An integrated methodology for establishing industrial effluent limits in developing countries: Iran as a case study

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Abstract

Background Environmental policies should be developed in a contextual decision-making process regarding local environmental concerns emphasizing the economic, technical, social and institutional considerations. Establishing emission limit levels, especially in the industrial sector, is one of the most problematic environmental issues in developing countries, for which it is essential to include several criteria that reflect their country-specific constraints and capacities. Since Best Available Technology (BAT) is acknowledged to be the reference element for sustainable development and a basis for Emissions Limit Values (ELVs), the objective of this study is to present a reliable methodology for establishing ELVs thresholds with an emphasis on the BAT concept for national regulation at the sector level.

Methods A hybrid fuzzy multiple-criteria decision-making (FMCDM) process, consisting of the Analytic Hierarchy Process (AHP) and fuzzy Technique for Order of Preference by Similarity to Ideal Solution (fuzzy TOPSIS) method, is structured to aggregate the different criteria and rank different ELV alternatives in this complicated evaluation. In order to use the most profound knowledge and judgment of a professional expert team, this qualitative assessment highlights the importance of supportive information.

Results The results obtained indicate that experts have considered the country-specific information as a reliable reference in their decisions. Among different key evaluation criteria in effluent standard setting, the highest experts' priority is "Environmental protection". For both the conventional and toxic pollutants, the influence of all other criteria namely "Economic feasibility", "Technology viability" and "Institutional capacity", as constraining criteria in developing countries, have not reduced the responsibility towards the environmental objectives. In ELVs ranking, experts have made their decisions with respect to the specific characteristics of each pollutant and the existing capacities and constraints of the country, without emphasizing on any specific reference.

Conclusions This systematic and transparent approach has resulted in defensible country-specific ELVs for the Iron and Steel industry, which can be developed for other sectors. As the main conclusion, this paper demonstrates that FMCDM is a robust tool for this comprehensive assessment especially regarding the data availability limitations in developing countries.

Keywords Industrial effluent · Emissions limit values · BAT · AHP · Fuzzy TOPSIS · Iron and steel industry

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Introduction

In most developing countries, the improvement of environmental policy is a crucial issue because environmental problems are linked to the social and economic aspects, which must be considered in the development of any environmental programme or regulation [1]. According to the Europe 2020 Strategy [2], the promotion of a greener, more competitive and more efficient economy is a priority for sustainable growth [3]. Since efficient water and wastewater management in industrial activities is one of the most important strategies in environmental friendly development, the prevention and control of pollution is recognized as being a cornerstone of industrial sustainability [4].

As the environmental regulation plays a key role in pollution prevention and emission reduction, governments have promoted regulations to protect the environment [5, 6]. Direct regulation (command and control) is one of the main subdivisions of the environmental regulation and includes specific standards, such as mandatory limitations and prohibitions that force companies to adapt to new environmental changes, and then checks their compliance with the regulations [7] through inspections and controls [8]. In this way, sufficient and effective wastewater regulations act as essential devices for improving environmental performance and can be very influential, especially in developing countries. They are performed through defining, applying and enforcing effluent standards for wastewater discharges [9, 10].

The process of effluent standard setting is more challenging among developing countries. The limitations and varying capacities of countries to establish and implement effluent standards have led to a high variation in the setting approaches, the number of selected pollutants, their related ELVs and even the procedures for revision of the standards.

Iran, as a developing country, presently faces water scarcity, thereby necessitating the provision of practical guidance to improve its existing effluent standards. Now, “The Wastewater Effluent Standard” is applied as the main standard for water pollution control. In this uniform standard, which was compiled by the Department of Environment (DOE), effluents discharged from different sources should be in accordance with the standards defined as maximum concentrated pollution of 52 parameters for three points of discharge; i.e. surface water, absorbent wells, and water used for agriculture and irrigation.

Regarding the crucial role of environmental pollution deriving from industrial activities [8, 11, 12], industry-specific effluent standards (ISESs) are applied in most countries. In addition, the uniform limitations among different sectors cannot reflect the differences in their processes, treatment technologies and management abilities [13]. Therefore, the main objective of this research is to develop a methodology for determining national ISESs in a specific sector through a

scientific, transparent, systematic, and reproducible way. The Iron and Steel industry, as one of the most strategic sectors in the country, was selected for examining the method. The fundamental role of this sector in Iran’s economy along with its increasing growth highlight the need for a country-specific effluent standard.

This paper suggests an approach to estimate the most appropriate ELVs for the effluent of the Iron and Steel industry as follows. After a literature survey on the establishing approaches of industrial effluent standards, the framework is detailed in “Methods”. Then, the results from implementation of the method to the case study are presented and discussed in “Results”. Finally, in the last section, the major concluding remarks are briefly presented.

Establishing effluent standards

In general, effluent standards are set based on two main approaches: technology or the environmental quality objective. The first approach focuses on the prevention of pollution and reduction at the source, while the second emphasizes the principle of the carrying capacity in the receiving water bodies and compliance with the water quality standards.

