
**General principles and guidelines
for cost analysis in planning of
decentralized wastewater treatment
and/or reuse**

*Principes généraux et lignes directrices pour l'analyse des coûts lors
de la planification du traitement décentralisé et/ou de la réutilisation
des eaux usées*

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

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).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

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 2, *Water reuse in urban areas*, in collaboration with Technical Committee ISO/TC 224 *Drinking water, wastewater and stormwater systems and services*.

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

While energy consumption for water and wastewater treatment is significant, up to 80 % of it is used for conveyance. This includes pumping of wastewater to the treatment facility and pumping the effluent to its reuse site. In centralized wastewater treatment and reuse system schemes, the long-distance conveyance through piping systems and pumping stations is also associated with capital investment, which would be hard to bear for those people living in areas of low population densities.^{[1],[2]} Thus, a network of decentralized wastewater treatment and reuse systems will potentially reduce both the capital expenses (CAPEX) and operating expenses (OPEX) in some cases, compared with conventional planning of centralized wastewater treatment and reuse systems. Another benefit of decentralized treatment is enabling local reuse, mainly for irrigation.^{[3],[4]}

Distributed design is the concept of providing several decentralized wastewater treatment systems instead of one central plant, as outlined in other International Standards, such as ISO 23056, which defines and describes different degrees of decentralization of wastewater treatment plants and discusses considerations that should be taken in the selection of each alternative. Due to development in automation and telecommunication, as well as in biological wastewater treatment processes, the distributed design concept has become a viable option. Potential savings in using distributed design include:

- lower collection and pumping system construction costs;
- lower collection and pumping system operation and maintenance costs;
- lower energy consumption for pumping;
- local availability for reuse in agriculture or industry or landscape irrigation.

However, potential drawbacks include:

- higher specific cost of each plant compared with a centralized wastewater treatment and reuse system;
- higher operator attention required for many plants compared with one plant.

This document aims to provide guidelines for life cycle cost assessment for any degree of distribution in the planning of a network of decentralized wastewater treatment and reuse systems in order to enable the cost optimization of the design.

General principles and guidelines for cost analysis in planning of decentralized wastewater treatment and/or reuse

1 Scope

This document specifies the general principles and provides guidance on the quantitative characterization of the life cycle cost of a complete wastewater management system, including collection, treatment and, optionally, reuse. It enables the consideration of different degrees of distribution, including non-sewered systems for one or more dwellings and associated trucking operations.

The methodology provided in this document is applicable to urban or rural areas wherein several decentralized wastewater treatment and reuse systems can provide a lower cost solution than a single centralized plant. Similarly, the same methodology can be applied for industrial reuse systems, where several separate plants on a large industrial site can be considered instead of one treatment system.

The scope of this document includes the following:

- a) Guidance on the determination of the degrees of distribution of decentralized wastewater treatment and reuse systems.
- b) A definition of the elements and components included in the life cycle cost of the different degrees of distribution in wastewater management systems, including construction, operation and maintenance.
- c) Guidance on the required steps for calculating life cycle cost indicators, including considerations of term and interest, operation and maintenance, replacement parts, equipment life expectancy, the value of water for reuse and other income from by-products.
- d) A definition of the metrics for reporting results, including the cost per unit, scope, term and interest.

The following secondary costs and other considerations are not within the scope of this document:

- cost of eventual disposal of the system;
- guidance on wastewater treatment process selection and design;
- health and sustainability considerations (although health and sustainability are primary considerations in design and decisions);
- social impact factors and/or environmental risks and impacts.

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, symbols 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 terminology databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <https://www.electropedia.org/>

3.1.1

distributed system

two or more treatment plants in different geographical locations linked to a central system, either physically or by management

Note 1 to entry: See WEF Fact Sheet “Distributed Systems Overview” (ref. WSEC-2019-FS-012).^[6]

3.1.2

degree of distribution

number of treatment plants to treat a certain population

Note 1 to entry: A high degree of distribution means many plants to treat the population, while a low degree of distribution means a number as low as one centralized plant to treat that same population.

3.1.3

non-sewered system

NSS

system that is not connected to a networked sewer and collects, conveys and fully treats the specific input to allow for safe reuse or disposal of the generated solid output and/or effluent

Note 1 to entry: A non-sewered system is also referred to as an “on-site treatment system”, see ISO 24513:2019, 3.5.16.

[SOURCE: ISO 30500:2018, 3.1.1.1, modified — Note to entry replaced.]

3.1.4

total installed cost

final cost of designing, fabricating and building a capital project or industrial asset

Note 1 to entry: The total installed cost includes the cost of labour and materials.

