2}$)

This factor refers to how likely WWTT is to fail when implementing various treatment processes. In addition, the stability of the technologies is confirmed by frequent comparisons of treatment results.

3.3.3. Operability and Simplicity OST ($F_{3–3}$)

This factor refers to the simplicity of operating WWT processes and the most efficient treatment processes that are adopted and used extensively.

3.4. Social-Political Factor SOF (F_4)

The social-political factor includes dimensions related to the construction of WWT projects and the extent of their impact on the surrounding community. Six sub-factors have been identified to measure the social-political factor of WWT processes: public acceptance, employment, governmental policy, odor, and noise.

3.4.1. Public Acceptance PAC ($F_{4–1}$)

Public acceptance refers to the acceptability of the sites of the WWT plants by the residents of communities surrounding the plants and the absence of conflict or hostility.

3.4.2. Employment EMP ($F_{4–2}$)

This factor refers to the jobs created by the establishment of the WWT plants, and must be taken into consideration for measuring social sustainability.

3.4.3. Governmental Policy GOP ($F_{4–3}$)

This factor indicates the extent of government support to implement sustainable development in the field of WWT. Policy support indicates the level of consistency between the WWT technology and the policy system (i.e., financial and strategy support) associated with guiding the improvement of WWT procedures.

3.4.4. Odors ODS ($F_{4–4}$)

This factor usually refers to the odors that result from WWT plants, which may be the cause of complaints by local communities. Odors are limited by good planning, operation, and commitment to an appropriate distance between WTT stations and the residential buildings and communities.

3.4.5. Noise NOS ($F_{4–5}$)

This factor refers to the production of unwanted noise pollution in the neighboring region of the WWT stations that may affect the surrounding population.

As a result of these considerations, this study provides a comprehensive index system to evaluate wastewater treatment techniques using the above factors and sub-factors. For other problem-solving activities, researchers and users can add or delete sustainability factors sub-factors according to their problem or unique stakeholder requirements.

4. Preliminaries on Neutrosophic Theory, DEMATEL, and TOPSIS Methods

Empirical evidence of responses to the DEMATEL method, TOPSIS method, and neutrosophic theory indicated three main categories in the literature, which are discussed in this section.

4.1. Neutrosophic Theory

Smarandache first put forward the philosophical idea of the neutrosophic theory, which is a popularization of the fuzzy set (FS) and the IFS [24]. The notion of the FS was announced by [35]. Since then, MCDM techniques grounded on fuzzy sets have progressed well and are utilized in many fields. Solangi et al. presented a study to assess energy policies for sustainable energy development in Pakistan under a fuzzy environment [36]. Liu et al. introduced a fuzzy three-stage methodology for sustainable supplier selection [37]. Nevertheless, the fuzzy theory does not adequately express the subjectivity inherent in the predilections of decision-makers nor the uncertainty in the decision-making process, due to its reliance on a single degree of membership.

Grounded on the shortcomings of fuzzy theory in dealing with ambiguity and uncertainty sufficiently, Atanassov prolonged the FS to the IFS which included membership, non-membership, and hesitation degrees [38]. MCDM methods based on IFSs have been well-utilized in many areas. Büyüközkan et al. [39] developed a study for selecting cloud computing technology under an IF environment, and Büyüközkan and Göçer presented a hybrid intuitionistic fuzzy MCDM methodology for supplier selection [40].

Despite such application, neither FS nor IFS is adept at handling issues involving information uncertainty [41]. Therefore, the neutrosophic theory is significant as it overcomes the limitations of the FS and IFS. Neutrosophic theory can completely treat with indeterminacy, while fuzzy theory cannot treat at all with indeterminacy, and intuitionistic fuzzy theory only partially deals with indeterminacy [42]. Indeterminacy is a separated element in the neutrosophic environment, while in fuzzy and intuitionistic fuzzy environments, indeterminacy is dependent, or does not exist [42].

The neutrosophic theory has therefore been applied in many fields by researchers and decision-makers and there are many real-life applications under the neutrosophic environment. Vafadarnikjoo et al. introduced an assessment of customers' motivations to buy remanufactured goods by using single-valued neutrosophic sets (SVNSs) [43]. Liang et al. sought an appropriate way to evaluate the performance of the circular economy grounded on the MCDM approach under the neutrosophic environment [44]. Safdar et al. developed a study for designing a reverse logistics network to manage electronic waste under a neutrosophic environment [45]. Nabeeh et al. presented an approach for assessing green credit ranking and its effect on sustainability performance based on MCDM methodology under a neutrosophic environment [46]. Lastly, several neutrosophic numerical scales were developed as trapezoidal neutrosophic numbers [42], bipolar neutrosophic numbers [47], interval neutrosophic numbers [48], and TNNs [23]. In this study, we used the TNNs. In this regard, we provide some definitions related to neutrosophic theory and the TNNs.

Definition 1. *Let* $a = \langle (lo, md, up); \alpha, \theta, \ \beta \rangle$ *be an SVNS where lo, md, up signifies the lower, middle, and upper of NNs. In addition,* $T_a(x)$ *is the truth,* $I_a(x)$ *is the indeterminacy, and*$F_a(x)$ *is the falsity.*

$$T_a(x) = \begin{cases} \left(\frac{x-lo}{md-lo}\right)\alpha_a \text{ if } lo \le x \le md \\ \alpha_a \text{ if } x = md \\ \left(\frac{up-x}{up-md}\right)\alpha_a \text{ if } md \le x \le up \\ 0 \text{ otherwise} \end{cases} \quad (1)$$

$$I_a(x) = \begin{cases} \frac{(md-x)}{(md-l)}\theta_a \text{ if } lo \le x \le md \\ \theta_a \text{ if } x = md \\ \frac{(x-up)}{(up-md)}\theta_a \text{ if } md < x \le up \\ 1 \text{ otherwise} \end{cases} \quad (2)$$

$$F_a(x) = \begin{cases} \frac{(md-x)}{(md-lo)}\beta_a \text{ if } lo \le x \le md \\ \beta_a \text{ if } x = md \\ \frac{(x-up)}{(up-md)}\beta_a \text{ if } lo < x \le up \\ 1 \text{ otherwise} \end{cases} \quad (3)$$

Definition 2. *Let* $a = \langle (lo_1, md_1, up_1); \alpha_1, \theta_1, \ \beta_1 \rangle$ *and* $\widetilde{b} = \langle (lo_2, md_2, up_2); \alpha_2, \theta_2, \ \beta_2 \rangle$ *be two TNNs. Then:*

Addition of two TNNs:

$$\tilde{a} + \widetilde{b} = \langle (lo_1 + l_2, md_1 + md_2, \ up_1 + \ up_2); \alpha_1 \ \cap \ \alpha_2, , \theta_1 \ \cup \ \theta_2, \beta_1 \ \cup \ \beta_2 \rangle \quad (4)$$

Subtraction of two TNNs:

$$\tilde{a} - \widetilde{b} = \langle (lo_1 - up_2, md_1 - md_2, up_1 - \ lo_2); \alpha_1 \ \cap \ \alpha_2, \theta_1 \ \cup \ \theta_2, \beta_1 \ \cup \ \beta_2 \rangle \quad (5)$$

Inverse of two TNNs:

$$\tilde{a}^{-1} = \langle \left(\frac{1}{up_1}, \frac{1}{md_1}, \frac{1}{lo_1} \right); \alpha_1, \theta_1, \ \beta_1 \rangle, \text{ Where } (\tilde{a} \ne 0) \quad (6)$$

Multiplication of two TNNs:

$$\tilde{a}\widetilde{b} = \begin{cases} \langle (lo_1 lo_2, md_1 md_2, up_1 up_2); \alpha_1 \cap \alpha_2, \theta_1 \cup \theta_2, \beta_1 \cup \beta_2 \rangle \ \text{if}(up_1 > 0, up_2 > 0) \\ \langle (lo_1 up_2, md_1 md_2, up_1 lo_2); \alpha_1 \cap \alpha_2, \theta_1 \cup \theta_2, \beta_1 \cup \beta_2 \rangle \ \text{if}(up_1 < 0, up_2 > 0) \\ \langle (up_1 up_2, md_1 md_2, lo_1 lo_2); \alpha_1 \cap \alpha_2, \theta_1 \cup \theta_2, \beta_1 \cup \beta_2 \rangle \ \text{if}(up_1 < 0, up_2 < 0) \end{cases} \quad (7)$$

Division of two TNNs:

$$\frac{\widetilde{a}}{\widetilde{b}} = \begin{cases} \langle \left(\frac{lo_1}{up_2}, \frac{md_1}{md_2}, \frac{up_1}{lo_2} \right); \alpha_1 \cap \alpha_2, \theta_1 \cup \theta_2, \beta_1 \cup \beta_2 \rangle \ \text{if}(up_1 > 0, up_2 > 0) \\ \langle \left(\frac{up_1}{up_2}, \frac{md_1}{md_2}, \frac{lo_1}{lo_2} \right); \alpha_1 \cap \alpha_2, \theta_1 \cup \theta_2, \beta_1 \cup \beta_2 \rangle \ \text{if}(up_1 > 0, up_2 > 0) \\ \langle \left(\frac{u_{p1}}{lo_2}, \frac{md_1}{md_2}, \frac{lo_1}{up_2} \right); \alpha_1 \cap \alpha_2, \theta_1 \cup \theta_2, \beta_1 \cup \beta_2 \rangle \ \text{if}(up_1 > 0, up_2 > 0) \end{cases} \quad (8)$$

4.2. DEMATEL Method

Gabus and Fontela presented the DEMATEL technique for the first time in 1972 to depict factors that impact scientific, economic, and political issues [49]. DEMATEL is one of the important group decision-making techniques that allow decision-makers to characterize cause-and-effect elements, decide direct and indirect consequences of elements, and eventually determine insignificant elements [50]. DEMATEL aims to determine and process composite rational images from decision-makers to give a consistent and distinctive rational image. It has been utilized by several scholars in different fields. Kiani Mavi and Standing presented a study for determining serious success elements of sustainable venture administration using DEMATEL under a fuzzy environment [51]. Su et al. enhanced sustainable supply chain management by applying DEMATEL [52].

4.3. TOPSIS Method

Hwang and Yoon developed an easy and helpful MCDM technique called TOPSIS [53]. It shows the basis for evolving the approach for selection, particularly when the decision is to be taken in a mysterious environment. TOPSIS is grounded on the notion that the superlative alternate is the one that has the shortest space to the favorable ideal solution and the extreme space to a negative ideal solution. In this regard, this method is based on a negative and positive quixotic solution, in which the positive quixotic solution decreases the cost factors and increases the profit factors, while the negative quixotic solution decreases the profit factors and increases the cost factors [53]. A robust quixotic solution has the maximum classification for all attributes while the unfavorable quixotic solution has the minimum attribute values. TOPSIS is efficiently extended to solve MCDM problems under vague environments. Lei et al. presented research for supplier selection using the TOPSIS method by applying probabilistic linguistic information [54]. Wang et al. [55] introduced a study for evaluating symbiotic technology in the steel industry by applying the entropy TOPSIS technique and Wang et al. [56] developed an MCDM methodology, where TOPSIS used for selecting phytoremediation of petroleum-polluted soils in gas areas.

5. Proposed RISK Assessment Framework for Water/WasteWater CPS (RAF-CPWS)

This section presents a novel risk assessment framework, named RAF-CPWS, which perfectly measures the risks of water and wastewater CPS and their factors. The neutrosophic MCDM approach combined with DEMATEL and TOPSIS techniques to evaluate the four considered WWTTs and select the most sustainable WWTTs under the neutrosophic environment. The proposed model is divided into three phases: data collection, evaluation of factors using DEMATEL, and ranking of alternatives using TOPSIS. In addition, a schematic diagram was charted to summarize the core steps of the proposed RAF-CPWS framework, from the beginning of data collection to the arrangement of the technologies selected in the study, as shown in Figure 2.

