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Evaluation methods for industrial wastewater treatment reuse processes

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Contents

Page

Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 282, *Water reuse*, Subcommittee SC 4, *Industrial water reuse*.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Reuse of industrial wastewater is an important strategy for reducing freshwater consumption and wastewater generation. Treated industrial wastewater can be used for various purposes [6,10,14]. The dominant industrial applications are cooling water for power generation, boiler feed water, equipment cleaning and general process water uses. Reused water may also be applied for non-industrial applications most typically including toilet and urinal flushing, and landscape irrigation [9,13,14].

Currently, various methods are applied to evaluate the resource use, energy and environmental performance respectively, which can be also used in industrial systems, including Life Cycle Assessment (ISO 14040), Environmental Risk Assessment (IEC 31010), Best Available Technology (Directive 2010/75/EU), Ecological Footprint (ISO 14046), Circular Economy (BS 8001) and other methods [1,2,16,17]. The primary evaluation criteria selection for industrial wastewater treatment reuse processes has historically been based on a cost-benefit analysis, however, economic factors are no longer the main decision factor, nowadays, industries take into consideration a number of sustainable factors, including economics, environment, social and technology characteristics [2,7,9,10,15-18].

The evaluation of wastewater treatment reuse processes requires systematic methods to evaluate the performance expectations of alternative wastewater treatment reuse processes [2,10,18].

This document provides guidelines for assessing wastewater treatment reuse processes through enhanced information analysis, to ensure protection of environmental and human health, to promote the transition of the circular economy and improve water management.

Evaluation methods for industrial wastewater treatment reuse processes

1 Scope

This document specifies the principles and framework for comprehensive evaluation of industrial wastewater treatment reuse processes, including:

a) establishing goals and scope;

b) illustrating the evaluation procedure; and

c) determination of evaluation indicators (technology indicator/sub-indicators, environment indicator/sub-indicators, resource indicator/sub-indicators, economy indicator/sub-indicators).

This document describes how to comprehensively evaluate industrial wastewater treatment reuse processes using the proposed calculation approaches and recommended indicators. It does not specify methodologies for single evaluation indicators.

The document is intended to provide assistance to a broad range of industrial wastewater treatment and reuse project stakeholders including professionals (planning, management, designers, and operators), administrative agencies (monitoring, assessment, regulation and administration) and local authorities.

This document is applicable to

a) evaluating comparing and selecting industrial wastewater treatment reuse processes,

b) implementing continuous improvements,

c) upgrading processes and improving performance for existing treatment and reuse facilities.

The intended application of the comprehensive evaluation result is considered within the goal and scope definition.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 20670, *Water reuse — Vocabulary*

3 Terms, definitions and abbreviated terms

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 20670 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.1.1
Delphi method
information-gathering technique used as a way to reach consensus of experts on a subject

Note 1 to entry: The Delphi method is applied as consensus tool for determining weights of indicators/sub-indicators in this document.

Note 2 to entry: A facilitator uses a questionnaire to solicit ideas about the important project points related to the subject. The responses are summarized and are then recirculated to the experts for further comment. Consensus may be reached in a few rounds of this process.

[SOURCE: ISO/IEC/IEEE 24765:2017, 3.1102]

3.1.2
indicator
quantitative or qualitative measure of impacts

[SOURCE: ISO 19208:2016, 3.8]

3.2 Abbreviated terms

The abbreviated terms in Table 1 apply.

Table 1 — Abbreviated terms

Abbreviation	Full term
BOD_5	5-day biochemical oxygen demand
COD	chemical oxygen demand
ELR	environment load ratio
ESI	energy sustainability index
EYR	the energy yield ratio
GHG	greenhouse gas
GWP	global warming potential
LCY	local currency
PAC	poly-aluminum chloride
PAM	polyacrylamide
TDS	total dissolved solids
TSS	total suspended solids

4 Evaluation principles

4.1 Comprehensiveness

The evaluation system provides a multi-criteria analysis framework to evaluate alternatives using parameters that are relevant to the proposed processes. The analysis considers all attributes of multiple indicators (technology, environment, resource, and economy) and address specific requirements by using sub-indicators based on the evaluation indicators, which are consistent with factors involved in a Sustainability Analysis to a certain extent [2,7]. Other social or political criteria can be taken into account according to local policy or regulations [9].

a) Technology

Address the technological parameters of the industrial wastewater treatment processes applied for water reuse.

b) Environment

Address the environmental parameters and impacts of the industrial wastewater treatment processes applied for water reuse system.

c) Resource

Address the resource recovery, allocation and utilization for water reuse.

d) Economy

Address the economic impacts of the industrial wastewater treatment processes applied for water reuse.

4.2 Operability

The selection of evaluation indicators is general, reasonable and attainable, so that the evaluation indicators are concise, clear and easy to get. It is also in line with the actual needs to manage the water environment.