The definition and application of these approaches are dissimilar in different countries, and, to a large extent depend on their technical, financial, social and institutional capabilities, and constraints. A review of the effluent standards in different countries, especially developed ones, can provide a scientific view of the current approaches in water management and their constraints, requirements, and strengths for application in the context of rational and enforceable regulations.

In the USA, the Environmental Protection Agency (EPA) has suggested technology-based numerical limitations for 58 main industrial categories in its codified regulations. These effluent limitations are set at several levels of control technology, such as: Best Practicable Control Technology Currently Available (BPT) for conventional, toxic, and non-conventional pollutants, and BAT for toxic, and non-conventional pollutants. With respect to these guidelines, the National Pollutants Discharge Elimination System determines the final effluent limitations for individual discharge facilities considering their water quality impacts.

In the European Union (EU), in terms of technology-based standards for industrial wastewater discharge, the Integrated Pollution Prevention and Control Directive (IPPC) provides a framework for the comprehensive and integrated regulation of six major industrial categories consisting of Energy industry, Production and processing of metals, Mineral industry, Chemical industry, Waste management and other activities with 38 main subcategories [2, 14].

As can be perceived, the technology-based approach plays a fundamental role in establishing the main guidelines and regulations for controlling point source discharges, especially

industrial facilities, and, in many developed countries, the technology-based requirements have been included in their environmental permits [15]. Since these effluent regulations mostly categorize industrial activities, the procedure for setting effluent standards on an industry-by-industry basis has been developed among different countries, even developing ones. However, the number of industries with specific effluent standard varies in terms of their economic, institutional, technical, and scientific development.

The technology-based approach, often referred to as BAT [13], discusses the techniques for pollution prevention and end-of-pipe techniques (i.e. techniques for reducing emissions) [8, 16]. IPPC emphasizes the fundamental concepts of BAT [3, 6, 17–22], which includes technology, equipment and operational practices, and BAT associated emission levels (BAT-AEL) in a series of BAT reference documents known as BREFs [14, 20, 21]. However, it neither prescribes the use of any specific technique nor includes any methodology for assessment of the BAT techniques [3]. In addition, although BAT-AEL is a crucial basis for ELVs, no clearly established and generally accepted methodology for its determination has been described in the literature [16]. Unfortunately, copying standards from others, especially developed countries, results in ELVs that are impractical and inefficient. Regarding the significant differences between developed and developing countries in terms of their capabilities, especially their data availability, even an identical method for effluent standard setting cannot be proposed.

The appropriate approach has to be developed concerning different aspects of a) the technical characteristics of the involved sector, b) the local environmental conditions, c) the geographical location [8, 23], and d) the economic viability and institutional infrastructure of the country. Therefore, BAT-AELs have to be estimated in an integrated and flexible approach to consider all specific local conditions and preferences.

Basically, the process for the determination of ELVs relies to a large extent on expert judgment [16]. Decision-makers have to ponder and evaluate numerous potentially conflicting criteria and indicators simultaneously, and analyse a large amount of data. It is a difficult process that is dependent upon the professional judgment of experts [24] who have both sound knowledge and extended experience [3].

Since it is a fundamentally complex multidimensional process in which viewpoints from multiple decision-makers (DMs) have to be integrated, adopting a rational decision-making procedure is very important. Multiple-criteria decision-making (MCDM) is a sub-discipline and full-grown branch of operations research that concerns the designing of mathematical and computational tools to support the subjective evaluations [25]. MCDM techniques are transparent and systematic tools for overcoming two main challenges in decision-making processes: 1. the avoidance of information loss, and 2. the inclusion of expert opinions under a group in

a well-structured framework [26]. They are used to estimate the respective weights of the criteria and rank the project alternatives by making comparative assessments in an understandable framework. In all environmental application areas, DMs have to organize, integrate and quantify a considerable amount of heterogeneous information in their judgments for solving sophisticated problems.

Among the numerous MCDM techniques, the AHP and TOPSIS are the two most widely used approaches. In AHP, which was originally developed by Saaty [27], the inherent complexity of a multiple criteria decision-making problem is modelled and processed through the construction of a hierarchical structure with different levels [28, 29]. At each level, pairwise comparisons of elements regarding their contribution towards the above level elements are made on Saaty's fundamental 9-point scale. Then, the aggregated pairwise comparisons form a matrix of preferences for computing the weight of each decision element. The natural flexibility of AHP gives the opportunity to combine with other techniques resulting in powerful decision-making. One of the other advantages of the AHP is its ability to verify the coherence of the judgments by calculating the consistency ratio. In addition, the common use of AHP may be related to the availability of user-friendly and commercially supported software packages, such as Expert Choice, which makes the calculation and presentation of results simple and quick [28, 30].

TOPSIS, which was introduced by Hwang and Yoon [31], is the other well-known classical MCDM method. Its systematic procedure sorts the alternatives in decreasing order of the Closeness Coefficient, which is calculated with respect to the distance of a given alternative from both the positive and negative ideal solutions concurrently [32]. According to this method, the most appropriate alternative has the shortest and longest distances from the positive and negative ideal solutions, respectively.