5.1. Data Collection Phase

The data collection phase is one of the most important steps in that those responsible for collecting data must know all of the concepts and information related to simulating the water/wastewater CPS and its SCADA system. Furthermore, the information-gathering phase requires a great familiarity with the different data collection methods to ensure that the data are collected with sufficient and high accuracy. Accordingly, a committee consisting of four experts in the field of drinking water and sanitation has been identified to be responsible for gathering the necessary data on assessing available technologies. To collect the data with the view of real testbed water CPS, Figure 3 depicts the testbed of water CPS at the IoT Lab of UNSW Canberra. This testbed was employed to examine the credibility of the factors and subfactors used in this study. Four technologies of WWT were selected to be evaluated: AAO (A_1), TOD (A_2), ASOD (A_3), and SBRAS (A_4).

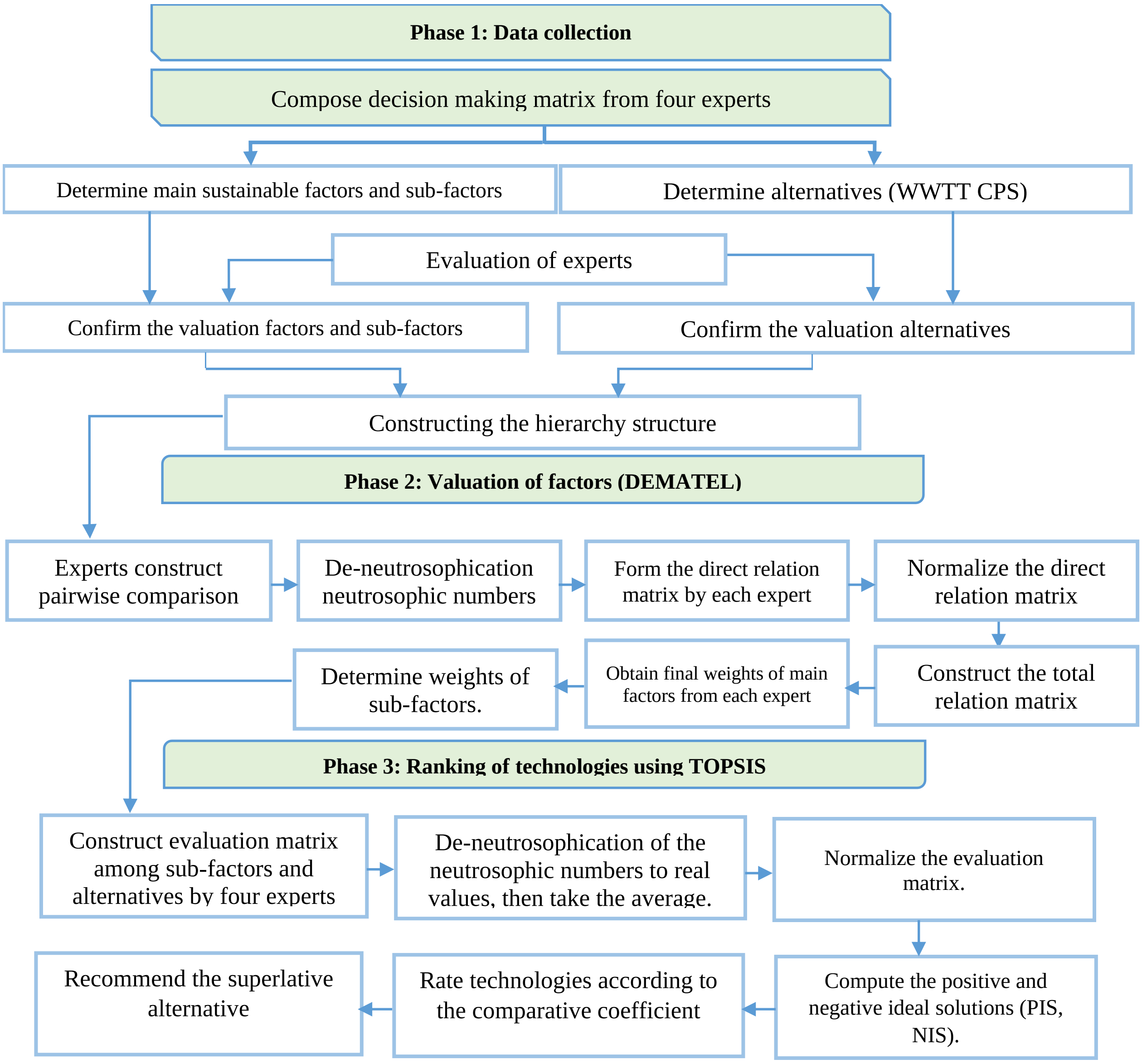

Figure 2. Proposed RAF-CPWS for assessing risks of water/wastewater CPS.

5.2. Factors Evaluation Phase

In this phase, we employed the neutrosophic DEMATEL method to identify the weights of the core sustainability and security factors (economic, environmental, technological and cybersecurity, and social-political) as well as the weights of sub-factors, tested on the water CPS at the IoT Lab of UNSW Canberra. DEMATEL is applied to assess the attributes interrelationship between the key factors and sub-factors, particularly those dealing with subjective vagueness and human uncertainty within the decision-making procedure by the utilization of the neutrosophic approach. The following stages were adopted to utilize the DEMATEL technique under the neutrosophic environment:

Stage 1. Create the linguistic variables and the neutrosophic scale founded on TNNs which are utilized to evaluate key factors and sub-factors and determine their priorities; in addition, assess WWTTs according to key factors and their sub-factors.

Stage 2. Construct a decision matrix A by each specialist (expert) between the key factors by utilizing the semantic terms as in Equation (9) and then by the TNNs according to Equation (10). Experts express their subjective opinions about the significance weights of each factor by applying semantic terms.

$$A = \begin{array}{c} F_1 \\ F_2 \\ \vdots \\ F_n \end{array} \overset{\begin{array}{cccc} F_1 & F_2 & \ldots & F_n \end{array}}{\begin{pmatrix} - & a_{12} & \ldots & a_{1i} \\ \ldots & - & \ldots & a_{2i} \\ a_{31} & \ldots & - & \ldots \\ a_{j1} & a_{j2} & \ldots & - \end{pmatrix}} \quad (9)$$

where $[a_{ij}]$, i, j = 1, 2 . . . n and a_{ij} is the performance assessment of the factor of the ith factor $F_1, F_2, \ldots, F_i$ regarding the jth factor $F_1, F_2, \ldots, F_j$. The previous equation treats with the matrix of dimension n × n, where n is the number of factors. The element's value that is associated with the diagonal of the matrix is equal to 0.5 such that a_{ij} = 0.5.

$$A = \begin{pmatrix} - & \langle(lo, md, up); \alpha, \theta, \beta\rangle_{12} & \ldots & \langle(lo, md, up); \alpha, \theta, \beta\rangle_{1i} \\ 1/\langle(lo, md, up); \alpha, \theta, \beta\rangle_{21} & - & \ldots & \langle(lo, md, up); \alpha, \theta, \beta\rangle_{2i} \\ \ldots & \ldots & - & \ldots \\ 1/\langle(lo, md, up); \alpha, \theta, \beta\rangle_{j1} & 1/\langle(lo, md, up); \alpha, \theta, \beta\rangle_{j2} & \ldots & - \end{pmatrix} \quad (10)$$

Stage 3. Create the initial direct relation matrix M base on decision matrices created by all responsible experts about giving their opinions on the problem and its aspects by converting the TNNs to integer values by applying Equation (11).

$$S(a) = \frac{1}{8} \times (lo + md + up) \times (2 + \alpha - \theta - \beta) \quad (11)$$

Stage 4. Construct the generalized direct relation matrix by utilizing Equations (12)–(13), grounded on the initial direct relation matrix that was created. In addition, it must be taken into account that the main diagonal has a value of 0.5.

$$K = \frac{1}{Max_{1 \le i \le n} \sum_{j=1}^{n} a_{ij}} \quad (12)$$

$$S = K \times M \quad (13)$$

where M is the initial direct relation matrix n × n and K is a set of elements identified by pairwise comparison to identify the significance of the factors.

Stage 5. Develop the total relation matrix T according to Equation (14), grounded on the generalized relation matrix.

$$T = S \times (I - S)^{-1} \quad (14)$$

where S is the generalized direct relation matrix and I is the identity matrix. The item t_{ij} denotes the unintended effects of element i on j. Thus, T signifies the total relation matrix of each pair of scheme elements.

Stage 6. Calculate the total of rows according to Equation (15) that is denoted by R, as well as the total of columns by applying Equation (16) that is denoted by C. Then, calculate R + C and R − C where the horizontal axis is "Prominence" and the vertical axis is "Relation", where $T = [t_{ij}]_{n\times n}$, i, j = 1, 2 . . . n.

$$R = \left[\sum_{i=1}^{n} t_{ij}\right]_{1\times n} \quad (15)$$

$$C = \left[\sum_{j=1}^{n} t_{ij}\right]_{n\times 1} \quad (16)$$

Stage 7. Identify the significance of the key factors by applying Equation (17). The obtained weights of the key factors are used in determining the global weights of sub-factors used in ranking WWTTs.

$$w = \frac{w}{\sum_{i=1}^{n} w} \tag{17}$$

Stage 8. Obtain the final weights of key factors by taking the mean of the final weights from the experts. Likewise, the weights of the sub-criteria are determined by performing the same steps for all sub-factors of each key factor. Accordingly, the global weights of the sub-factors are determined by multiplying the value of the weight of the main factor with the weight of the local sub-factors obtained.

Figure 3. Water CPS testbed used at the IoT lab of UNSW Canberra.

5.3. Ranking of Alternatives Phase

In this phase, we followed the steps of the TOPSIS method which was employed to rank the four WWTTs, namely, AAO, TOD, ASOD, and SBRAS, that were used in this case study. In this regard, the process of ranking the available technologies using the TOPSIS method depends on the weights of the main factors and their sub-factors that were summarized and obtained using the DEMATEL method.

Stage 9. Construct a decision matrix X by each expert between the considered technologies and corresponding sub-factors by using the semantic variables, and then by TNNs. Following this, convert the TTNs to real numbers according to Equation (11).

Stage 10. Create the decision matrix X among the considered technologies and corresponding sub-factors as shown in Equation (18), based on the average of the four experts' matrices.

$$X = \left(X_{ij}\right)_{m\times n} = \begin{pmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{pmatrix} \quad (18)$$

where m refers to the considered technologies, and n denotes the sub-factors, if x_{ij} is the evaluation of the ith considered technologies $A_1, A_2, \ldots, A_n$ according to the j^{th} factor F_1, $F_2, \ldots, F_m$.

Stage 11. Based on the decision matrices that were created between the considered technologies and the sub-factors for all the key factors, the decision matrices are normalized using Equation (19).

$$\dot{R} = \left(r_{ij}\right)_{m\times n} = x_{ij}/\left(\sqrt{\sum_{i=1}^{m} x_{ij}^2}\right) \quad (19)$$

Stage 12. Based on the normalized matrix, the weighted normalized matrix is computed by applying Equation (20).

$$P = \left[p_{ij}\right]_{m\times n} = w_j \times r_{ij}; \quad (20)$$

where w_j is the weight of each sub-factor.

Stage 13. Determine the positive ideal solution (PIS, I^+) according to Equation (21), and the negative ideal solution (NIS, I^-) by applying Equation (22).

$$I^+ = \left\{p_1{}^+, p_2{}^+, \ldots, p_j{}^+, \ldots, p_n{}^+\right\} \quad (21)$$

where $p^+ = \left\{(\max_i p_{ij} \; |j \in J_b\right), (\min_i p_{ij} |j \in J_{nb})\Big| \in [1\ldots m]\Big\}$, in which J_b and J_{nb} are sets of advantageous and non-advantageous factors, respectively.

$$I^- = \left\{p_1{}^-, p_2{}^-, \ldots, p_j{}^-, \ldots, p_n{}^-\right\} \quad (22)$$

where $p^- = \left\{(\min_i p_{ij} \; |j \in J_b\right), (\max_i p_{ij} |J \in J_{nb})\Big| \in [1\ldots m]\Big\}$, and J_b and J_{nb} are sets of advantageous and non-advantageous factors, correspondingly.