4.3 Relevance

The evaluation process and parameters of the industrial wastewater treatment reuse processes should be extracted in a relevant manner and appropriately quantified.

4.4 Transparency

Due to the inherent complexity for evaluation, transparency is an important guiding principle to ensure proper results. Calculating process of sub-indicators should be recorded and available for clarification when requested.

5 Evaluation procedure

5.1 General

Figure 1 illustrates the general framework.

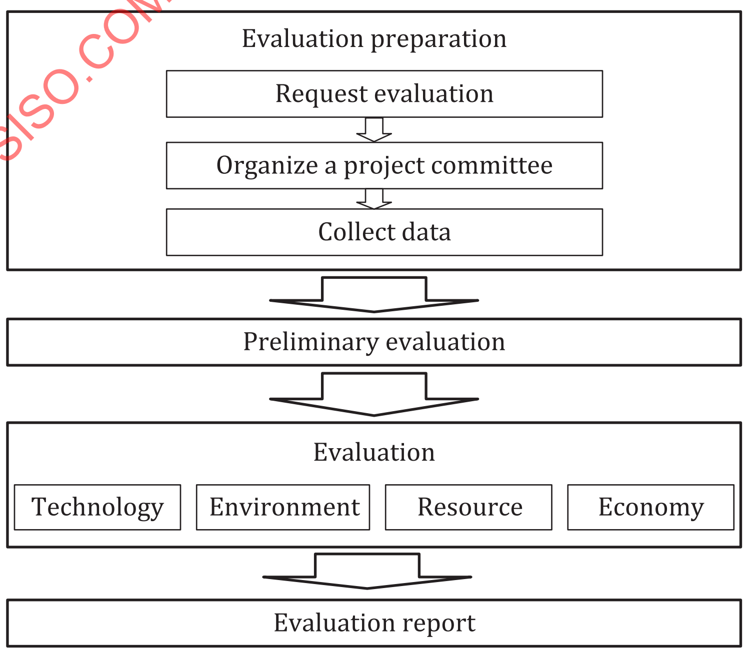


Figure 1 — Framework of evaluation procedure

5.2 Procedure description

5.2.1 Evaluation preparation

Step 1: Request evaluation

The enterprises, industry managers or related organizations develop evaluation requirements and submit the relevant documents. The documents can include, but not limited to the following:

a) The basic information form, which includes:

- the actual position of enterprises;
- major processes and equipment;
- water quality parameters of industrial influents and effluents;
- type of reuse and reuse demands.

b) record files of major pollutants emissions;

c) record files of resources and energy consumption;

d) assessment reports of environmental impact;

e) assessment reports of public safety impact;

f) other essential documents.

NOTE 1 Data (list b, c) can be obtained from relevant research reports and references or statistics for new projects without record files. Reports (list d) include the assessment of freshwater consumption and possible effects of respective direct reduction in the effluent quality, i.e., possible increase of pollutants concentration.

Step 2: Organize a project committee

Establish a project committee which may be composed of experts, skilled operators, industrial shareholders or managers, supervisors, etc. The project committee is asked to undertake the following objectives, respectively.

a) Carry out the evaluation task.

b) Supervise field surveys and sampling tests.

c) Validate the integrity and accuracy of the data on the base of the statistical reports and original records provided by the enterprises.

Step 3: Collect data

Collect raw and supporting data from related industries or enterprises via basic information surveys, please refer to Table D.4 in Annex D. Field surveys, sample tests, and enterprises' record files can be used to collect data if evaluated processes have adequate operational recording data. Research reports and references analysis also can be used to collect data if it is a new process and/or new project with little or no existing operating record.

NOTE 2 Step 1, step 2 and step 3 are recommended steps of evaluation preparation whose main task is to collect data. Other optional steps are also allowed to carry out the evaluation preparation as long as they satisfy the need of collecting adequate information.

5.2.3 Preliminary evaluation

The preliminary evaluation procedure is as following:

a) Analyse and summarize the existing treatment and reuse technologies globally according to the category of industrial wastewater, and determine which technologies or processes are evaluated.

b) Make a simple primary selection of the above processes. The main considerations include:

— Whether the processes achieve the required constituent removal performance.

— According to "Guidelines for Water Reuse 2012"[10] and relevant standards (e.g., ISO 20468-1) to determine whether the technology can meet its corresponding reuse water quality requirements [2,3].

— Whether it is convenient for updating construction considering site, public facilities and other conditions.

— Other necessary conditions and considerations.

c) The project committee (see step 2 in 5.2.1) combined with stakeholders, engineers, technicians and relevant experts to discuss, and distinguish the two major categories: preliminary feasible processes and infeasible processes based on the actual situation of the enterprises. The former processes are selected for further evaluation.

5.2.4 Evaluation

The preliminary feasible processes are comprehensively evaluated from four aspects: technology indicator, environment indicator, resource indicator and economy indicator. See Clause 6.