A comprehensive literature review by Huang et al. [30] and Mardani et al. [33] demonstrates MCDM tools, especially the hybrid fuzzy MCDM (FMCDM), which has been successfully employed for environmental decisions, particularly where data availability is a limitation; a common situation in developing countries. In fact, in recent decades, most of the MCDM techniques have been extended to solve problems in a fuzzy environment [34]. Therefore, the FMCDM has been increasingly applied due to its capability to incorporate the uncertainties inherent in subjectivity and improve the quality of practical decision problems [29, 33].

Several studies have employed the AHP and TOPSIS approaches under fuzzy environment. In water and wastewater context, Kim et al. [35] ranked the sites for treated wastewater instream use by applying fuzzy TOPSIS. Chung and Kim (2014) developed both fuzzy TOPSIS and non-fuzzy MCDM approaches for locating the treated wastewater and highly treated wastewater usage. Minatour et al. [36] applied an extended

group fuzzy TOPSIS method in rating problems related to water supply management. Qu et al. [37] developed a fuzzy TOPSIS approach for selecting the most preferred water technologies in different disaster water supply scenarios. Onu et al. [38] presented an application of the fuzzy TOPSIS for determining the most appropriate water supply option. Tan et al. [29] employed fuzzy AHP approach for assessing the municipal wastewater treatment technologies. Ouyang et al. [39] suggested fuzzy AHP with multidimensional scaling for ranking the natural wastewater treatment alternatives. Hu et al. [40] proposed a comprehensive method based on fuzzy AHP to evaluate the wastewater treatment levels for enterprises. On the other hand, extending the TOPSIS method with other tools, especially AHP and the fuzzy set approach, is the most common trend in recent TOPSIS papers [25]. In this combined procedure, the AHP method determines the criteria weights and checks the consistency of the judgments in the pairwise comparisons, and the algorithmic procedure of fuzzy TOPSIS compares the alternatives to rank the final order of preference. In this way, Zhang et al. [41] integrated fuzzy AHP with fuzzy TOPSIS for identifying more sustainable mine water management practices, and Zyoude et al. [42] proposed a framework for water loss management in developing countries using fuzzy AHP and fuzzy TOPSIS.

Methods

The decision-making process for establishing ELVs related to industrial effluents has been developed through a stepwise methodology. A hybrid FMCDM technique consisting of AHP and fuzzy TOPSIS has been employed for the Iron and Steel sector in Iran. This industry is the most strategic sector after the Oil and Gas industry in the country. According to the report of the World Steel Association (2017), the volume of Iran's Steel production, in 2016, reached 17.895 million tons, showing a 9.8% increase compared with the same period in 2015. Now, Iran is the top steel producer in the Middle East. It is ranked 14th among the major Steel producing countries and, also, as the second steel producer by Direct Reduction in the world [43]. Its importance and significant growth resulted in its selection as the case study.

The methodological framework can be detailed in the main steps of: Preparing the supportive information, Structuring the model, Forming the expert team and gathering their judgments, Determining the weights of the evaluation criteria, and Ranking the alternatives and identifying the optimal ELVs for the respective pollutants.

Providing the reference information

The participation of the DMs is the central part of this approach [44]. The accuracy of the judgments depends largely

on the quality and quantity of the research requirements. Therefore, the dynamic and reliable methodology of this study necessitates taking into account various aspects covering the whole environmental performance of the plant. It can be concluded that different but complementary approaches have to be conducted to give a clear and complete vision, and provide profound knowledge and background information for DMs. In this way, the following prerequisites are considered as starting points.

BAT and the optimal wastewater treatment technologies

Since BAT is an essential reference element in the establishing of ELVs [15, 18], the information concerning this concept has to be included in the questionnaires. The country-specific BAT for wastewater treatment technologies (WTTs), at the sector level, is considered to be crucial information for experts and plays an important role in the development of reliable emission reduction strategies [18]. The results of WTTs assessment indicate the capability of plants in pollution reduction and compliance with ELVs. In another study [45], the most commonly used industrial WTTs in the Iron and Steel industry were identified through a comprehensive literature review and consultation with experts. Then, these technologies were evaluated based on six evaluation criteria and their thirty associated indicators with emphasis on the real considerations in Iran.

BPT and its associated emission levels

Furthermore, the actual technological set-up and the prevailing structure of the industrial sector in the country must be considered in the environmental policies [19]. Therefore, the current environmental performance levels in Iron and Steel plants have to be reflected in the study. In general, the pollution prevention and reduction measures related to the BAT concept at the sector level are applied as a robust tool for assessing the environmental performance of the plants, and the results of this evaluation identify the plants reflecting the BPT in the country. In fact, their BPT associated emission levels (BPT-AELs) play a valuable role in developing practical ELVs.

In an earlier paper by the same authors [46], a detailed analysis was conducted based on the BAT concept, in the related plants. For this purpose, regarding the degree of compliance with BAT principles, the plants reflecting BPT were identified as the best representative plants and their emission datasets were collected. After classifying these datasets into non-censored datasets, a censored dataset with one detection limit (DL), and a censored dataset with multiple DLs, they were screened using specific statistical analysis tests, and the BPT-AELs were computed for the Iron and Steel industry in Iran.