3.2 Symbols and abbreviated terms

AOP	advanced oxidation processes
C_I	investment cost
C_M	maintenance cost
C_N	negative cost
C_O	operating cost
CAPEX	capital expenses
IFAS	integrated fixed-film activated sludge
MABR	membrane aerated biofilm reactor

MBBR	moving bed bio reactor
MBR	membrane bio reactor
NPV	net present value
OPEX	operating expenses
PE	population equivalent
PV	present value
RO	reverse osmosis
SBR	sequencing batch reactor
UASB	upflow anaerobic sludge blanket
UV	ultraviolet (irradiation, in context of disinfection)
WRRF	water resource recovery facility

4 Description of different degrees of distribution in planning and design

The difference between decentralized wastewater treatment systems (3.1.1) and distributed wastewater treatment systems (see ISO 20670) is that distributed systems are located in different geographical locations but are linked to a central system either physically or by management, whereas decentralized systems can be located in a different geographical location but are not linked physically or are not managed under the umbrella of a centralized system.

The degree of distribution (3.1.2), meaning the number of treatment units for a given population, can be as high as one system for each household (on-site systems) or as low as one single treatment plant for a city, town or village (centralized system), or many degrees in between, such as one system per street or one system for every cluster of households or drainage basin. The collection of wastewater can be via a piped network (a sewer system) or by motorized vehicles, such as vacuum trucks, in non-sewered systems. Determining the required number of systems can be challenging in the design of a wastewater treatment and reuse plan. In some cases, the means to meet this challenge can be through an economic estimation of the long-term cost.

A single large plant may benefit from the economy of scale of its equipment and from lower operation and maintenance costs compared with a distributed system made up of multiple decentralized systems. However, distributed systems can offset much of this benefit through lower CAPEX for piping and pumping as well as lower OPEX for pumping energy, on both wastewater and water for reuse. Therefore, the overall cost benefit of a distributed design or a centralized design changes from one place to another and should be calculated in order to make a decision based on costs.

A structured analysis of the total cost per unit of wastewater treatment for reuse was demonstrated by multiple computerized simulations for different types of terrain and different population densities. [9] The results show that for the lowest population density found in rural areas, the highest degree of distribution is associated with the lowest cost in flat, hilly or mountainous terrains, whereas in suburban areas it greatly depends upon the terrain. A less distributed design results in a lower cost in flat terrain, whereas a more distributed design results in a lower cost in mountainous terrain.

An example of two different degrees of distribution for a specific case is given by van Afferden et al., [10] showing a distributed scenario of nine decentralized systems (indicated there by white triangles with a dark frame) and just one pumping station, all managed by one utility. For comparison, a centralized scenario with one wastewater treatment plant is shown (indicated there by a single dark triangle),

supported by six pumping stations (indicated there by bright rectangles connected to dashed lines) and several kilometres of a trunk pipe.

NOTE There are cases in small rural communities in which the communal decentralized wastewater treatment and reuse systems are not equipped to treat sludge. In such cases, the sludge generated in these facilities is collected and brought to centralized wastewater treatment plants for treatment.

5 Generalized elements of wastewater treatment and reuse systems

5.1 General

In the planning of wastewater management systems for reuse or other purposes, there are many components and subsystems to be selected and designed, as listed in 5.2 to 5.5. All costs associated with all these elements of the system should be included in the cost comparison of different degrees of distribution of the entire plan.

The following subsections provide context, along with a brief explanation of the nature and scope of each of these elements.

5.2 Collection

The collection system is roughly divided into stages from the source towards its final destination, as shown in available publications.^[11] For the purposes of this document, the following notation will be followed in order of flow, from each home in a lateral sewer up to the intercepting sewer or pressure main that reaches the wastewater treatment plant (based on EPA notation^[12]): a) lateral sewer; b) branch sewer; c) trunk sewer (main sewer); d) intercepting sewer; e) pressure main.

Systems may have all or part of these collection system components for different degrees of distribution. For example, an on-site treatment system will typically only have a lateral sewer collecting from the dwelling to the treatment system.

Trucking or hauling of wastewater or sludge is sometimes an alternative to collection and conveyance systems, especially in non-sewered systems or on-site treatment systems. When any part of the wastewater is disposed of by trucking or hauling, it is accounted for as an operational cost instead of an investment cost.

5.3 Conveyance

Pumping stations and lift stations are used whenever wastewater conveyance by gravity is not possible, either as an intermediate or final run of part of the collection system. Different designs are common for a sewage pumping or lift station, with the following typical main components:^{[13], [14]}

- a) screening to protect the pumps from clogging;
- b) a pit or a well to intercept the sewage and provide an operational volume and buffering;
- c) pumps, including redundancy;
- d) discharge pressure piping;
- e) venting and optional means for odour control.

Vacuum collection systems are a recent alternative to gravity collection systems when the latter are not practicable due to area limitation. The vacuum collection sewers use suction (negative pressure) to move the sewage through the following three main stages:^{[15], [16]}

- Vacuum valve pit: sewage collection from individual households or homes by gravity. Once the pit is full, a valve is opened and atmospheric pressure forces the wastewater to the vacuum branches.