Stage 14. Determine the Euclidean distance among the positive and negative perfect solution d_i^+ and d_i^- respectively by applying Equations (23) and (24).

$$d_i^+ = \sqrt{\sum_{j=1}^{n} \left(P_{ij} - P_j{}^+\right)^2}, \; j = 1, 2, \ldots, m. \quad (23)$$

$$d_i^- = \sqrt{\sum_{j=1}^{n} \left(P_{ij} - P_j{}^-\right)^2}, \; j = 1, 2, \ldots, m. \quad (24)$$

Stage 15. Determine the proportional closeness (S_i) to the d_i^+ and d_i^- for each technology by applying Equation (25), then rank the technologies according to the value of S_i.

$$S_i = \frac{d_i^-}{d_i^+ + d_i^-} \; i = 1, 2, \ldots, m \quad (25)$$

6. Evaluation of Wastewater Treatment CPS

6.1. Application of the Suggested Framework

In this part, we apply the proposed RAF-CPWS framework using the water CPS testbed at the IoT Lab of UNSW Canberra to show the stages of data collection and alternative ranking. Figure 4 summarizes the factors of the problem, including the four main sustainable factors, their fifteen sub-factors, and the four WWTTs.

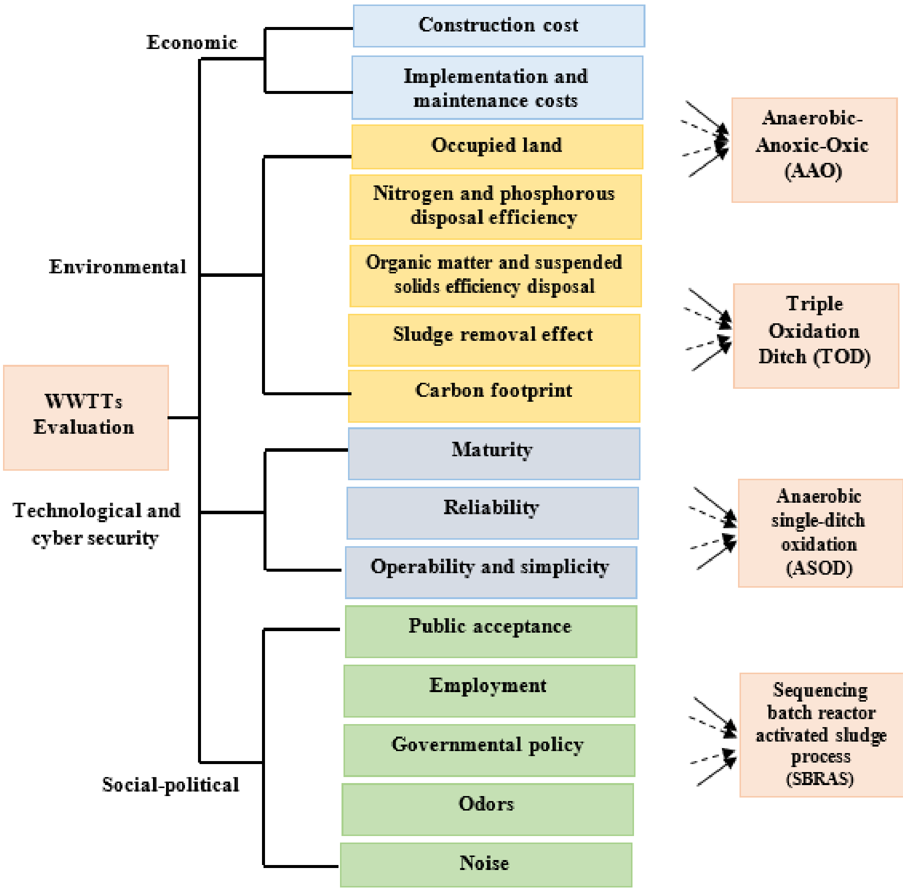

Figure 4. Key factors, sub-factors, and WWTT CPS.

6.1.1. Data Collection Phase

At first, the committee responsible for collecting the data is identified. The committee consists of four groups, each of which has separate executive tasks and is responsible for a specific part of the problem and studying its details. Each group selects one person as a spokesperson for the group—we refer to these spokespeople as 'experts' in the following sections (the four groups are therefore represented by four 'experts').

Subsequently, the aspects of the problem such as the main sustainability factors are determined: economic factor ECF (F_1), environmental factor ENF (F_2), technological and cybersecurity factor TEF (F_3), and social-political factor SOF (F_4). The economic factor sub-factors are construction cost COC (F_{1-1}) and implementation and maintenance costs OMC (F_{1-2}). The environmental factor sub-factors are occupied land OCL (F_{2-1}), nitrogen and phosphorous disposal efficiency NPD (F_{2-2}), organic matter and suspended solids disposal efficiency OSD (F_{2-3}), sludge removal effect SRE (F_{2-4}), and carbon footprint CAF (F_{2-5}). The technological and cybersecurity factor sub-factors are maturity MAT (F_{3-1}), reliability REL (F_{3-2}), and operability and simplicity OST (F_{3-3}). The social-political factor sub-factors are public acceptance PAC (F_{4-1}), employment EMP (F_{4-2}), governmental policy GOP (F_{4-3}), odors ODS (F_{4-4}), and noise NOS (F_{4-5}). The WWTTs to be evaluated are AAO, TOD, ASOD, and SBRAS. In addition, a hierarchical structure for the problem grounded on the key sustainability factors and its sub-factors and alternatives is constructed as shown in Figure 4. The linguistic expressions and their equivalent triangular neutrosophic numbers to assess the factors and locate their priorities are defined as in Table 2. Fulfillment of the technologies is assessed using the semantic variables as in Table 3.

Table 2. Semantic variables and equivalent of TNNs utilized for measuring factors and sub-factors.

Semantic Variables	Acronyms	TNNs ⟨(lo, md, up);α, β, θ⟩
Little agreed	LIA	⟨(0.11, 0.26, 0.27); 0.49, 0.11, 0.29⟩
Natural agree	NTA	⟨(0.37, 0.34, 0.48); 0.70, 0.19, 0.16⟩
Primary agree	PRA	⟨(0.49, 0.61, 0.75); 0.60, 0.18, 0.12⟩
Seriously agreed	SRA	⟨(0.87, 0.79, 0.75); 0.80, 0.08, 0.12⟩
Highly strong agreed	HSA	⟨(0.99, 0.89, 0.87); 0.90, 0.12, 0.07⟩

Table 3. Semantic variables and equivalent of TNNs utilized for rating considered alternates.

Semantic Variables	Acronyms	TNNs ⟨(lo, md, up);α, β, θ⟩
Exceedingly little	EXL	⟨(0.09, 0.29, 0.37); 0.10, 0.19, 0.16⟩
Little	LL	⟨(0.27, 0.24, 0.19); 0.58, 0.19, 0.31⟩
Moderate little	MOL	⟨(0.39, 0.40, 0.46); 0.59, 0.09, 0.21⟩
Moderate	MO	⟨(0.55, 0.65, 0.75); 0.79, 0.09, 0.11⟩
Moderate potent	MOP	⟨(0.69, 0.64, 0.82); 0.89, 0.19, 0.11⟩
Potent	PO	⟨(0.89, 0.87, 0.89); 0.89, 0.19, 0.21⟩
Exceedingly potent	EXP	⟨(0.97, 0.89, 0.94); 0.90, 0.11, 0.09⟩

6.1.2. Factors Evaluation Phase

In this part, the first steps of applying the DEMATEL method begin with knowing the weights of the key factors and their sub-factors. The calculations for this method can be found in the tables in Appendix A. Initially, the first steps of the DEMATEL method are applied and four decision matrices are created between the key sustainability factors to reach and determine the final weights of the key factors used in determining the optimal WWTT, according to Equation (9), using the semantic variables in Table 2, as in Table A1. Subsequently, the four decision matrices from semantic variables are converted to neutrosophic numbers according to Equation (10) by using the neutrosophic numbers in Table 3, as exhibited in Table A2. In this regard, for dealing with data clearly and smoothly, TNNs are converted into real numbers using Equation (11). Accordingly, one of the steps of the core DEMATEL method is applied, constructing the four generalized direct relation matrices by using Equation (12) and then by applying Equation (13) as exhibited in Table A3.

The four total relation matrices are developed by utilizing Equation (14) and showing results in Table A4. Consequently, the total of rows is computed according to Equation (15) that is denoted by R, and the total of columns by applying Equation (16) that denoted by C. Also, the values of R + C and R − C are computed as exhibited in Table A4. In this regard, the significance of the key factors by all specialists are identified by utilizing Equation (17) as exhibited in Table 4 and as shown in Figure 5. Figure 5 shows the relation between the key factors by all experts and their weights on the horizontal and vertical axes, respectively. Then, we obtain the concluding weights of the key sustainability factors by taking the mean of the final weights for the four experts as in Table 4 and as shown in Figure 6. Figure 6 shows the relation between the key factors used in the assessment and their weights on the horizontal and vertical axes, respectively. Similarly, the weights of sub-factors are identified founded on the collective decisions of the experts as exhibited in Tables A5–A12. Also, the final weights of all sub-factors are charted in many figures to be more clear and easy for the reader as in Figures 7–10. These figures show the relationship between the main factors' sub-factors and their weights on the horizontal and vertical axes, respectively. Finally, the global weights based on the key sustainability factors and the local weights of sub-factors are computed as presented in Table 5.

Table 4. Weights of key factors using the DEMATEL method.

Main Factors	Final Weights by Expert$_1$	Final Weights by Expert$_2$	Final Weights by Expert$_3$	Final Weights by Expert$_4$	Final Weights by All Experts	Rank
F_1 (ECF)	0.264	0.258	0.215	0.281	0.27	2
F_2 (ENF)	0.252	0.233	0.252	0.270	0.25	3
F_3 (TEF)	0.213	0.197	0.238	0.219	0.18	4
F_4 (SOF)	0.272	0.313	0.293	0.230	0.30	1

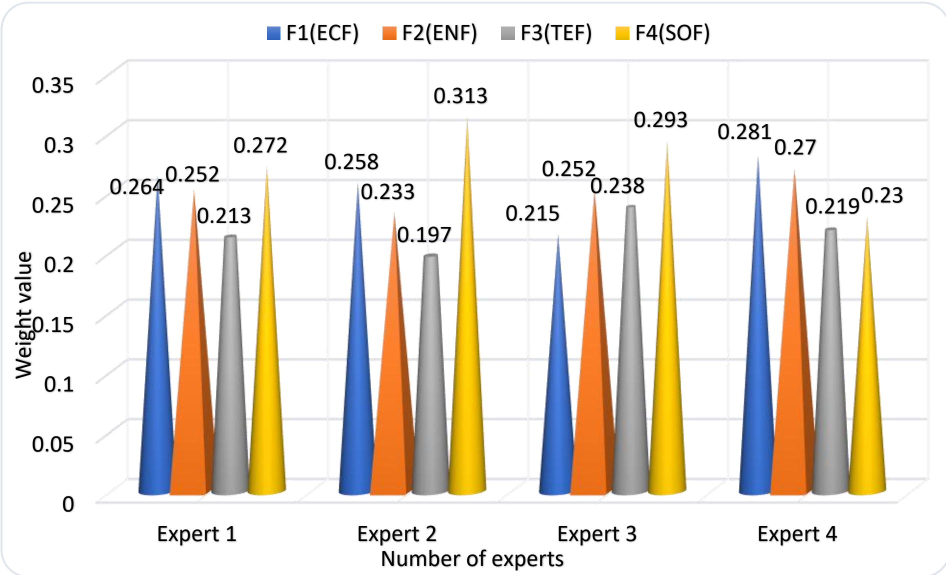

Figure 5. Weights of key factors using the DEMATEL method.