Social effects which are outside the scope of this document, including education, cultural values, operator training requirements, job creation and other social criteria should be taken into account according to local policy or regulations.

5.2.5 Evaluation report

Step 1: Evaluation results analysis

Compare the comprehensive scores of proposed evaluated processes. Then, make the evaluation report by combining analysis of the evaluation results with consideration on the actual situation of the industrial enterprise. The whole processes that meet the requirements are identified along with the recommended processes, are referred as solutions available for users and decision makers.

Step 2: Prepare evaluation reports

The evaluation report should include the basic condition of the industrial enterprise, the relevant technical conditions, the evaluation process and results, etc.

6 Evaluation

6.1 Evaluation indicators

The evaluation system consists of four primary indicators: technology, environment, resource and economy. Each indicator category is divided into a few sub-indicators. The sub-indicators are refinement of the primary indicators. The overall indicator framework of evaluation system is shown in Table 1. The further details are given in Annex A; calculation of the qualitative sub-indicators refers to Annex B.

Table 1 — Example indicators of industrial wastewater treatment reuse processes

Indicators	Sub-indicators	Note	Related reference
Technology	Te1. Technology maturity	Qualitative	A.1.1
	Te2. Equipment utilization ratio	Quantitative	A.1.2
	Te3. Equipment readiness ratio	Quantitative	A.1.3
	Te4. Stability	Qualitative	A.1.4
	Te5. System management	Qualitative	A.1.5
	Te6. Maintainability and complexity of implementation	Qualitative	A.1.6
	……		
Environment	En1. Conventional pollutants removal rate	Quantitative	A.2.1
	En2. Other concerned pollutants removal rate	Quantitative	A.2.2
	En3. Sludge production rate	Quantitative	A.2.3
	En4. Total GHG emissions	Quantitative	A.2.4
	En5. Energy sustainability index (ESI)	Quantitative	A.2.5
	En6. Odour control and ventilation	Qualitative	A.2.6
	……		
Resource	Re1. Wastewater reuse rate	Quantitative	A.3.1
	Re2. Resource recovery	Quantitative	A.3.2
	Re3. Energy recovery	Quantitative	A.3.3
	Re4. Energy consumption	Quantitative	A.3.4
	Re5. Chemicals consumption	Quantitative	A.3.5
	……		
Economy	Ec1. Capital cost	Quantitative	A.4.1
	Ec2. Operating cost	Quantitative	A.4.2
	Ec3. Disposal cost	Quantitative	A.4.3
	Ec4. Revenues	Quantitative	A.4.4
	……		
NOTE: Not all sub-indicators in Table 1 are mandatory in carrying out an evaluation. Other sub-indicators (such as risk management, environmental and public safety, etc.) can be selected or added depending on situation.			

6.2 Evaluation method description

6.2.1 General

A step by step method is illustrated as the following steps (step 1~step 5) and a sample evaluation table is given in Table 2.

6.2.2 Evaluation steps

Step 1: Individual evaluation of sub- indicators

To deal with sub-indicators through normalization, the values should be dimensionless [7].

Calculate the individual evaluated value, "I_i", expressed as dimensionless number of the sub-indicators, "i", using Formulae (1) and (2).

For the higher value, the better indicators, using Formula (1):

$$I_i = \frac{S_i - S_{min}}{S_{max} - S_{min}} \quad (1)$$

For the lower value, the better indicators, using Formula (2):

$$I_i = \frac{S_{max} - S_i}{S_{max} - S_{min}} \quad (2)$$

where

S_i is the individual evaluation value, of sub-indicators, "*i*";

i is the serial number of sub-indicators, i=1, 2, 3...n.

S_{max} and S_{min} are the maximum and minimum value, respectively, of the same evaluation sub-indicator in different processes to be evaluated.

Step 2: Individual score of sub-indicators

Calculate the individual score of the sub-indicator, "P_i", using Formula (3):

$$P_i = I_i \times K_i \quad (3)$$

where

I_i is the normalized value of sub-indicators, "*i*";

K_i is the weight coefficient of sub-indicators, "*i*". Refer to Annex C to determine K_i.

Step 3: Individual evaluation of indicators

Calculate the individual evaluated value, "Q_j", expressed as dimensionless number, of the indicators, "*j*", using Formula (4):

$$Q_j = \sum_{i=1}^{n} P_i \quad (4)$$

where

j is the serial number of indicators, j=1, 2, 3, 4;

n is the total number of sub-indicators under indicator, "*j*";

P_i is the individual score of sub-indicators "*i*", under indicator, "*j*".

Step 4: Individual score of indicators

Calculate the individual score of indicators, "M_j", using Formula (5):

$$M_j = Q_j \times F_j \quad (5)$$

where

Q_j is the individual evaluated value of indicator "*j*";

F_j is the weight coefficient of indicator "*j*". Refer to Annex C to determine F_j.