The above information, along with some other reference values, such as the national discharging effluent standard, the recommended BAT-AELs by IPPC [47] and the effluent guidelines of the World Bank [48] were presented in the questionnaire.

Decomposing and modelling of problem

In setting practical and reliable ELVs, especially in developing countries, the decision-making process has to be conducted on the basis of environmental, technical, economic, and institutional considerations. However, the relative importance associated with each of these aspects varies by the country and regional priorities. Therefore, in this research, the evaluation criteria consisting of Environmental protection, Economic feasibility, Technology viability, and Institutional capacity were determined to apply in the final assessments.

In addition, 15 parameters were identified as the main pollutants in the Iron and Steel industry [46]. In many advanced effluent standards, the pollutants have been classified with respect to their different characteristics. EPA proposes BPT effluent limitations for conventional, toxic, and non-conventional pollutants, while EU directives consider a separate hazardous group as priority and priority hazardous substances [14]. Therefore, in this study, the involved criteria were assessed for two distinct groups of conventional and toxic pollutants – the total suspended solids, COD, and oil and grease were designated as conventional pollutants; and metals and manmade organic compounds were designated as toxic pollutants. Regarding the reference information, for each pollutant, different values were proposed as alternatives.

According to these criteria and alternatives, a decision hierarchy model was established in three levels – objective, criteria and alternatives – and a questionnaire was developed on the basis of the approved hierarchy frame.

This questionnaire comprised two main phases. In the first one, the pair-wise comparison matrices were formed. The values of the elements of the matrices had to be determined by experts using Saaty's nine-point scale [27]. In the second part, all the reference information was presented, and, for each pollutant, experts were asked to evaluate the related alternatives based on the identified criteria using five linguistic variables: VP=Very Poor, P=Poor, M = Medium, G = Good and VG = Very Good.

The validity of the questionnaire (content validity) was examined by means of a pre-test. Three environmental experts consisting of one specialist from DOE, and two professors (one specialist in WTTs and standard setting, and one specialist in MCDM modelling) were asked to check the validity. In this procedure, the invited experts were asked to evaluate each item regarding relevance, clarity, simplicity and accuracy by using a four-point scale. The scoring pattern was “0, 0.35, 0.75 and 1” for the defined scale of: “not appropriate, need

major revision, need minor revision and appropriate”, respectively. The arithmetic mean was used for calculating each item's Content Validity Index (CVI). The items that had the CVI less than 0.75 were excluded or modified. After related modifications, the questionnaire was finalized for implementation.

Collecting experts' opinions

The selection of experts was crucial in this research. In order to gather various perspectives, a team of twelve experts from the best-known professors in universities and experts in high positions in the Iron and Steel industry and DOE was formed. They were chosen because of their significant knowledge and experience concerning the industrial environmental impacts, WTTs and standard setting. These experts were from different fields, such as environmental engineering, water resources management and environmental management.

Among the expert team, there were experts who had participated in previous stages of research, determining the optimal WTTs, and identifying the BPT and BPT-AELs in Iran's Iron and Steel industry. Their comprehensive view of all the stages of research was very helpful in increasing the validity of the decision-making process. In order to acquire more information concerning their vision of the research problem and their reasons for their judgments, all the questionnaires were filled out through individual face-to-face interviews.

Assessing the criteria weights: AHP method

As mentioned in “Decomposing and modelling of problem”, to determine the weights of the identified criteria, two separate pairwise comparison matrices were built up for conventional and toxic pollutants. In each pairwise comparison matrix, experts compared the relevance of each decision element to the others with respect to the overall goal. The individual preferences of each expert were collated in terms of Saaty's scale.

In the next step, the judgments were synthesized using Expert Choice software. At first, the reliability of each expert's judgments in the pairwise comparisons were checked by performing the consistency test for each matrix. According to Saaty, if inconsistency is equal or less than 0.1, the pairwise comparison matrix is acceptable and verified as a consistent one. Regarding the results of the consistency of the matrices, the individual decisions were aggregated to derive single composite scores. Many approaches can be applied for integration of the individual judgments. For the AHP approach, only the geometric mean is recommended to combine the judgments because it is in accordance with the reciprocity condition in AHP [26, 49]. In this way, two group matrices resulted from the aggregation. Then, the weights of the criteria in the two distinct groups of conventional and toxic pollutants were computed and applied as input for the final prioritization of the alternatives.

Table 1 Linguistic labels and scoring pattern used in the fuzzy TOPSIS method [51–53]

Descriptions	Linguistic labels	Crisp Values	Triangular fuzzy Values
Very Poor	VP	1	(0, 0, 0.2)
Poor	P	3	(0, 0.2, 0.4)
Medium	M	5	(0.3, 0.5, 0.7)
Good	G	7	(0.6, 0.8, 1)
Very Good	VG	9	(0.8, 1, 1)

Ranking the alternatives: Fuzzy TOPSIS method

The fuzzy TOPSIS method adapts the classical TOPSIS procedure to the operations associated with the fuzzy numbers [50]. This research employs the fuzzy TOPSIS method with triangular fuzzy numbers (TFNs) (Table 1) to rank the alternatives in a fuzzy environment. Therefore, the crisp values of the individual judgments were transferred into the TFNs, and, in accordance with Meixner [54], the geometric mean of each element of each fuzzy number was calculated to aggregate the individual decisions.