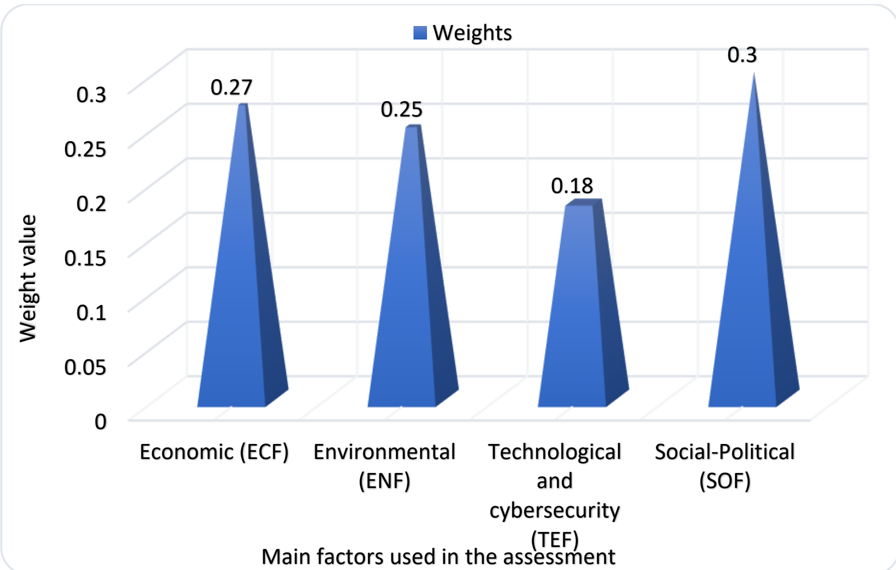

Figure 6. Concluding weights of the four key factors using DEMATEL.

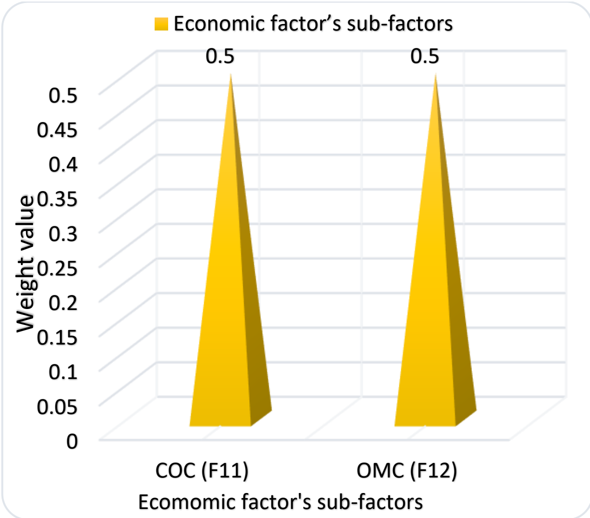

Figure 7. Local weights of the economic factor’s sub-factors.

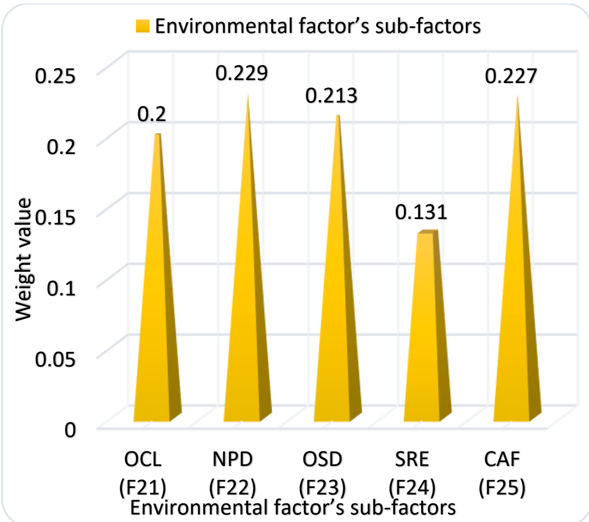

Figure 8. Local weights of the environmental factor’s sub-factors.

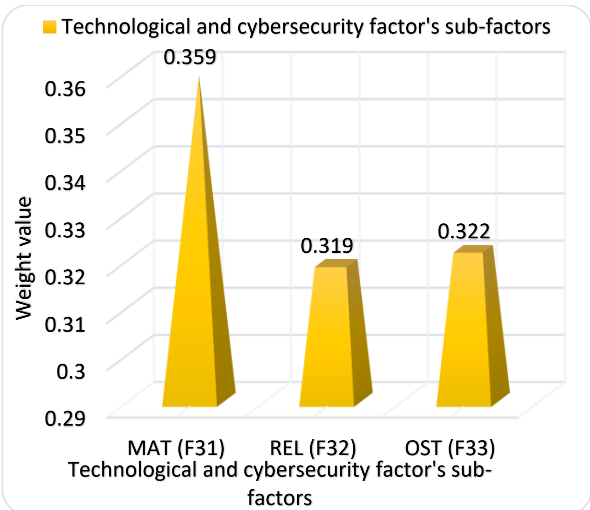

Figure 9. Local weights of the technological and cybersecurity factor’s sub-factors.

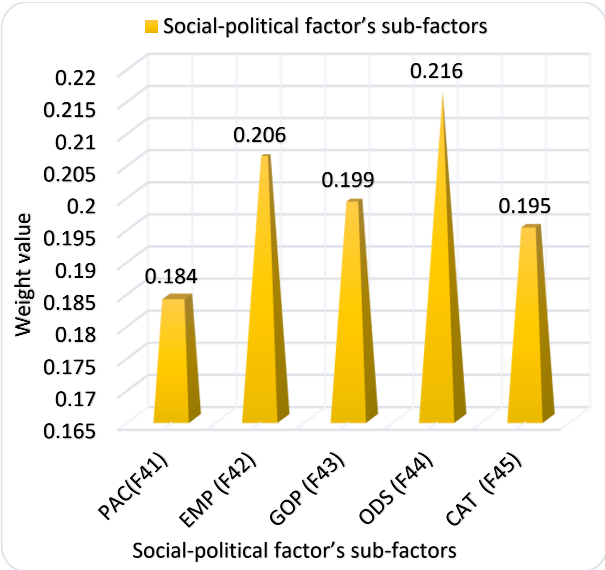

Figure 10. Local weights of the social-political factor's sub-factors.

Table 5. The proportion of the local and global sub-factors using DEMATEL.

Main Factors	F_1 (ECF)		F_2 (ENF)					F_3 (TEF)			F_4 (SOF)				
Weight	0.27		0.25					0.18			0.30				
Sub-factors	$F_{1–1}$	$F_{1–2}$	$F_{2–1}$	$F_{2–2}$	$F_{2–3}$	$F_{2–4}$	$F_{2–5}$	$F_{3–1}$	$F_{3–2}$	$F_{3–3}$	$F_{4–1}$	$F_{4–2}$	$F_{4–3}$	$F_{4–4}$	$F_{4–5}$
Local weights	0.500	0.500	0.200	0.229	0.213	0.131	0.227	0.359	0.319	0.322	0.184	0.206	0.199	0.216	0.195
Global weights	0.135	0.135	0.050	0.057	0.053	0.033	0.057	0.064	0.057	0.058	0.055	0.062	0.059	0.064	0.058
Rank	11	10	2	5	3	1	5	9	5	6	4	8	7	9	6

6.1.3. Ranking of Alternatives Phase

At this phase, the results of the TOPSIS method are applied and explained, which is responsible for the part of demonstrating the best technology among the four WWTTs that were taken into account through the study, namely, AAO, TOD, ASOD, and SBRAS. In addition, the computations and results of the TOPSIS method steps are shown in Appendix A, especially in Tables A13–A16. Accordingly, the four decision matrices are constructed by each expert between considered technologies and corresponding sub-factors according to Equation (18), as in Table A13, utilizing the semantic variables and TNNs as shown in Table 3. Subsequently, the four decision matrices constructed of TTNs are converted to real values by applying Equation (11); then, the average of the four experts' matrices is taken and brought into the aggregated table as presented in Table A14. Consequently, the aggregated data in Table A14 are normalized according to Equation (19) and as presented in Table A15. Accordingly, the weighted normalized data are computed to fulfill the requirements of the TOPSIS method, which is one of the core steps in applying the TOPSIS method by utilizing Equation (20) and as presented in Table A16. Consequently, the PIS and the NIS are computed according to Equation (21) and Equation (22), respectively, as shown in Table A16. Then, we estimate the positive and negative perfect solution, respectively, d_i^+ and d_i^-, according to Equations (23) and (24) as presented in Table 6. In general, based on the data that were calculated in the previous steps and upon determining each of the positive and negative ideal solutions for d_i^+ and d_i^- respectively, the proportional closeness is estimated according to Equation (25) for each technology as presented in Table 6. Lastly, the WWTTs are ranked in descending order based on the value of proportional closeness as charted in Figure 11. Figure 11 shows the relation among the considered WWTTs used in the assessment and their proportional closeness value on the horizontal and vertical lines, respectively.

Table 6. Rating of WWTTs by TOPSIS technique.

WWTTs	d_i^+	d_i^-	S_i	Rank (S_i)
A_1 AAO	0.1242	0.0131	0.0971	4
A_2 TOD	0.0543	0.0963	0.6373	2
A_3 ASOD	0.0441	0.1034	0.7024	1
A_4 SBRAS	0.0934	0.0636	0.4045	3

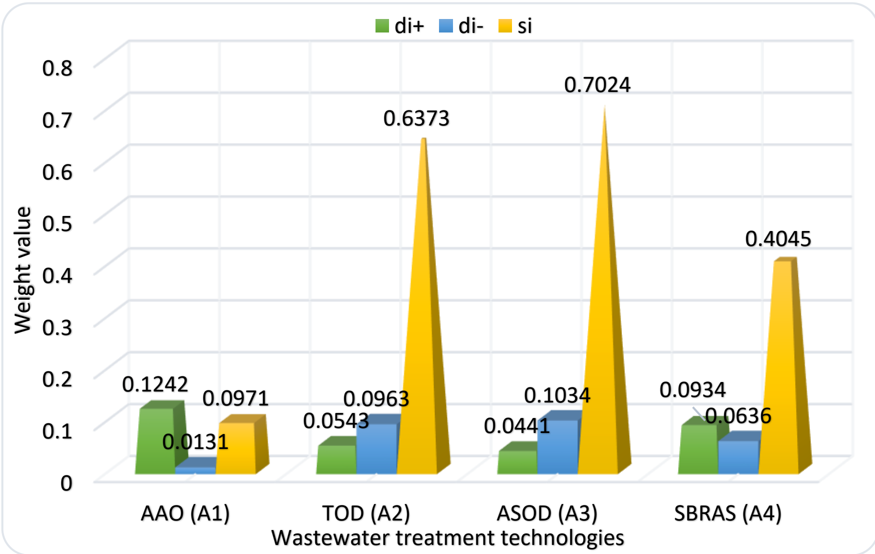

Figure 11. Final ranking of WWTT by TOPSIS.

6.1.4. Consequences Analysis

In this part, the obtained consequences from the proposed approach in the assessment process of WWTT CPS are explained. In this article, the results are allocated into two portions. The first portion is associated with the results of defining the concluding weights of the key factors and their sub-factors using the DEMATEL method under the neutrosophic environment, while the remainder of the results is the result of ranking WWTT CPS using the neutrosophic TOPSIS method.