Step 5: Calculate comprehensive evaluation score

Calculate the comprehensive score of the evaluated industrial wastewater treatment technology for reuse, “E”, and using Formula (6):

$$E = \sum_{j=1}^{4} M_j \tag{6}$$

where M_j is the individual score of indicators “j”.

Sort the comprehensive scores (E) of proposed evaluated processes in descending order. Make the evaluation report by combining analysis of evaluation results with consideration on the actual situation of the industrial enterprise.

6.2.3 Example evaluation table

Table 2 — Example evaluation table of industrial wastewater treatment reuse processes

serial number	Indicators	Sub-indicators	Related value of sub-indicators			Related value of indicators		
			K Weight of sub-indicator (refer to Annex C)	*I* Individual evaluated value of sub-indicator	*P* Individual score of sub-indicator $P_i = I_i \times K_i$	*F* Weight of indicator (refer to Annex C)	*Q* Individual evaluated value of indicator $Q_j = \sum_{i=1}^{n} Pi$	*M* Individual score of indicator $M_j = Q_j \times F_j$
1	Technology indicator	Te1. Technology maturity						
		Te2. Equipment utilization ratio						
		Te3. Equipment readiness ratio						
		Te4. Stability						
		Te5. System management						
		Te6. Maintainability and complexity of implementation						
		……						
2	Environment indicator	En1. Conventional pollutants removal rate						
		En2. Other concerned pollutants removal rate						
		En3. Sludge production rate						
		En4. Total GHG emissions						
		En5. Energy sustainability index (ESI)						
		En6. Odour control and ventilation						
		……						
3	Resource indicator	Re1. Wastewater reuse rate						
		Re2. Resource recovery						
		Re3. Energy recovery						
		Re4. Energy consumption						
		Re5. Chemicals consumption						
		……						
Comprehensive evaluation score *E*								

Table 2 *(continued)*

serial number	Indicators	Sub-indicators	Related value of sub-indicators			Related value of indicators		
			K Weight of sub-indicator (refer to Annex C)	*I* Individual evaluated value of sub-indicator	*P* Individual score of sub-indicator $P_i=I_i×K_i$	*F* Weight of indicator (refer to Annex C)	*Q* Individual evaluated value of indicator $Q_j=\sum_{i=1}^{n} Pi$	*M* Individual score of indicator $M_j=Q_j×F_j$
4	Economy indicator	Ec1. Capital cost						
		Ec2. Operating cost						
		Ec3. Disposal cost						
		Ec4. Revenues						
		……						
Comprehensive evaluation score *E*								

NOTE An example of evaluation case is given in Annex D.

Annex A
(informative)

List of evaluation indicators and sub-indicators

A.1 Technology indicator

A.1.1 Te1 Technology maturity

The technology maturity is a qualitative sub-indicator classified as five levels: R & D phase, field test, industrial demonstration, industrial application, and commercialization.

A.1.2 Te2 Equipment utilization ratio

Calculate the average operation ratio, expressed as a percentage, of the equipment, W_o, using Formula (A.1):

$$W_o = \frac{t_1}{t_1 + t_2} \quad (A.1)$$

where

t_1 is the average days of the equipment in operation per year;

t_2 is the average days of downtime per year.

A.1.3 Te3 Equipment readiness ratio

The readiness (perfectness) ratio of critical equipment of the selected process flow should be taken into full account.

Calculated the equipment readiness ratio, W_E, of equipment, using the Formula (A.2):

$$W_E = \frac{T_{in}}{T} \quad (A.2)$$

where

T_{in} is the days of equipment in good condition during time T;

T is the time, expressed in days, of total statistic days.

A.1.4 Te4 Stability

The operational stability of the selected process is a qualitative sub-indicator including the shock resistance load capacity and the water quality stability rate [5,7].

Shock resistance load capacity: It makes a certain impact on the wastewater treatment facilities when influent water changed extremely. Time required for system back to the previous state shows the strength of anti-shock loading capability.

Water quality stability rate: It shows the probability of the treated wastewater that can meet the discharge standard. It is the ratio of number of days meeting effluent quality standards to the number of days throughout the year.

NOTE This sub-indicator can refer to ISO 20468-1.

A.1.5 Te5 System management

It is a qualitative sub-indicator considering the following aspects: a) the rules and regulations, b) training and technical data, c) level of system automation[12], and d) general data requirements [5].

A.1.6 Te6 Maintainability and complexity of implementation

Maintainability is an inherent quality characteristic of product/equipment, which measures the maintenance difficulty and cost when mechanical/equipment products go wrong. Maintainability can reflect system effectiveness and life-cycle cost of products [15].

The complexity of implementation is correlated with the level of automatic control and the situation of manual management. As known, the level of automatic control will directly affect the stability of the operation of wastewater treatment technology and the investment amount in the project.

A.2 Environment indicator

A.2.1 En1 Conventional pollutants removal rate

The removal rate of total nitrogen, total phosphorus, TSS, *Escherichia coli*, chloride, pH, COD, BOD_5 and other conventional pollutants per unit during industrial wastewater treatment process [1,18].