The procedure for the fuzzy TOPSIS method, as explained in another paper by the same authors [45], was performed as follows:

1. Constructing the fuzzy judgment matrix,
2. Normalizing the fuzzy decision-matrix,
3. Building the weighted normalized fuzzy decision-matrix,
4. Determining the Fuzzy Positive Ideal Solution (FPIS) and the Fuzzy Negative Ideal Solution (FNIS),
5. Calculating the fuzzy distance of each alternative to FPIS and FNIS,
6. Computing the Relative Closeness (RC) to the ideal solution, and
7. Ranking the priorities.

For each pollutant, the above steps were conducted with respect to its related weights.

Table 2 Ranking the candidate alternatives of industrial WTTs in Iran's Iron and Steel industry

Ranking	Alternative
1	NFSFF* + Electrolytic splitting + Reverse osmosis and Evaporation
2	NFSFF + Reverse osmosis and Evaporation
3	NFSFF + Nanofiltration and Evaporation
4	NFSFF + Ion Exchange + Evaporation
5	NFSFF + Microfiltration + Ultrafiltration
6	NFSFF

*NFSFF is Neutralisation + Flocculation + Sedimentation + Flotation + Filtration

Results

The main objective of this research is to develop an integrated, rational and effective decision support method for setting reliable effluent standards. In order to use the best professional judgments of the experts, the inclusion of supportive information was highlighted in this methodology. Since the issue of identifying these materials is not within the scope of this paper, only the final results are presented in Tables 2 and 3.

In this research, the decision-making process was performed using a two-step AHP and fuzzy TOPSIS methodology.

AHP: Criteria weights

Firstly, in order to ensure the reliability of the experts' judgments, the consistency of all pairwise comparison matrices was checked (Tables 4 and 5). Since all inconsistencies were equal or less than 0.1, all comparison judgments had good consistencies and were acceptable.

Therefore, all the matrices were employed for constructing the aggregated group decision matrices and their consistencies were also checked. According to the obtained results, the inconsistencies were 0.03 for both the conventional and toxic pollutants. Subsequently, the weight of each criterion was computed with respect to its final related group matrices (Figs. 1 and 2).

Fuzzy TOPSIS: ELVs ranking

The crisp values of group judgments on suggested ELVs for each pollutant are presented in Table 6. The experts' priorities for each alternative, consisting of Alt.1, Alt.2, and Alt.3, were aggregated by computing the geometric means. These values can provide an overall picture of experts' decisions with respect to each individual criterion. Regarding the linguistic variables used in the questionnaire, and the mean of the ranking values of "Medium" and "Good", the value below 6 indicates the limiting effect of the criterion under study towards the related alternative. On the other hand, in the main ranking procedure, for each pollutant,

Table 3 The estimated BPT-AELs for Iron and Steel industry in Iran

Parameter	TSS (ppm)	COD (ppm)	Oil and grease (ppm)	Turbidity (NTU)	Cd (ppm)	Cr (ppm)	Cu (ppm)	Ni (ppm)	Pb (ppm)	Zn (ppm)	Fe (ppm)	CN (ppm)	F (ppm)	Phenol (ppm)	Hg (ppm)
BPT-AELs	54	87	11.5	31	0.044	0.056	0.063	0.128	0.228	0.16	0.199	0.013	2.4	0.694	0.002

the relative closeness to the ideal solution was computed to rank the suggested ELVs. In these fuzzy matrices, the order of the alternatives is from the lowest to the highest values irrespective of their reference. Among the background information, the BPT-AELs and existing standards are considered as the current country-specific levels. Table 7 presents the final rankings obtained.

Sensitivity analysis

With respect to the uncertainty in the decision procedure, performing the sensitivity analysis is very beneficial. In sensitivity analysis, the effect of criteria's weights on alternative ranking can be studied in details. According to the obtained results, the "Economic feasibility" was the second influential criterion for both conventional and toxic pollutants. Hence, for all pollutants, the priority rankings were determined and compared when the importance of this criterion was doubled (Table 8). For conventional pollutants, the new weight of the "Economic feasibility" did not change the ranking priorities, although for COD and Oil, the difference of alternatives 1 and 2 had decreased to a closer distance. Among toxic pollutants, except CN, the similar trends are observed for both economic weights. Therefore, the doubled importance of economic criterion had not considerable effect on experts' priorities.

Discussion

The weighting of criteria for both the conventional and toxic pollutants indicates that the experts consider "Environmental protection" as being the first priority in the setting of an effluent standard. It has a substantial weight difference to the other criteria and its significantly high weight, especially for toxic pollutants, shows that the influence of all other criteria, which are considered as constraining criteria in developing countries, cannot justify the low responsibility towards the environmental objectives.