- First, weights of the key sustainable factors have been identified by four experts in the field of drinking water and sanitation separately. The first expert determined that the social-political factor is the most important with a weight of 0.272 and the least important was the technological and cybersecurity factor; 0.213. The second expert determined that the social-political factor is the most important with a weight of 0.313 and the least important was the technological and cybersecurity factor; 0.197. The third expert identified that the social-political factor was the highest with a weight of 0.293 and the economic factor was the lowest at 0.215. The fourth expert determined that the economic factor has a top value equal to 0.281, and the technological and cybersecurity factor has a minimum value equal to 0.219. Based on the weights determined by the four experts, the final weights were determined for the key sustainable factors, where the social-political factor is the most important with the weight of 0.30 and the least important was the technological and cybersecurity factor at 0.18.
- Second, the weights of sub-factors showed that the construction cost factor is the highest at 0.135 and the carbon footprint is the lowest weight at 0.033.
- Third, the results of the TOPSIS method showed that A_3 anaerobic single oxidation ditch (ASOD) is the most sustainable technology for WWT followed by A_2 triple oxidation ditch (TOD) and lastly, A_1 anaerobic anoxic oxic (AAO).

7. Comparative Analysis

In this article, a comparative study has been conducted to demonstrate the effectiveness and advantages of the proposed DEMATEL-TOPSIS approach under the neutrosophic environment. Comparison is based on the issue, results, or at the expense of the study as a whole, and the objective of using this approach is to simplify the characteristics of data that we want to compare and to identify methods of convergence, commonalities, and the differences. The proposed approach was compared with two other approaches in different environments: the group MADA method based on IFS [8] and the IT2F approach founded on an MCGDM [12]. All approaches presented various outcomes in the ranking of the WWTTs. Each approach has been implemented, with various numbers of core sustainability factors, sub-factors, and numbers of identified WWTTs.

Overall, all the rating risk assessment and decision-making approaches that are used for highlighting the best alternatives have many purposes; the most important of them is highlighting the best alternate and the best rating scheme. A comparison is led between the proposed approach and its results based on the weights computed in Table 5, in addition to the data that were aggregated between the alternatives and sub-factors in Table A14. Figure 12 and Table 7 show the outcomes of the above-mentioned approaches to improve visibility. Figure 12 shows the relation between the number of WWTTs used in the study and the value of their ranking on the horizontal and vertical lines, respectively.

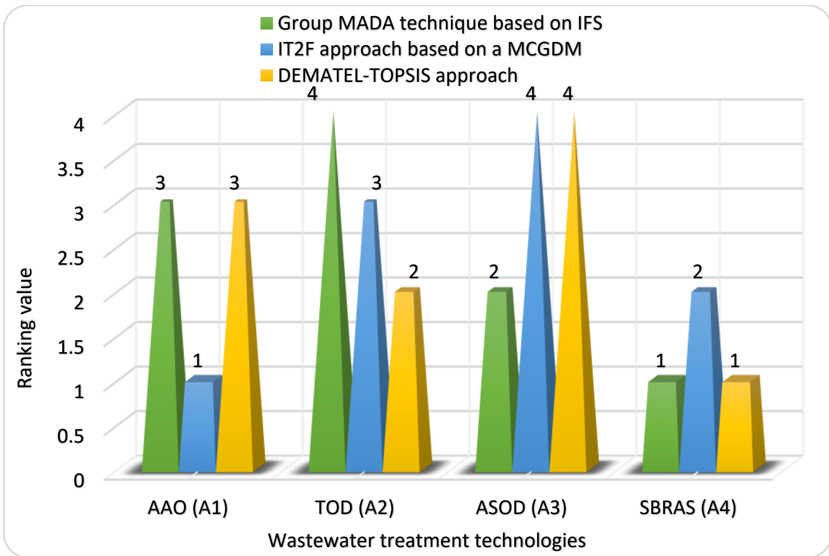

Figure 12. Comparison of different approaches results.

Best alternate: this paper suggests one approach comprising two MCDM methods: DEMATEL-TOPSIS under neutrosophic environment, with the optimal sustainable technology of wastewater treatment as the ASOD technology, followed by TOD technology. In contrast, ASOD is the best sustainable wastewater treatment technology by the group MADA method based on IFS methodology, followed by AAO technology, and AAO is the best approach for the interval type-2 fuzzy approach founded on an MCGDM methodology followed by TOD technology. This shows the consistency among the DEMATEL-TOPSIS approach proposed here and the other compared, given that the same information is used. Nevertheless, the other compared approaches with them do not consider some aspects of the problem nor do they optimally deal with some information under uncertainty compared to the proposed approach.

Table 7. Proportional comparison between various MCDM methodologies.

Methodologies Used in Comparison		
Group MADA method based on IFS [8]	IT2F approach based on a MCGDM [12]	The proposed DEMATEL-TOPSIS approach
The environment in which the study was conducted		
Intuitionistic fuzzy	Fuzzy	Neutrosophic
The type of modification used in the approach		
Enhancement	Enhancement	Hybridization
The persons responsible for expressing their opinions in the aforementioned studies		
Different experts	Three experts	Four experts
Core sustainability factors		
Four core sustainability factors included economic, environmental, technological, and social-political.	Four main sustainability factors included economic, environmental, technical, and society.	Four main sustainability factors included economic, environmental, technological and cybersecurity, and social-political.
The numeral of sustainability sub-factors		
Ten sub-factors	Eight sub-factors	Fifteen two sub-factors
The numeral of WWT technologies		
Four WWT technologies	Four WWT technologies	Four WWT technologies
Measures		
Triangular fuzzy measure	IT2F measure	Triangular neutrosophic measure
Rating WWT technologies by other approaches		
Group MADA method based on IFS $A_3 > A_4 > A_2 > A_1$ ASOD > SBRAS > TOD > AAO	IT2F approach grounded on a MCGDM $A_1 > A_3 > A_4 > A_2$ AAO > ASOD > SBRAS > TOD	Ranking by proposed DEMATEL-TOPSIS approach $A_3 > A_2 > A_4 > A_1$ ASOD > TOD > SBRAS > AAO
Pearson rank correlation coefficient		
0.800	0.600	-

Best rating: Table 7 presents some approaches that can be a perfect ranking approach and on the contrary, there are variations among them. In this regard, for the suggested DEMATEL-TOPSIS approach, the variations among it and the group MADA method based on the IFS approach are the rating position of SBRAS and TOD. Further, for the DEMATEL-TOPSIS approach and IT2F approach grounded on an MCGDM, the differences are in the arrangements of the positions of AAO, ASOD, TOD. These changes and the presence of a slight similarity between the results of the proposed method and the other methods with which it is compared are acceptable and natural, due to the different opinions of experts and decision-makers. Finally, these differences are allowable for determining the successfulness, effectiveness, validity, appropriateness, and superiority of the submitted approach.

Finally, after making comparisons with previous studies, we applied a Pearson correlation coefficient to assess reliabilities and demonstrate the extent of correlation between the results of our approach and the results of the approaches used in the comparison in order to demonstrate the efficacy and validity of the proposed technique. In this regard, we suggested that the degree of similarity between any two methods of MCDM is equal to 0.800, so if the value of the Pearson coefficient between any two methods is greater than or equal to 0.800, this means a high degree of similarity between the two methods in their results in addition to a high degree of compatibility. On the contrary, if the value of the Pearson coefficient is less than 0.800, this indicates a large difference between the two methods in the results and the presence of slight compatibility between the two methods. In this regard, the rate correlation coefficients between the proposed approach and group

MADA method based on the IFS approach is equal to 0.800, which shows a large degree of compatibility between the two comparative approaches in their results. The rate correlation coefficient between the suggested technique and the IT2F approach grounded on a MCGDM approach is equal to 0.600, which shows that there is no significant similarity between the two methods of comparison in their results. In sum, based on the results of the previous discussion, it appears that the proposed model has priority over one of the comparison approaches, which is the IT2F approach grounded on the MCGDM approach.

8. Sensitivity Analysis

A sensitivity analysis was conducted to identify the strengths of the performance value between the current and alternative WWTTs grounded on varying the weights of the four main factors. Seven different cases were generated on factor weights to investigate the impacts of the weights of the factors on the rating of the available WWTTs as showed in Table 8 and Figure 13, where Figure 13 shows the relationship among the different states on the horizontal line and the value of the change in weight on the vertical line.

Table 8. Changes in factor weights for the seven cases.

Factors	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7
F_1	0.27	0.25	0.52	0.19	0.21	0.20	0.22
F_2	0.25	0.25	0.18	0.50	0.15	0.17	0.30
F_3	0.18	0.25	0.10	0.09	0.43	0.08	0.23
F_4	0.30	0.25	0.20	0.22	0.21	0.55	0.25

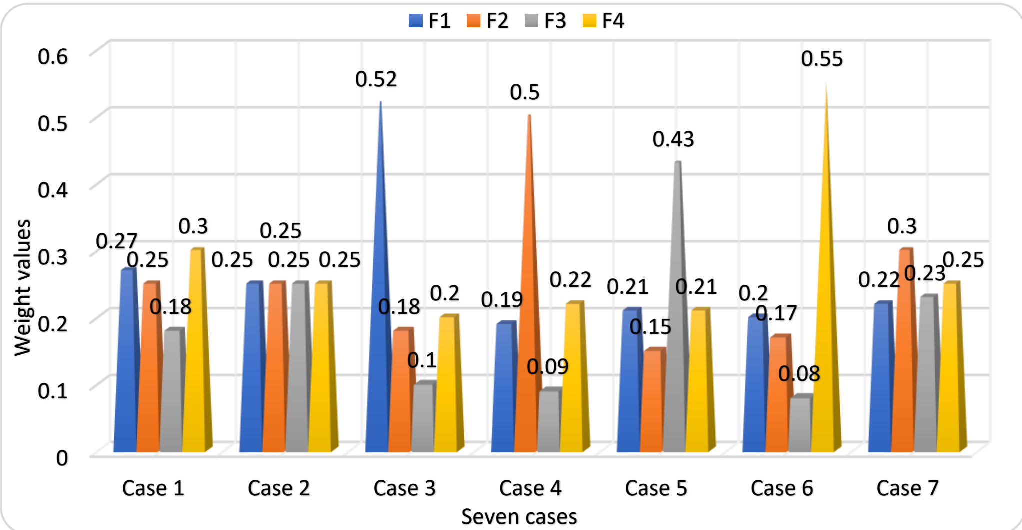

Figure 13. Changes in weights for the seven cases.

- Case 1, the weights of the main factors obtained from conducting the study are considered according to data collection from experts.
- Case 2, all weights of the principal factors are assumed as equal in weight, without considering that one factor is better than the other.
- Case 3 assumed that factor F_1 was augmented by 25%, and the remained factors decreased by the amount of the percentage increase to remain the total weights of factors equal 1.
- Case 4 assumed that factor F_2 was augmented by 25%, and the remained factors decreased by the amount of the percentage increase to remain the total weights of factors equal 1.

- Case 5 assumed that factor F_3 was augmented by 25%, and the remained factors decreased by the amount of the percentage increase to remain the total weights of factors equal 1.
- Case 6 assumed that factor F_4 was augmented by 25%, and the remained factors decreased by the amount of the percentage increase to remain the total weights of factors equal 1.
- Case 7 assumed that factor F_1 and factor F_4 was decreased by 10%, and the remained factors increased by the amount of the percentage decrease to remain the total weights equal to 1.

In this regard, Figures 14–19 show results of the sensitivity analysis based on changing weights of main factors according to seven cases in Table 8.

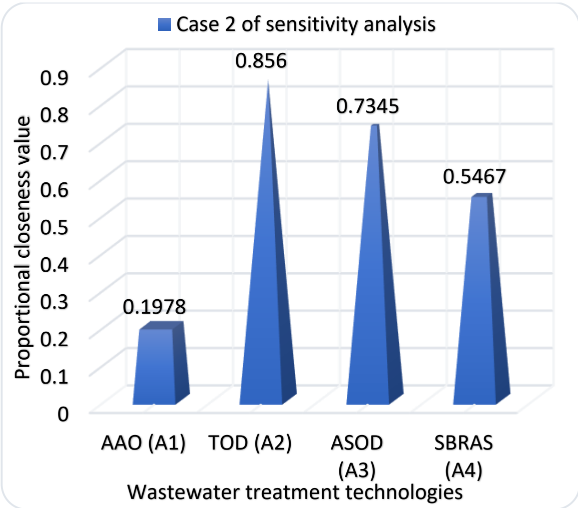

Figure 14. Ranking of WWTTs according to equality of all factors weights.