A.2.2 En2 Other concerned pollutants removal rate

It is the removal rate of the concerned pollutants, such as oil hydrocarbons, volatile phenols, chlorides, heavy metals (mercury, cadmium, chromium (i.e., hexavalent species), total chromium, lead, arsenic), and other chemical constituents. In addition, selection should change according to the quantity and quality of industrial wastewater in different process and area. No uniformity should be imposed since conditions can vary [1,18].

A.2.3 En3 Sludge production rate

It is the production rate of semi-liquid (or semi-solid) residue or solids separated from suspension in a liquid in industrial processes and treatment of sewage and wastewater. R_s, using Formula (A.3)

$$R_S = \frac{m_S}{V_t} \tag{A.3}$$

where

R_s is the sludge production rate;

m_s is the amount, expressed in kg, of sludge produced during industrial wastewater treatment reuse processes;

V_t is the volume, expressed as m^3, of treated industrial wastewater during the statistical period.

A.2.4 En4 Total GHG emissions

Global warming potential (GWP) is used to measure the contribution of GHG emissions to global warming [10,18]. Refer to Greenhouse Gas Equivalencies Calculator in References [20].

Calculate the total greenhouse emission, expressed as impact value, using Formula (A.4)

$$IV_i = EFGWP_i \times A_i \quad \text{(A.4)}$$

where

IV_i	is the impact value of greenhouse gases;
$EFGWP_i$	is the coefficient of GWP correlation of greenhouse gas I, e.g. CO_2, CH4, and N_2O;
A_i	is the amount of greenhouse gas I, e.g. CO_2, CH4, and N_2O.

NOTE 1 Calculating En5 can refer to ISO 20468-2.

NOTE 2 En5 can be calculated by software or related website.

A.2.5 En5 Energy sustainability index (ESI)

It is ratio of EYR to ELR, and it reflects both ecological and economic benefits in terms of the overall sustainability of the system [19-22].

ESI=EYR/ELR

EYR Energy yield ratio

Reflects the feedback energy from the economic system and is a measure of how much the energy yield contributes to the economic system. *EYR* is used to judge the energy efficiency and economic competitiveness of a system based on purchased inputs.

ELR Environment load ratio

The ratio of non-renewable input energy, (including purchased energy and energy from non-renewable resources) to renewable resources input energy; this parameter denotes the pressure economic activities place on the environment.

NOTE See Reference [21].

A.2.6 En6 Odour control and ventilation

Odour mainly refers to sulphur compounds, nitrogen, carbon and oxygen compounds [8].

A.3 Resource indicator

A.3.1 Re1 Wastewater reuse rate

It is the rate of industrial wastewater reuse. In the statistical period, calculate the rate, expressed as a percentage, of the industrial wastewater reuse, K_w, using Formula (A.5)

$$K_w = \frac{V_w}{V_d + V_w} \times 100\ \% \quad \text{(A.5)}$$

where

V_w	is the volume, expressed in m^3, of the water reused by the enterprise or industry in the statistical period;
V_d	is the volume, expressed in m^3, of the wastewater discharged by enterprise.

A.3.2 Re2 Resource recovery

The recycling amount of heavy metals, inorganic salts, nitrogen, phosphorus, sulphur and others recycles during wastewater treatment and reuse process.

A.3.3 Re3 Energy recovery

During the statistical period, energy recovery from thermal heat, anaerobic digestion and solar energy. Organic energy production. In the process of wastewater treatment, some industrial organic wastes can be converted into recoverable combustible gas or liquid fuel biomass energy, such as methane, hydrogen, etc. calculated as heat energy, E_{H}, using Formula (A.6):

$$E_{\mathrm{H}} = C_{\mathrm{COD}} \times R \times V_t \times c_1 \times c_2 \qquad \text{(A.6)}$$

where

E_{H} is the energy recovery, expressed as kJ, of organic wastes, thermal and solar energy;

C_{COD} is the concentration, expressed as kg/m^3, of COD in the industrial wastewater;

R is the removal rate, expressed as percentage, of equipment;

V_t is the volume, expressed as m^3, of treated industrial wastewater during the statistical period;

C_1 is the biogas production rate, 0,35~0,7 m^3/kg COD.

A.3.4 Re4 Energy consumption

All the energy consumption used for wastewater treatment, such as, electricity consumption, water consumption, energy of management, and pumping energy for residuals and wastewater in the treatment process.

A.3.5 Re5 Chemicals consumption

The chemicals resources (chemicals, materials, etc.) shall be consumed by disposal in industrial wastewater treatment, such as adsorbent, coagulant, pH buffer, methanol, lime, etc.

A.4 Economy indicator

A.4.1 Ec1 Capital cost

Capital cost comprise all costs related to the purchase of mechanical equipment, technological installations, engineering services, construction cost, land use fee, etc. [3,7,15].