Among the three other criteria, the economic aspect is the most influential criterion with weights of 0.193 and 0.153 for conventional and toxic pollutants, respectively. The order of importance for "Technology viability" and "Institutional capacity" varies for conventional and toxic pollutants. These two criteria show a minor difference for toxic pollutants, which is explained by the need for more advanced analytical equipment in their measurement and less complicated technology for their removal, while the simpler method of analysis for the conventional pollutants results in the lower weight of its "Institutional capacity". Therefore, in setting the effluent standards, the "Technology viability" for toxic pollutants and "Institutional capacity" for conventional pollutants acts as the least influential criterion.

Since these obtained weights are applied for computing the weighted normalized fuzzy decision-matrix, they directly affect the final ranking in the fuzzy TOPSIS and are of the utmost importance in determining the ELVs. According to the obtained results, the aggregated values for the first alternative of "Cd", "Cr (VI)", "CN" and "Hg" with respect to the criterion "institutional capacity" are 2.50, 3.58, 5.67 and 4.85, respectively. Hence, the "institutional capacity" plays a constraining role in the final ranking of these acute toxic pollutants. This can be explained by the fact that the suggested ELVs for the first alternative of "Cd", "Cr (VI)", "CN" and "Hg" are 0.01, 0.06, 0.02 and 0.002, respectively. These values are as low as the detection limits of the analytical equipment and results in low aggregated values for the criterion "institutional capacity".

To identify the experts' priorities concerning the emission levels of each pollutant, the rankings are described in detail.

Conventional pollutants: The first experts' priority is for the lowest ELVs. These levels in "TSS" and "Oil and grease" are lower than the BPT-AELs and the existing standard, as country-specific levels, while for "COD", the lowest value is in accordance with these levels. Therefore, it can be

Table 4 Inconsistencies of pairwise comparison matrices related to the conventional pollutants

Expert	1	2	3	4	5	6	7	8	9	10	11	12
Inconsistency	0.04	0.08	0.03	0.1	0.03	0.04	0.04	0.07	0.00	0.00	0.08	0.04

Table 5 Inconsistencies of pairwise comparison matrices related to the toxic pollutants

Expert	1	2	3	4	5	6	7	8	9	10	11	12
Inconsistency	0.09	0.03	0.08	0.05	0.05	0.04	0.1	0.07	0.05	0.00	0.06	0.03

perceived that experts have not made their assessments based on just the standards for the developed countries or the current standard or BPT-AELs.

Toxic pollutants: All priorities are for the two first alternatives. In general, the experts consider a similar ranking for “Cu”, “Ni”, “Pb” and “Zn” over “Economic feasibility”, “Technology viability” and “Institutional capacity”. However, their ranking for the criterion “Environmental protection” indicates some differences, resulting in their final ELV rankings.

For “Cu”, “Ni” and “Zn”, the experts’ priority is for both alternatives 1 and 2, and the second alternative with just a minor difference has a higher RC. The first priority is based on the BPT-AELs, which are sometimes as low as 0.1 of the existing standard, while the reference for the second priority differs among the pollutants. In addition, among these pollutants, the RC differences between alternatives 2 and 3 are not similar. For example, the most considerable difference belongs to “Ni”, 0.5997, while they are similar and very low for “Cu” and “Zn”, 0.0786”. For “Pb”, the RC differences between alternatives 1–2 and 2–3 are significant: 0.1871, and 0.407, respectively. The first priority is in accordance with BPT-AELs and some advanced standards, which is 0.2 of the existing standard. For both “Ni” and “Pb”, the low priority for alternative 3 with respect to the criterion “Environmental protection” has resulted in the considerable RC difference between alternatives 2 and 3. All these findings can be applied in the process of standard setting, and provide an opportunity for decision-makers to be flexible in their judgments in accordance with the specific local context using a rational approach.

Among the toxic pollutants:

“Fe” shows a similar ranking for the criterion “institutional capacity” to “Cu”, “Ni”, “Zn” and “Pb”. Since the BPT-AEL is considerably lower than the other related values, this level has not been suggested. Even the existing standard, which is about 30 times higher than the BPT-AEL, is not the first priority and experts chose the higher value. However, the ranking results indicate that BPT-AELs are often considered as a reliable reference, and, mostly, they are the first priority.

“F”, “CN” and “Hg” in addition to “Cu”, “Ni”, “Zn” and “Pb” are among toxic pollutants, too. For “F”, alternatives 1

and 2, which are in accordance with the BPT-AEL and the existing standard, respectively, are the experts’ priorities. For “CN” and “Hg”, the BPT-AELs, as the first priorities, are considerably lower than all the other ELVs. However, for “Hg”, the next alternative, which is about 0.2 of the first priority, has a very close ranking. Therefore, the selection of BPT-AELs was not the first priority for all the pollutants. BPT-AELs are sometimes the lowest ELVs, and, occasionally, regarding the toxicity of pollutants, higher than the levels of developed countries.