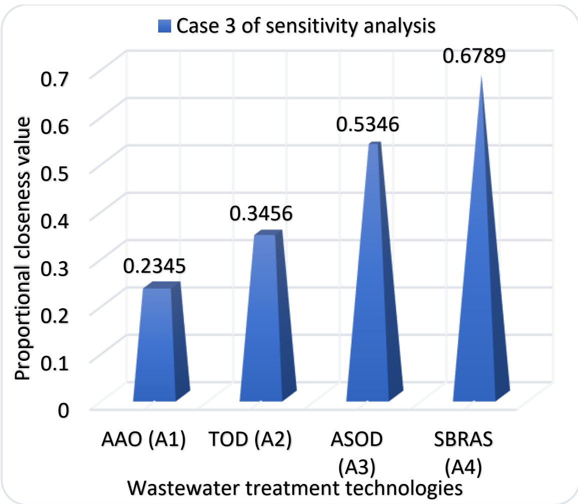

Figure 15. Ranking of WWTTs according to variation in the economic factor that augmented by 25%.

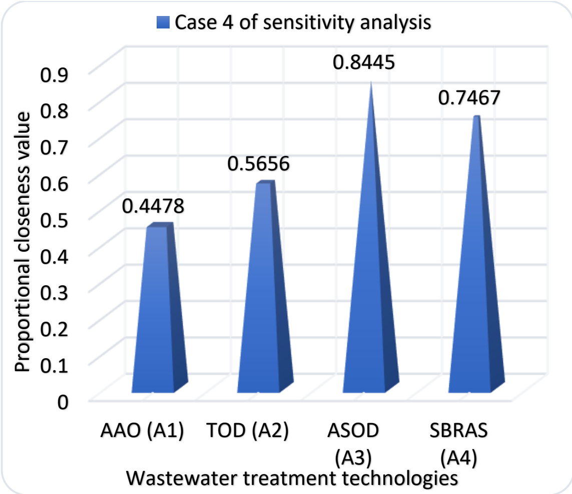

Figure 16. Ranking of WWTTs according to variation in the environmental factor that augmented by 25%.

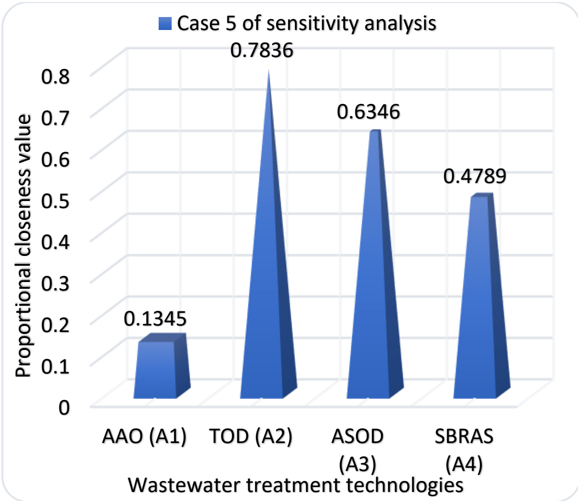

Figure 17. Ranking of WWTTs according to variation in the technological and cybersecurity factor that augmented by 25%.

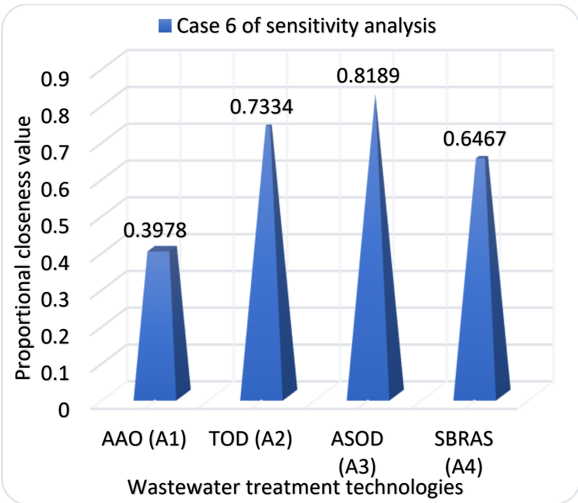

Figure 18. Ranking of WWTTs according to variation in the social-political factor that augmented by 25%.

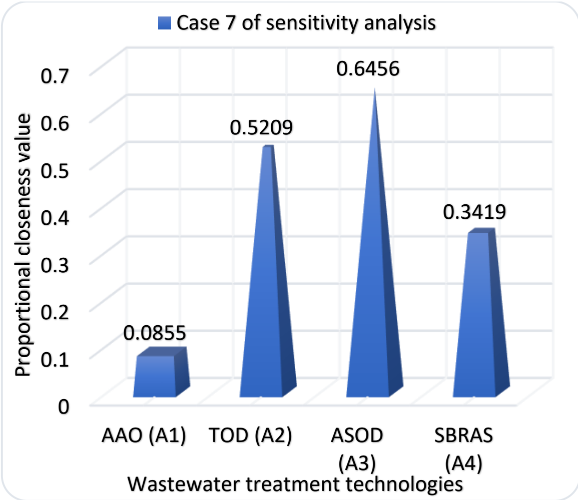

Figure 19. Ranking of WWTTs according to variation in the economic and technological factors that reduced by 10%.

In case 1, the weights obtained from conducting the study were considered as in Table 4 and Figure 6. Hence, the results show that the third technology ASOD (A_3) is the best technology with a weight of 0.702, followed by the second technology TOD (A_2) with a weight of 0.637, and the first technology AAO (A_1) comes in the last rank with a weight of 0.097.

In case 2, after analyzing the data according to the change in the weight of all factors and their equal weight, the results show that the second technology TOD (A_2) is the optimal technology with a weight of 0.8560, followed by the third technology ASOD (A_3) with a weight of 0.7345, and the first technology AAO (A_1) comes in the last rank with a weight of 0.1978.

In case 3, after performing an analysis of the data according to the change in the weight of the economic factor F_1 with an increase of 25%, the results show that the fourth technology SBRAS (A_4) is the optimal technology with a weight of 0.6789, followed by the third technology ASOD (A_3) with a weight of 0.5346, and the first technology AAO (A_1) comes in the last rank with a weight of 0.2345.

In case 4, after performing an analysis of the data according to the change in the weight of the environmental factor F_2 with an increase of 25%, the results show that the third technology ASOD (A_3) is the optimal technology with a weight of 0.8445, followed by the fourth technology SBRAS (A_4) with a weight of 0.7467, and the first technology AAO (A_1) comes in the last rank with a weight of 0.4478.

In case 5, after performing an analysis of the data according to the change in the weight of the technological and cybersecurity factor F_3 with an increase of 25%, the results show that the third technology TOD (A_2) is the best technology with a weight of 0.7836, followed by the third technology ASOD (A_3) with a weight of 0.6346, and the first technology AAO (A_1) comes in the last rate with a weight of 0.1345.

In case 6, after performing an analysis of the data according to the change in the weight of the social-political factor F_4 with an increase of 25%, the results show that the third technology ASOD (A_3) is the ideal technology with a weight of 0.8189, followed by the second technology TOD (A_2) with a weight of 0.7334, and the first technology AAO (A_1) comes in the last rank with a weight of 0.3978.

In case 7, after performing an analysis of the data according to the change in the weight of the economic factor F_1 and the social-political factor F_4 with a decrease of 10%, the results show that the third technology ASOD (A_3) is the optimal technology with a weight of 0.6456, followed by the second technology TOD (A_2) with a weight of 0.5209, and the first technology AAO (A_1) comes in the last rate with a weight of 0.0855.

In sum, by the results of the sensitivity analysis, it was found that in all the cases that were conducted, the best technology may change with the change of weights. In some cases, ASOD technology is the optimal technology, while for another case it is SBRAS technology, and in other cases it is TOD technology. Nevertheless, the first technology, AAO, is the worst in all cases that were conducted according to the change in weights as in Figures 14–19.

9. Technical Implications

Proper treatment of wastewater is indispensable for public health, as well as for the sustainability of water resources and protection of the natural environment, all of which have a major effect on economic and social well-being. The managerial implications of choosing more sustainable wastewater treatment technologies are as follows:

- The suggested neutrosophic DEMATEL-TOPSIS methodology is employed in an actual case is for selecting the optimal WWTT that is advantageous to scholars, stakeholders, and water engineers, legislators, and officials.
- The proposed methodology provides for the possibility of dealing with uncertainty by conducting the study under a neutrosophic environment and using many semantic variables and their equivalent neutrosophic numbers to describe the technologies and selecting the best WWTT in all cases of uncertainty.
- Sustainable development—access to a wastewater infrastructure within the appropriate environmental standards, which would ensure the existence of a strong and sound society characterized by social justice to balance environmental, social, and economic development.
- Public Health and Environmental Protection—providing appropriate collection and treatment systems to protect public health and reduce environmental pollution, to meet sustainable development goals.
- Coping with water scarcity—raising the efficiency of water use in all sectors and ensuring the sustainability of water extraction.
- Water quality—improving the quality of surface water by reducing pollution with chemicals and hazardous materials and reducing the proportion of untreated wastewater.
- Improving sanitation services—increasing the effectiveness of sanitation services by setting standards for sanitation networks and the technologies used in them, water coming out of stations, operation, and maintenance, in addition to standards for sludge disposal.
- Community participation—support and enhance the involvement of regional communities in ameliorating water and sanitation administration.
- Cybersecurity—creating a clear system layout can help to clear up confusion if an attack happens. As water operations grow, their networks grow more complicated, making it easier to make mistakes when compromised by cyber-attacks.
- Cybersecurity helps water and wastewater sector companies keep their systems and data safe, and water management companies must be vigilant.
- Cybersecurity helps block malware and unauthorized access and suspicious activities, which is paramount to keeping a water and wastewater operation safe.

10. Concluding Remarks

This study has proposed a risk assessment framework, the so-called RAF-CPWS, that evaluates the risks of water/wastewater and their technologies. This article has presented a hybrid DEMATEL-TOPSIS methodology grounded on the neutrosophic theory that allows experts and water engineers to participate in the evaluation process. Participants rely on the use of linguistic terms and triangular neutrosophic numbers rather than crisp numbers to determine the most sustainable technologies for WWT. The evaluation process includes four main factors (namely, economic, environmental, technological and cybersecurity, and socio-political), and fifteen sub-factors that include construction cost, implementation and maintenance costs, occupied land, nitrogen, and phosphorous disposal efficiency, organic matter, suspended solids disposal efficiency, sludge removal effect, carbon footprint, maturity, reliability, operability and simplicity, public acceptance, employment, governmental policy, odors, and noise. In this regard, four wastewater treatment technologies have been identified for the study. ASOD (anaerobic single oxidation ditch) has been identified as the most sustainable technology for WWT, followed by TOD (triple oxidation ditch) technology in the second rank. Also, AAO (anaerobic anoxic oxic) is ranked last among all available technologies. Also, several analyses were conducted based on the results, including a comparative analysis with some previous studies related to choosing the best WWTT CPS. The proposed methodology has proven its effectiveness and efficiency in selecting the best technologies compared to previous methodologies. In addition, a sensitivity analysis was conducted on the proposed results as a result of the change in weights of the main factors used in selecting the best WWTT CPS.

An evaluation criteria index was developed in this study, which can have wider applications through changing the evaluation alternatives and criteria according to the requirements of the stakeholder in the future. Furthermore, the developed risk assessment framework, named RAF-CPWS, can also be replicated for the selection of suitable and sustainable water treatment technologies.

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Appendix A

In this part, we present many applied tables to illustrate the detailed steps for applying the proposed hybrid model methods including DEMATEL and TOPSIS, starting with calculating the weights for the main factors and then the weights for the sub-factors. In addition, detailed tables are presented to calculate the order of alternatives by the TOPSIS method.

Table A1. Assessment of major factors by all experts using the semantic variables.