NOTE It can also refer to ISO 20468-1, ISO 22449-2.

A.4.2 Ec2 Operating cost

Operating cost consists of costs of make-up water, chemicals and power, employees' wages, maintenance cost, etc. [2,3,7].

NOTE It can also refer to ISO 20468-1, ISO 22449-2.

A.4.3 Ec3 Disposal cost

Disposal cost includes the cost for the demolition of the system and the rehabilitation cost for the land use by the system (if applicable) at the end of the system's useful life, including all labour cost, material cost and construction equipment usage cost related to the system [2,3].

NOTE It can also refer to ISO 20468-1, ISO 22449-2.

A.4.4 Ec4 Revenues

Revenues can be obtained from selling the products in waste treatment: electricity, heat, compost, and recycled materials. Furthermore, the evaluation of revenues was made on the basis of the data for waste treatment: composting (taking into account the market price of composting), incineration (taking into account the price of electricity produced) and anaerobic digestion (taking into account the price of electricity produced). The assessment of income from recycling was done on the basis of the market price of recycled materials [18].

Annex B
(informative)

Quantify qualitative sub-indicators

The sub-indicators are divided into two types: quantitative sub-indicators and qualitative sub-indicators, respectively.

a) Principles of evaluating the quantitative sub-indicators.

Calculate the quantitative sub-indicators on the basis of engineering application statistics and theoretical data of industrial wastewater treatment processes. It is also a need to measure and test the data onsite if necessary. Parts of calculate methods are according to Annex A.

b) Principles of evaluating the qualitative sub-indicators.

Quantify the qualitative sub-indicators on the basis of experts' experience. The method and procedure can refer to Table B.1.

Table B.1 — Quantified values of qualitative sub-indicators

Qualitative sub-indicators	Quantification of qualitative sub-indicators				
	0-0,2	0,2-0,4	0,4-0,6	0,6-0,8	0,8-1,0
Te1. Technology maturity	R & D phase	Field test	Industrial demonstration	Industrial application	Commercialization
Te4. Stability	Weak	Better	Average	Good	Excellent
Te5. System management	Weak	Better	Average	Good	Excellent
Te6. Maintainability and complexity of implementation	Very complex	Complex	Moderate	Uncomplicated	Simple
En6. Odour control and ventilation	Very low	Low	Medium	High	Very high

Annex C
(informative)

Determination of weights

C.1 Determine the indicator weight

The weight value of the indicators, F_j, and sub-indicators, K_i,

where

$0 \le K_i \le 1$, $0 \le F_j \le 1$; $\sum_{i=1}^{m} K_i = 1$, $\sum_{j=1}^{4} F_j = 1$.

Determine weights of indicators, F_j and weights of sub-indicators, K_i, respectively according to following processes.

Step 1: Organize a project committee to decide weights of indicators and sub-indicators

Specific requirements of the committee:

a) The committee is typical and representative, the scope of investigation is as far as possible.

b) The members in this panel are closely related to industrial wastewater treatment and have a high authority in the corresponding fields.

c) The committee involves a wide range of professionals, the professions may involve environmental engineering, environmental science, construction, economics, water supply and drainage and others. The working departments can involve government departments, teaching and scientific research institution.

d) The committee will provide advice, feedback and endorsement to the project team.

NOTE The weights vary in different evaluation cases.

Step 2: Make questionnaires of weight value

First, collect the problems going to be investigated together to avoid overlapping in terms of accuracy. Second, make the evaluation structure and index system clear. Then, design into a form to solicit opinions for the purpose of the survey respondents. The weight value questionnaire is referenced in Annex C, Table C.1.

Adopt Delphi method to carry out investigate program.

For investigating, should use a unified questionnaire and fill out the questionnaires in same way:

a) Ask questions, making consultation forms and distributing them to experts.

b) Collect consultation opinions and statistics, sort out all kinds of opinions.

c) Rotate the opinions consultation until it comes to a similar or same result.

Step 3: Analyse results

Determine the weight K_i and F_j by calculating the data using arithmetic average method. The concrete calculation method is as following:

Suppose that the total number of experts involved is n, and W_{ij} is the consulting value of the weight given by the *j*-th expert to the *i*-th indicator or sub-indicator, and the number of indicators or sub-indicators is m, and the sum of the weight should be 1 as given in Formula (C.1):

$$\sum_{i=1}^{m} W_{ij} = 1 \tag{C.1}$$

Calculate the mean weighted value, W_i, of each indicator or sub-indicator, using formula (C2):