For “Cd”, as a special toxic pollutant, the experts’ priority is for the lowest ELV, which is not BPT-AEL or the existing standard. Therefore, according to the experts’ decision, regardless of country-specific levels, its ELV has to be reduced.

For “Phenol”, a similar trend is observed, and for “Cr”, in the form of “Cr (VI)” and “Cr (total)”, the highest ranking belongs to the second alternative. For “Cr (VI)”, this ELV is less than the existing standard and higher than the BPT-AELs.

Therefore, it can be perceived that none of the reference values have been applied for all the pollutants, and, in this systematic approach, experts have the chance to make their decision with respect to the specific characteristics of each pollutant, and the existing capacities and constraints of the country.

Conclusion

This research presents a comprehensive methodology for determining the ELVs of industrial wastewater at the sector level. Regarding the large-scale implications of these values, it is essential that the methodology be objective, transparent and also reproducible.

It is crucial to emphasize the fact that ELVs depend on contextual criteria and cannot be dictated based on values determined by other countries. This environmental decision, as a dynamic concept, should consider the existing technical practicability, environmental benefits, economic viability and institutional infrastructure of the country.

As a result of the limitations in data availability, especially in developing countries, a qualitative approach has been developed based on expert judgment and the participating

Fig. 1 Priorities with respect to the main goal for conventional pollutants

Fig. 2 Priorities with respect to the main goal for toxic pollutants

multiple stakeholders, even with conflicting points of view. Therefore, the present methodology introduces a robust operational decision-making framework for using the best professional judgment of experts and incorporating large amounts of well-structured information to present an integrated picture for the establishment of ELVs. It also provides the opportunity for reconciliation and negotiation between the industry, the regulatory authority and the best known professional experts, in terms of the ELVs, through a progressive approach.

The inclusion of country-specific supportive information, as an important reference, is another advantage of this approach. Since the BAT, consisting of integrated pollution prevention and reduction principles, is the key concept in deriving this information for the sector under study, the methodology corresponds closely to the industrial sustainability. The information concerning the optimal WTTs presents the priorities of experts in the context of the advanced technological growth in the country, and gives a perspective concerning the opportunities for improving the existing ELVs. In addition, during the filling out of the questionnaires, the face-to-face interviews indicated that experts consider such information, especially their related values, BPT-AELs, as the most vital reference. According to the final results of this research,

among all conventional pollutants, the experts' priorities are for the first alternatives which show that, in their opinion, these lowest values are attainable and the industry has the ability to comply with these ELVs. On the other hand, among toxic pollutants, the experts' priorities do not follow a specific pattern. These obtained findings highlight the need for a transparent and systematic decision-making process.

In this specific multiple objective-decision, two widely accepted MCDM methods were applied to capture the priorities through criteria weighting and the ranking of alternatives. The fuzzy TOPSIS method, applied for ranking, has a compensatory nature, and can be used to balance the priorities of the different stakeholders involved. However, TOPSIS is incapable of identifying the weights and checking the judgments consistencies, and the AHP was employed as the complementary method. One of the main advantages of this hybrid method is that the final decision results are according to the scores. Therefore, the suggested ELVs for each pollutant can be compared accurately and their score differences indicate how much each one is preferred in respect to the others. This is highly valued by decision-makers because the selections can be justified transparently and the other alternatives can be examined using a more flexible approach.

Table 6 The aggregated crisp values resulting from the expert's ranking

Parameter	Criteria											
	Environmental protection			Economic feasibility			Technology viability			Institutional capacity		
	Alt.1	Alt.2	Alt.3	Alt.1	Alt.2	Alt.3	Alt.1	Alt.2	Alt.3	Alt.1	Alt.2	Alt.3
TSS	9.00	8.11	5.10	4.40	6.48	8.11	4.79	6.29	7.99	7.20	7.35	8.45
COD	7.99	5.87	4.43	5.39	7.15	7.30	6.21	7.72	8.05	7.45	7.77	7.77
Oil and grease	8.63	7.56	5.06	5.59	7.20	7.61	5.75	7.61	7.77	6.26	7.56	7.56
Cd	8.81	7.56	5.17	4.02	5.59	7.20	5.21	6.95	7.61	2.50	4.85	6.66
Cr (VI)	9.00	9.00	6.76	4.89	5.99	7.40	6.25	7.15	8.05	3.58	5.91	6.52
Cr (total)	9.00	9.00	3.79	4.89	5.99	7.40	6.25	7.15	8.05	6.21	6.34	7.88
Fe	8.81	8.63	6.81	7.09	7.40	8.28	7.56	7.72	7.88	6.81	6.81	6.81
Cu	8.81	8.81	6.81	6.17	6.17	8.05	7.40	7.56	7.72	6.81	6.81	6.81
Ni	8.63	8.63	2.74	6.17	6.17	8.05	7.40	7.56	7.72	6.81	6.81	6.81
Pb	8.63	6.62	3.00	6.17	6.17	8.05	7.40	7.56	7.72	6.81	6.81	6.81
Zn	8.81	8.81	6.81	6.17	6.17	8.05	7.40	7.56	7.72	6.81	6.81	6.81
CN	9.00	7.00	4.86	4.02	6.17	7.10	5.21	6.62	6.76	5.67	6.34	7.56
F	9.00	9.00	6.95	6.08	6.34	7.35	6.44	6.85	7.88	6.62	6.76	7.10
Phenol	8.45	6.44		5.17	6.66		5.83	7.15		6.48	6.61	
Hg	8.81	7.45		4.82	5.91		5.63	6.34		4.85	5.51	