$Expert_1$	**F_1 (ECF)**	**F_2 (ENF)**	**F_3 (TEF)**	**F_4 (SOF)**
F_1 (ECF)	-	HRI	LIA	NTA
F_2 (ENF)	NTA	-	NTA	HSA
F_3 (TEF)	PRA	NTA	-	PRA
F_4 (SOF)	HSA	LIA	PRA	-
$Expert_2$	**F_1 (ECF)**	**F_2 (ENF)**	**F_3 (TEF)**	**F_4 (SOF)**
F_1 (ECF)	-	NTA	NTA	HSA
F_2 (ENF)	NTA	-	PRA	SRA
F_3 (TEF)	NTA	LIA	-	PRA
F_4 (SOF)	HSA	SRA	PRA	-
$Expert_3$	**F_1 (ECF)**	**F_2 (ENF)**	**F_3 (TEF)**	**F_4 (SOF)**
F_1 (ECF)	-	PRA	NTA	HSA
F_2 (ENF)	PRA	-	SRA	HSA
F_3 (TEF)	NTA	SRA	-	HSA
F_4 (SOF)	HSA	HSA	HSA	-

Table A1. *Cont.*

$Expert_4$	**F_1 (ECF)**	**F_2 (ENF)**	**F_3 (TEF)**	**F_4 (SOF)**
F_1 (ECF)	-	HSA	NTA	HSA
F_2 (ENF)	LIA	-	LIA	NTA
F_3 (TEF)	NTA	SRA	-	LIA
F_4 (SOF)	LIA	NTA	LIA	-

Table A2. Assessment of major factors by neutrosophic numbers.

$Expert_1$	**F_1 (ECF)**	**F_2 (ENF)**	**F_3 (TEF)**	**F_4 (SOF)**
F_1 (ECF)	-	⟨(0.87, 0.79, 0.75); 0.80, 0.10, 0.10⟩	⟨(0.11, 0.26, 0.27); 0.49, 0.11, 0.29⟩	⟨(0.37, 0.34, 0.48); 0.70, 0.19, 0.16⟩
F_2 (ENF)	⟨(0.37, 0.34, 0.48); 0.70, 0.19, 0.16⟩	-	⟨(0.37, 0.34, 0.48); 0.70, 0.19, 0.16⟩	⟨(1.00, 0.90, 0.85); 0.90, 0.10, 0.05⟩
F_3 (TEF)	⟨(0.50, 0.60, 0.75); 0.60, 0.20, 0.10⟩	⟨(0.37, 0.34, 0.48); 0.70, 0.19, 0.16⟩	-	⟨(0.50, 0.60, 0.75); 0.60, 0.20, 0.10⟩
F_4 (SOF)	⟨(1.00, 0.90, 0.85); 0.90, 0.10, 0.05⟩	⟨(0.11, 0.26, 0.27); 0.49, 0.11, 0.29⟩	⟨(0.50, 0.60, 0.75); 0.60, 0.20, 0.10⟩	-
$Expert_2$	**F_1 (ECF)**	**F_2 (ENF)**	**F_3 (TEF)**	**F_4 (SOF)**
F_1 (ECF)	-	⟨(0.37, 0.34, 0.48); 0.70, 0.19, 0.16⟩	⟨(0.37, 0.34, 0.48); 0.70, 0.19, 0.16⟩	⟨(1.00,0.90,0.85);0.90,0.10,0.05⟩
F_2 (ENF)	⟨(0.37, 0.34, 0.48); 0.70, 0.19, 0.16⟩	-	⟨(0.50, 0.60, 0.75); 0.60, 0.20, 0.10⟩	⟨(0.87, 0.79, 0.75); 0.80, 0.10, 0.10⟩
F_3 (TEF)	⟨(0.37, 0.34, 0.48); 0.70, 0.19, 0.16⟩	⟨(0.11, 0.26, 0.27); 0.49, 0.11, 0.29⟩	-	⟨(0.50, 0.60, 0.75); 0.60, 0.20, 0.10⟩
F_4 (SOF)	⟨(1.00, 0.90, 0.85); 0.90, 0.10, 0.05⟩	⟨(0.87, 0.79, 0.75); 0.80, 0.10, 0.10⟩	⟨(0.50, 0.60, 0.75); 0.60, 0.20, 0.10⟩	-
$Expert_3$	**F_1 (ECF)**	**F_2 (ENF)**	**F_3 (TEF)**	**F_4 (SOF)**
F_1 (ECF)	-	⟨(0.50, 0.60, 0.75); 0.60, 0.20, 0.10⟩	⟨(0.37, 0.34, 0.48); 0.70, 0.19, 0.16⟩	⟨(1.00, 0.90, 0.85); 0.90, 0.10, 0.05⟩
F_2 (ENF)	⟨(0.50, 0.60, 0.75); 0.60, 0.20, 0.10⟩	-	⟨(0.87, 0.79, 0.75); 0.80, 0.10, 0.10⟩	⟨(1.00, 0.90, 0.85); 0.90, 0.10, 0.05⟩
F_3 (TEF)	⟨(0.37, 0.34, 0.48); 0.70, 0.19, 0.16⟩	⟨(0.87, 0.79, 0.75); 0.80, 0.10, 0.10⟩	-	⟨(1.00, 0.90, 0.85); 0.90, 0.10, 0.05⟩
F_4 (SOF)	⟨(1.00, 0.90, 0.85); 0.90, 0.10, 0.05⟩	⟨(1.00, 0.90, 0.85); 0.90, 0.10, 0.05⟩	⟨(1.00, 0.90, 0.85); 0.90, 0.10, 0.05⟩	-
$Expert_4$	**F_1 (ECF)**	**F_2 (ENF)**	**F_3 (TEF)**	**F_4 (SOF)**
F_1 (ECF)	-	⟨(1.00, 0.90, 0.85); 0.90, 0.10, 0.05⟩	⟨(0.37, 0.34, 0.48); 0.70, 0.19, 0.16⟩	⟨(1.00, 0.90, 0.85); 0.90, 0.10, 0.05⟩
F_2 (ENF)	⟨(0.11, 0.26, 0.27); 0.49, 0.11, 0.29⟩	-	⟨(0.11, 0.26, 0.27); 0.49, 0.11, 0.29⟩	⟨(0.37, 0.34, 0.48); 0.70, 0.19, 0.16⟩
F_3 (TEF)	⟨(0.37, 0.34, 0.48); 0.70, 0.19, 0.16⟩	⟨(0.87, 0.79, 0.75); 0.80, 0.10, 0.10⟩	-	⟨(0.11, 0.26, 0.27); 0.49, 0.11, 0.29⟩
F_4 (SOF)	⟨(0.11, 0.26, 0.27); 0.49, 0.11, 0.29⟩	⟨(0.37, 0.34, 0.48); 0.70, 0.19, 0.16⟩	⟨(0.11, 0.26, 0.27); 0.49, 0.11, 0.29⟩	-

Table A3. Generalized direct relation matrix for main factors.

$Expert_1$	**F_1 (ECF)**	**F_1 (ENF)**	**F_3 (TEF)**	**F_4 (SOF)**
F_1 (ECF)	0.233100	0.365035	0.077855	0.163170
F_2 (ENF)	0.163170	0.233100	0.163170	0.440559
F_3 (TEF)	0.248019	0.163170	0.233100	0.248019
F_4 (SOF)	0.440559	0.077855	0.248019	0.233100
$Expert_2$	**F_1 (ECF)**	**F_2 (ENF)**	**F_3 (TEF)**	**F_4 (SOF)**
F_1 (ECF)	0.181159	0.126812	0.126812	0.342391
F_2 (ENF)	0.126812	0.181159	0.192754	0.283696
F_3 (TEF)	0.126812	0.060507	0.181159	0.192754
F_4 (SOF)	0.342391	0.283696	0.192754	0.181159
$Expert_3$	**F_1 (ECF)**	**F_2 (ENF)**	**F_3 (TEF)**	**F_4 (SOF)**
F_1 (ECF)	0.149925	0.159520	0.104948	0.283358
F_2 (ENF)	0.159520	0.149925	0.234783	0.283358
F_3 (TEF)	0.104948	0.234783	0.149925	0.283358
F_4 (SOF)	0.283358	0.283358	0.283358	0.149925
$Expert_4$	**F_1 (ECF)**	**F_2 (ENF)**	**F_3 (TEF)**	**F_4 (SOF)**
F_1 (ECF)	0.182482	0.344891	0.127737	0.344891
F_2 (ENF)	0.060949	0.182482	0.060949	0.127737
F_3 (TEF)	0.127737	0.285766	0.182482	0.060949
F_4 (SOF)	0.060949	0.127737	0.060949	0.182482

Table A4. Total relation matrix for main factors.

Expert$_1$	**F_1 (ECF)**	**F_1 (ENF)**	**F_3 (TEF)**	**F_4 (SOF)**	**R_i**	**C_i**	**R + C**	**R − C**
F_1 (ECF)	3.694450	3.069838	2.259401	3.493043	12.51673	16.27939	28.79612	−3.76266
F_2 (ENF)	4.339470	3.404271	2.785838	4.354356	14.88394	12.59375	27.47769	2.290185
F_3 (TEF)	3.859831	2.953742	2.505224	3.651675	12.97047	10.26484	23.23531	2.705632
F_4 (SOF)	4.385639	3.165897	2.714376	3.933614	14.19953	15.43269	29.63222	−1.23316
Expert$_2$	**F_1 (ECF)**	**F_2 (ENF)**	**F_3 (TEF)**	**F_4 (SOF)**	**R_i**	**C_i**	**R + C**	**R − C**
F_1 (ECF)	1.040310	0.841510	0.829489	1.339948	4.051257	4.038935	8.090192	0.012322
F_2 (ENF)	0.948253	0.866374	0.880538	1.250406	3.945571	3.364604	7.310175	0.580967
F_3 (TEF)	0.703175	0.532804	0.660222	0.869435	2.765636	3.412977	6.178614	−0.64734
F_4 (SOF)	1.347197	1.123916	1.042728	1.419406	4.933247	4.879196	9.812443	0.054052
Expert$_3$	**F_1 (ECF)**	**F_2 (ENF)**	**F_3 (TEF)**	**F_4 (SOF)**	**R_i**	**C_i**	**R + C**	**R − C**
F_1 (ECF)	0.948499	1.084919	0.986902	1.340107	4.360427	4.360427	8.720853	0.00000
F_2 (ENF)	1.084919	1.237615	1.261259	1.527931	5.111724	5.111724	10.22345	−0.00001
F_3 (TEF)	0.986902	1.261259	1.133394	1.460518	4.842073	4.842073	9.684145	0.00000
F_4 (SOF)	1.340107	1.527931	1.460518	1.619219	5.947774	5.947774	11.89555	0.00000
Expert$_4$	**F_1 (ECF)**	**F_2 (ENF)**	**F_3 (TEF)**	**F_4 (SOF)**	**R_i**	**C_i**	**R + C**	**R − C**
F_1 (ECF)	0.391608	0.819351	0.333693	0.739986	2.284638	0.967112	3.25175	1.317526
F_2 (ENF)	0.147710	0.382369	0.147710	0.289323	0.967112	2.161599	3.128711	−1.19449
F_3 (TEF)	0.280084	0.635425	0.337999	0.317198	1.570705	0.967112	2.537818	0.603593
F_4 (SOF)	0.147710	0.324454	0.147710	0.347238	0.967112	1.693745	2.660857	−0.72663

Table A5. Assessment of economic sub-factors by semantic variables.

Assessment of Economic Sub-Factors	**Economic Factor ECF (F_1)**	
	COC (F_{1-1})	**OMC (F_{1-2})**
COC (F_{1-1})	-	SRA
OMC (F_{1-2})	PRA	-

Table A6. Assessment of environmental sub-factors by semantic variables.