$$W_i = \frac{1}{n} \sum_{j=1}^{n} W_{ij} \tag{C.2}$$

C.2 Weight value questionnaire

Table C.1 — Weight value questionnaire

Indicators (*Q*)	Weight value (*F*)[a]	Sub-indicators (*I*)	Weight value (*K*)
Technology indicator		Te1. Technology maturity	
		Te2. Equipment utilization ratio	
		Te3. Equipment readiness ratio	
		Te4. Stability	
		Te5. System management	
		Te6. Maintainability and complexity of implementation	
		……	
Environment indicator		En1. Conventional pollutants removal rate	
		En2. Other concerned pollutants removal rate	
		En3. Sludge production rate	
		En4. Total GHG emissions	
		En5. Energy sustainability index (ESI)	
		En6. Odour control and ventilation	
		……	
Resource indicator		Re1. Wastewater reuse rate	
		Re2. Resource recovery	
		Re3. Energy recovery	
		Re4. Energy consumption	
		Re5. Chemicals consumption	
		……	
Economy indicator		Ec1. Capital cost	
		Ec2. Operating cost	
		Ec3. Disposal cost	
		Ec4. Revenues	
		……	

[a] The weight value of each indicator/sub-indicators in the process of industrial wastewater treatment is given according to the experience, the value is between [0, 1], and the sum of all indicators/sub-indicators in same level should be 1.

Annex D
(informative)

Example of evaluation case

The basic data was selected and collected from textile printing and dyeing industry in China (Scenario A), as shown in the Table D.1 below, the process flow chart is shown in Figure D.1, the data collecting form is attached to the end of Annex D, Table D.4.

Table D.1 — Basic data for evaluation

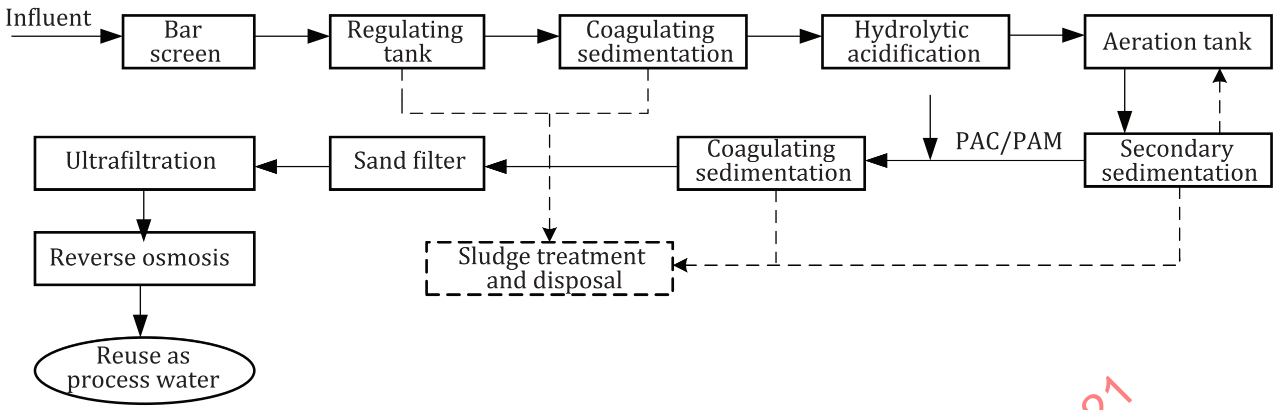
Parameters	Scenario A
Wastewater resource	Textile printing and dyeing industry
Wastewater volume	30000 m^3/d
Te1. Technology maturity	0,8/dimensionless
Te2. Equipment utilization ratio	100%
Te3. Equipment readiness ratio	100%
Te4. Stability/dimensionless	0,7/dimensionless
Te5. System management	0,7/dimensionless
Te6. Maintainability and complexity of implementation	0,2/dimensionless
En1. Conventional pollutants removal rate	92 % [a]
En2. Other concerned pollutants removal rate	98 % [b]
En3. Sludge production rate	30 %
En6. Odour control and ventilation	0,9/dimensionless
Re1. Wastewater reuse rate	53 %
Re4. Energy consumption	0,858 CNY[c]/m^3 [c]
Re5. Chemicals consumption	3,5 CNY/m^3
Ec1. Capital cost	7000 CNY
Ec2. Operating cost	4,43 CNY/m^3
Ec3. Disposal cost	1400 CNY
Ec5. Capital pay-off time	10,5 year

[a] In statistical analysis, chromaticity, BOD_5, COD, TSS, TN, NH_3-N and TP, are included in conventional pollutants. All of them have equal weighting factor and the same priority. Therefore, the final removal rate of conventional pollutants takes the average of all.

[b] In this statistic, other concerned pollutants removal rate means to rate of sulphide, which is important and special in textile printing and dyeing industry.

[c] CNY denotes Chinese Yuan.

NOTE: The following lists abbreviated terms are referred in Table D.1.



Key

——— wastewater

– – – sludge

Figure D.1 — Example of process flow of textile printing and dyeing industrial park wastewater treatment for reuse

The weights of each evaluation indicator are shown in Table D.2 (refer to Annex C Determination of weights).