Table 7 The final ranking results for different suggested alternatives for each pollutant

Parameter	Alternatives (ELVs)	Relative closeness	Ranking	Parameter	Alternatives (ELVs)	Relative closeness	Ranking
TSS	20	0.8694	1	Copper	0.1	0.9728	1
	35	0.8543	2		0.2	0.9737	1
	60	0.7292	3		0.5	0.8951	2
COD	100	0.9282	1	Nickel	0.2	0.9475	1
	200	0.8597	2		0.5	0.9493	1
	250	0.8115	3		2	0.3496	2
Oil and grease	5	0.9106	1	Lead	0.2	0.9473	1
	10	0.8631	2		0.5	0.7602	2
	15	0.7606	3		1	0.3532	3
Cadmium	0.01	0.8942	1	Zinc	0.2	0.9728	1
	0.05	0.8538	2		0.5	0.9737	1
	0.1	0.7869	3		2	0.8951	2
Chromium (VI)	0.06	0.9362	2	Iron	3	0.9570	2
	0.1	0.9580	1		5	0.9747	1
	0.5	0.8480	3		10	0.8945	3
Chromium (total)	0.3	0.9451	2	Cyanides (free)	0.02	0.9284	1
	0.5	0.9625	1		0.1	0.8844	2
	2.5	0.7089	3		0.5	0.7330	3
Phenol	0.5	0.9717	1	Fluoride	2	0.9795	1
	1	0.8915	2		2.5	0.9848	1
Mercury	0.002	0.9747	1		5	0.8511	2
	0.01	0.9656	2				

Table 8 Priorities of alternatives before and after sensitivity analysis related to “Economic feasibility”

Parameters		Priorities					
		Before			After		
		Alt.1	Alt.2	Alt.3	Alt.1	Alt.2	Alt.3
Conventional pollutants	TSS	0.336	0.349	0.315	0.311	0.347	0.342
	COD	0.367	0.335	0.298	0.344	0.341	0.315
	Oil and grease	0.367	0.335	0.298	0.344	0.341	0.315
Toxic pollutants	Cd	0.340	0.347	0.313	0.322	0.344	0.334
	Cr (VI)	0.324	0.355	0.320	0.314	0.351	0.336
	Cr (total)	0.364	0.379	0.257	0.347	0.370	0.283
	Fe	0.348	0.346	0.306	0.341	0.342	0.317
	Cu	0.345	0.345	0.310	0.337	0.338	0.325
	Ni	0.389	0.389	0.222	0.373	0.374	0.253
	Pb	0.414	0.347	0.239	0.394	0.339	0.267
	Zn	0.345	0.345	0.310	0.337	0.338	0.325
	CN	0.368	0.339	0.293	0.343	0.343	0.314
	F	0.343	0.344	0.313	0.337	0.340	0.323

This contextual decision-making process can be used as a practical guidance for the establishment of ELVs at the national level for other industrial sectors. However, these values can be improved by the participation of more stakeholders from different related sectors. In the next stages, these general ELVs can be developed by taking into account the specific local environmental considerations.

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Authors' contributions MM: prepared the initial proposal, inquired the data, conducted the statistical analysis, and wrote the draft. MB and AT: suggested the topic, commented on the proposal and methods, provided scientific support, edited and commented on the final draft. LA and NH: commented on the proposal and methods, supervised the research, edited and commented on the final draft. All authors read and approved the final manuscript.

Competing interest

The authors declare that they have no competing interests.

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Abbreviations *BAT*, Best Available Technology; *ELVs*, Emissions Limit Values; *FMCDM*, Fuzzy Multiple-Criteria Decision-Making; *AHP*, Analytic Hierarchy Process; *Fuzzy TOPSIS*, Fuzzy Technique for Order of Preference by Similarity to Ideal Solution; *DOE*, Department of Environment; *ISESs*, Industry-Specific Effluent Standards; *EPA*, Environmental Protection Agency; *BPT*, Best Practicable Control Technology Currently Available (BPT); *CVI*, Content Validity Index; *EU*, European Union; *IPPC*, Integrated Pollution Prevention and Control Directive; *BAT-AEL*, BAT associated emission level; *BPT-AEL*, BPT associated emission level; *BREFs*, BAT reference documents; *DMs*, Decision-Makers; *WTTs*, Wastewater Treatment Technologies; *DL*, Detection Limit; *TFNs*, Triangular Fuzzy Numbers; *FPIS*, Fuzzy Positive Ideal Solution; *FNIS*, Fuzzy Negative Ideal Solution; *RC*, Relative Closeness.

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