Assessment of Environmental Sub-Factors	**Environmental ENF (F_2)**				
	OCL (F_{2-1})	**NPD (F_{2-2})**	**OSD (F_{2-3})**	**SRE (F_{2-4})**	**CAF (F_{2-5})**
OCL (F_{2-1})	-	SRA	NTA	NTA	HSA
NPD (F_{2-2})	SRA	-	HSA	HSA	PRA
OSD (F_{2-3})	NTA	HSA	-	LIA	SRA
SRE (F_{2-4})	LIA	LIA	PRA	-	LIA
CAF (F_{2-5})	HSA	SRA	HSA	PRI	-

Table A7. Assessment of technological and cybersecurity sub-factors by semantic variables.

Assessment of Technological and Cybersecurity Sub-Factors	**Technological and Cybersecurity Factor TEF (F_3)**		
	MAT (F_{3-1})	**REL (F_{3-2})**	**OST (F_{3-3})**
MAT (F_{3-1})	-	SRA	HSA
REL (F_{3-2})	PRA	-	SRA
OST (F_{3-3})	NTA	LIA	-

Table A8. Assessment of social-political sub-factors by semantic variables.

Assessment of Social-Political Sub-Factors	Social-Political SOF (F_4)				
	PAC (F_{4-1})	EMP (F_{4-2})	GOP (F_{4-3})	ODS (F_{4-4})	NOS (F_{4-5})
PAC (F_{4-1})	-	LIA	HSA	PRA	NTA
EMP (F_{4-2})	NTA	-	SRA	HSA	PRA
GOP (F_{4-3})	PRA	SRA	-	SRA	SRA
ODS (F_{4-4})	HSA	HSA	LIA	-	HSA
NOS (F_{4-5})	SRA	HRI	NTA	PRA	-

Table A9. Total relation matrix of economic factor sub-factors.

Evaluation by Four Experts	Economic Factor ECF (F_1)						
	COC (F_{1-1})	OMC (F_{1-2})	R_i	C_i	R + C	R − C	Weights
COC (F_{1-1})	4.111554	5.111554	9.223108	7.584538	16.80765	1.63857	0.500
OMC (F_{1-2})	3.472984	4.111554	7.584538	9.223108	16.80765	−1.63857	0.500

Table A10. Total relation matrix of environmental factor sub-factors.

Evaluation by Four Experts	Environmental Factor ENF (F_2)									
	OCL (F_{2-1})	NPD (F_{2-2})	OSD (F_{2-3})	SRE (F_{2-4})	CAF (F_{2-5})	R_i	C_i	R + C	R − C	Weights
OCL (F_{2-1})	0.796524	0.958926	0.8678	0.679564	0.936299	4.239	3.787	8.026	0.452	0.200
NPD (F_{2-2})	0.918187	0.974182	1.099661	0.891296	0.91352	4.797	4.401	9.198	0.396	0.229
OSD (F_{2-3})	0.733274	0.978826	0.882835	0.611291	0.870523	4.077	4.484	8.561	−0.408	0.213
SRE (F_{2-4})	0.316462	0.37344	0.47542	0.382461	0.343479	1.891	3.392	5.284	−1.501	0.131
CAF (F_{2-5})	1.022763	1.115641	1.158599	0.827835	0.968943	5.094	4.033	9.127	1.061	0.227

Table A11. Total relation matrix of technological and cybersecurity factor sub-factors.

Evaluation by Four Experts	Technological and Cybersecurity Factor TEF (F_3)							
	MAT (F_{3-1})	REL (F_{3-2})	OST (F_{3-3})	R_i	C_i	R + C	R − C	Weights
MAT (F_{3-1})	0.902377	1.006641	1.496496	3.405514	2.159639	5.565154	1.245875	0.359
REL (F_{3-2})	0.795102	0.769128	1.236458	2.800688	2.150635	4.951323	0.650052	0.319
OST (F_{3-3})	0.462161	0.374866	0.711957	1.548984	3.444911	4.993896	−1.89593	0.322

Table A12. Total relation matrix of social-political factor sub-factors.

Evaluation by Four Experts	Social-Political Factor SOF (F_4)									
	PAC (F_{4-1})	EMP (F_{4-2})	GOP (F_{4-3})	ODS (F_{4-4})	NOS (F_{4-5})	R_i	C_i	R + C	R − C	Weights
PAC (F_{4-1})	1.229069	1.153387	1.212081	1.284184	1.184673	6.063	7.489	13.552	−1.426	0.184
EMP (F_{4-2})	1.477815	1.546845	1.40172	1.699325	1.524172	7.650	7.591	15.241	0.059	0.206
GOP (F_{4-3})	1.608287	1.700769	1.407635	1.743567	1.665742	8.126	6.554	14.680	1.572	0.199
ODS (F_{4-4})	1.715437	1.721684	1.33413	1.660076	1.690451	8.122	7.840	15.962	0.282	0.216
NOS (F_{4-5})	1.458362	1.468517	1.198879	1.452863	1.366874	6.945	7.432	14.377	−0.486	0.195

Table A13. Evaluation matrix of four WWTT technologies according to the sustainable sub-factors.

Expert$_1$	F_{1-1}	F_{1-2}	F_{2-1}	F_{2-2}	F_{2-3}	F_{2-4}	F_{2-5}	F_{3-1}	F_{3-2}	F_{3-3}	F_{4-1}	F_{4-2}	F_{4-3}	F_{4-4}	F_{4-5}
A_1 AAO	EXL	MO	MOL	MO	MOL	LL	EXL	EXL	EXL	MO	EXL	MO	MOL	EXL	EXL
A_2 TOD	MOL	MO	MO	PO	MOP	PO	EXP	EXP	MO	MO	MOP	PO	MOP	EXP	EXP
A_3 ASOD	MOP	MOL	MO	MOL	MO	MO	MOP	MOL	MO	MOP	MOL	MO	MOP	MOP	MOL
A_4 SBRAS	EXL	MOP	MOL	MOP	MOL	MO	MO	MOP	MOL	MO	MOP	MOL	MO	MO	MOP
Expert$_2$	F_{1-1}	F_{1-2}	F_{2-1}	F_{2-2}	F_{2-3}	F_{2-4}	F_{2-5}	F_{3-1}	F_{3-2}	F_{3-3}	F_{4-1}	F_{4-2}	F_{4-3}	F_{4-4}	F_{4-5}
A_1 AAO	EXL	MO	MOL	MO	MOL	LL	EXL	EXL	EXL	MO	EXL	MO	MOL	EXL	EXL
A_2 TOD	MOL	MO	MO	PO	MOP	PO	EXP	EXP	MO	MO	MOP	PO	MOP	EXP	EXP
A_3 ASOD	MO	MOP	MOL	MOP	MOL	MO	MO	MOP	MOL	MO	MOP	MOL	MO	MO	MOP
A_4 SBRAS	EXL	MOP	MOL	MOP	MOL	MO	MO	MOP	MOL	MO	MOP	MOL	MO	MO	MOP
Expert$_3$	F_{1-1}	F_{1-2}	F_{2-1}	F_{2-2}	F_{2-3}	F_{2-4}	F_{2-5}	F_{3-1}	F_{3-2}	F_{3-3}	F_{4-1}	F_{4-2}	F_{4-3}	F_{4-4}	F_{4-5}
A_1 AAO	EXL	MO	MOL	MO	MOL	LL	EXL	EXL	EXL	MO	EXL	MO	MOL	EXL	EXL
A_2 TOD	MOL	MO	MO	PO	MOP	PO	EXP	EXP	MO	MO	MOP	PO	MOP	EXP	EXP
A_3 ASOD	MOP	MOL	MO	MOL	MO	MO	MOP	MOL	MO	MOP	MOL	MO	MOP	MOP	MOL
A_4 SBRAS	EXL	MO	MOP	MO	MO	MOP	MO	MOP	MOP	MO	MOP	MO	MOP	MO	MOP
Expert$_4$	F_{1-1}	F_{1-2}	F_{2-1}	F_{2-2}	F_{2-3}	F_{2-4}	F_{2-5}	F_{3-1}	F_{3-2}	F_{3-3}	F_{4-1}	F_{4-2}	F_{4-3}	F_{4-4}	F_{4-5}
A_1 AAO	EXL	MO	MOL	MO	MOL	LL	EXL	EXL	EXL	MO	EXL	MO	MOL	EXL	EXL
A_2 TOD	MOL	MO	MO	PO	MOP	PO	EXP	EXP	MO	MO	MOP	PO	MOP	EXP	EXP
A_3 ASOD	MOP	MOP	MOL	MOP	MOL	MO	MO	MOP	MOL	MO	MOP	MOL	MO	MO	MOP
A_4 SBRAS	EXL	MO	MOP	MO	MO	MOP	MO	MOP	MOP	MO	MOP	MO	MOP	MO	MOP

Table A14. Aggregated valuation matrix.

Alts/ Factors	F_{1-1}	F_{1-2}	F_{2-1}	F_{2-2}	F_{2-3}	F_{2-4}	F_{2-5}	F_{3-1}	F_{3-2}	F_{3-3}	F_{4-1}	F_{4-2}	F_{4-3}	F_{4-4}	F_{4-5}
A_1 AAO	0.164	0.634	0.359	0.634	0.359	0.184	0.164	0.164	0.164	0.634	0.164	0.634	0.359	0.164	0.164
A_2 TOD	0.359	0.634	0.634	0.828	0.699	0.828	0.945	0.945	0.634	0.634	0.699	0.828	0.699	0.945	0.945
A_3 ASOD	0.683	0.529	0.497	0.529	0.497	0.634	0.667	0.529	0.667	0.667	0.529	0.529	0.667	0.667	0.529
A_4 SBRAS	0.164	0.667	0.529	0.667	0.497	0.667	0.634	0.699	0.529	0.634	0.699	0.529	0.667	0.634	0.699

Table A15. The normalized decision matrix.

Alts/ Factors	F_{1-1}	F_{1-2}	F_{2-1}	F_{2-2}	F_{2-3}	F_{2-4}	F_{2-5}	F_{3-1}	F_{3-2}	F_{3-3}	F_{4-1}	F_{4-2}	F_{4-3}	F_{4-4}	F_{4-5}
A_1 AAO	0.204	0.513	0.349	0.471	0.341	0.147	0.123	0.126	0.153	0.493	0.145	0.494	0.292	0.123	0.126
A_2 TOD	0.446	0.513	0.616	0.615	0.663	0.662	0.711	0.727	0.590	0.493	0.617	0.645	0.569	0.711	0.727
A_3 ASOD	0.848	0.428	0.483	0.393	0.471	0.507	0.502	0.407	0.621	0.519	0.467	0.412	0.543	0.502	0.407
A_4 SBRAS	0.204	0.539	0.514	0.495	0.471	0.533	0.477	0.538	0.493	0.493	0.617	0.412	0.543	0.477	0.538

Table A16. The weighted normalized decision matrix.

Alts/ Factors	F_{1-1}	F_{1-2}	F_{2-1}	F_{2-2}	F_{2-3}	F_{2-4}	F_{2-5}	F_{3-1}	F_{3-2}	F_{3-3}	F_{4-1}	F_{4-2}	F_{4-3}	F_{4-4}	F_{4-5}
A_1 AAO	0.027	0.069	0.017	0.027	0.018	0.005	0.007	0.008	0.009	0.029	0.008	0.031	0.017	0.008	0.007
A_2 TOD	0.060	0.069	0.031	0.035	0.035	0.022	0.041	0.047	0.034	0.029	0.034	0.040	0.034	0.046	0.042
A_3 ASOD	0.114	0.058	0.024	0.022	0.025	0.017	0.029	0.026	0.035	0.030	0.026	0.026	0.032	0.032	0.024
A_4 SBRAS	0.027	0.073	0.026	0.028	0.025	0.018	0.027	0.034	0.028	0.029	0.034	0.026	0.032	0.031	0.031
Best I^+	0.114	0.073	0.031	0.035	0.035	0.022	0.041	0.047	0.035	0.030	0.034	0.040	0.034	0.046	0.042
Worst I^-	0.027	0.058	0.017	0.022	0.018	0.005	0.007	0.008	0.009	0.029	0.008	0.026	0.017	0.008	0.007

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