Table D.2 — weights of indicators

Indicators	Weight value (*F*)	Sub-indicators	Weight value (*K*)
Technology indicator	0,30	Te1. Technology maturity	0,15
		Te2. Equipment utilization ratio	0,10
		Te3. Equipment readiness ratio	0,20
		Te4. Stability	0,20
		Te5. System management	0,30
		Te6. Maintainability and complexity of implementation	0,05
		……	
Environment indicator	0,20	En1. Conventional pollutants reduction	0,20
		En2. Other concerned pollutants reduction	0,35
		En3. Sludge production rate	0,20
		En4. Total GHG emissions	0,00
		En5. Energy sustainability index (ESI)	0,00
		En6. Odour control and ventilation	0,15
		……	

NOTE 1: The weight value of each indicator/sub-indicators in the process of industrial wastewater treatment is given according to the experiences, the value is between [0, 1], and the sum of all indicators/sub-indicators in same level should be 1.

NOTE 2: The weights of each indicator were obtained according to Annex C Determination of weights. The weights in Table D.2 are applied for the case in this annex but not for all the evaluation cases. The user should get their own weights according to the steps in Annex C or collect from survey or software.

Table D.2 *(continued)*

Indicators	Weight value (F)	Sub-indicators	Weight value (K)
Resource indicator	0,10	Re1. Wastewater reuse rate	0,30
		Re2. Resource recovery	0,00
		Re3. Energy recovery	0,00
		Re4. Energy consumption	0,30
		Re5. Chemicals consumption	0,40
		......	
Economy indicator	0,40	Ec1. Capital cost	0,20
		Ec2. Operating cost	0,30
		Ec3. Disposal cost	0,20
		Ec4. Revenues	0,00
		Ec5. Capital pay-off time	0,30

NOTE 1: The weight value of each indicator/sub-indicators in the process of industrial wastewater treatment is given according to the experiences, the value is between [0, 1], and the sum of all indicators/sub-indicators in same level should be 1.

NOTE 2: The weights of each indicator were obtained according to Annex C Determination of weights. The weights in Table D.2 are applied for the case in this annex but not for all the evaluation cases. The user should get their own weights according to the steps in Annex C or collect from survey or software.

Table D.3 — Calculation of comprehensive score

serial number	Indicators	Sub-indicators	Related value of sub-indicators			Related value of indicators		
			K Weight of sub-indicator (refer to Annex C)	I Individual evaluated value of sub-indicator	P Individual score of sub-indicator $P_i=I_i \times K_i$	F Weight of indicator (refer to Annex C)	Q Individual evaluated value of indicator $Q_j=\sum_{i=1}^{n} Pi$	M Individual score of indicator $M_j=Q_j \times F_j$
1	Technology indicator	Te1. Technology maturity	0,15	0,8	0,12	0,15	0,78	0,12
		Te2. Equipment utilization ratio	0.10	1,0	0,10			
		Te3. Equipment readiness ratio	0,20	1,0	0,20			
		Te4. Stability	0,20	0,7	0,14			
		Te5. System management	0,30	0,7	0,21			
		Te6. Maintainability and complexity of implementation	0,05	0,2	0,01			
		......						
2	Environment indicator	En1. Conventional pollutants removal rate	0,30	0,92	0,28	0,40	0,82	0,33
		En2. Other concerned pollutants removal rate	0,35	0,98	0,34			
		En3. Sludge production rate	0,20	0,30	0,06			
		En4. Total GHG emissions	0,00	Null	0,00			
		En5. Energy sustainability index (ESI)	0,00	Null	0,00			
		En6. Odour control and ventilation	0,15	0,90	0,14			
		......						
3	Resource indicator	Re1. Wastewater reuse rate	0,30	0,53	0,16	0,15	0,56	0,08
		Re2. Resource recovery	0,00	Null	0,00			
		Re3. Energy recovery	0,00	Null	0,00			
		Re4. Energy consumption	0,30	0,11	0,03			
		Re5. Chemicals consumption	0,40	0,92	0,37			
		......						
Comprehensive evaluation score, E = 0,63								

Table D.3 *(continued)*

serial number	Indicators	Sub-indicators	Related value of sub-indicators			Related value of indicators		
			K Weight of sub-indicator (refer to Annex C)	*I* Individual evaluated value of sub-indicator	*P* Individual score of sub-indicator $P_i = I_i \times K_i$	*F* Weight of indicator (refer to Annex C)	*Q* Individual evaluated value of indicator $Q_j = \sum_{i=1}^{n} Pi$	*M* Individual score of indicator $M_j = Q_j \times F_j$
4	Economy indicator	Ec1. Capital cost	0,20	0,99	0,20	0,30	0,34	0,10
		Ec2. Operating cost	0,60	0,22	0,13			
		Ec3. Disposal cost	0,20	0,40	0,01			
		Ec4. Revenues	0,00	Null	0,00			
		……						
Comprehensive evaluation score, E = 0,63								