- Vacuum mains: a network of vacuum piping collecting sewage from the collection chambers of individual housings and gradually converging towards the vacuum station. The pressure difference between the valve pit and the vacuum station pulls the wastewater through the vacuum mains.
- Vacuum station: producing the suction for the vacuum piping network connected to it and typically pumping the sewer to the wastewater treatment plant.

It is reiterated that trucking or hauling of wastewater or sludge is sometimes an alternative to collection and conveyance systems, especially in non-sewered systems or on-site treatment systems. When any part of the wastewater is disposed of by trucking or hauling, it is accounted for as an operating cost instead of an investment cost.

5.4 Treatment

The treatment plant, also referred to as a WRRF, includes all installed water treatment processes used to achieve compliance with local discharge standards or reuse requirements. These typically include the process sub-sections or categories^[17] described as follows and summarized in [Table C.1](#).

In cases where different effluent requirements are applicable for different plant sizes, such as between a decentralized plant and a centralized plant, each plant or plan may be made with the requirements for its type, as would be the eventual design for regulatory approval. For example, in some places, small wastewater treatment and reuse systems are not required to perform tertiary treatment for reuse in irrigation of tree-grown crops, whereas a large plant is required to perform tertiary treatment regardless. In such cases, the cost of tertiary treatment does not have to be included where it is not needed.

- a) Pre-treatment: physical processes to remove elements that could damage downstream equipment and also remove easily removable constituents to improve downstream process efficiency. Usually, pre-treatment units are designed to handle diurnal and seasonal flow variations.

The costing of pre-treatment shall include any aeration, mixing, chemicals, sludge treatment and disposal, whether constant, periodic or occasional over the costing period. The pre-treatment process contains some or all of the following main units:

- Screening: removal of large particulate matter and objects that can usually be disposed of as trash. There are manual or mechanical screens and the screens openings can be coarse or fine. Screening is often installed in two stages, with a coarse screen followed by a fine screen.
- Grit and grease removal unit: removes sand and gravel as well as fat, oil and grease.
- Equalization tank: equalizes flowrates and organic loads in order to reduce the size and cost of downstream units and to achieve constant loads on the process units. It should be considered that smaller sewer systems have a higher ratio of peak flow to average flow than larger systems.

- b) Primary treatment: partial removal of suspended solids by gravity in a sedimentation tank or pond. The quantity of sludge discharged from this operation shall be included in sludge treatment cost calculations. If chemicals are added to the primary treatment, their cost shall be included in the plant operating cost.

- c) Secondary treatment: a biological treatment process, including separation between solids and liquids, such as a secondary clarifier or membrane separation. Such processes are typically based on suspended biomass, such as the activated sludge process, SBR or MBR, a biofilm process or a combination of both, such as MBBR, IFAS, MABR or trickling filters. The process can be intensive, as in the examples mentioned, or an extensive process, such as constructed wetlands, including tidal, aeration ponds or a lagoon system. OPEX items of secondary treatment include:

- electricity for aeration with blowers or aerators or other means;
- electricity for pumping, in circulation of sludge or tank content or other;

- electricity consumption for mixing, agitation, raking and any other similar electromechanical drives;
- chemicals added to the process for coagulation or other purposes;
- replacement parts, such as UV lamps, membranes, pumps and other items which have a shorter life expectancy (shorter period of amortization) than the period taken for life cycle cost calculation;
- labour for operation, maintenance, analysis and other;
- any other directly related specific cost item.

- d) In some cases, following secondary treatment, filtration and/or disinfection is performed, mainly to reduce suspended solids, turbidity, phosphorus and microorganisms or pathogens.

The filtration could require any of the following, according to equipment selection as part of the design: pumping through the filters, backwashing, chemical dosing for coagulation or cleaning, air scouring. The corresponding OPEX items will be the power consumption of the pumps and blowers and the cost of the chemicals used for either coagulation or cleaning.

Chemical disinfection is typically performed by chlorine or chlorine derivatives, ozone or hydrogen peroxide. The associate OPEX items are the cost of the chemicals or the electricity cost of production of the oxidant. For example, disinfection with ozone could use an ozone generator from oxygen produced by a pressure swing adsorption system, in which case the electricity consumption of both units shall be included in the disinfection cost.

Alternatively, UV irradiation is selected as part of the design, in which case the power consumption is the main OPEX item.

- e) Advanced treatment (sometimes referred to as quaternary treatment) is all downstream treatment processes following tertiary treatment and typically involves RO and/or AOP.

RO is originally a membrane filtration process to separate dissolved salts, but also removes viruses, bacteria and micropollutants. Its main OPEX items are the electricity for high-pressure pumping, constant dosing and periodical cleaning chemicals, membranes and other replacement parts.

AOP is currently based on enhancement of an oxidation process, such as ozonation combined with UV. OPEX items for AOP processes depend on the processes selected in design, and can be chemicals and/or power consumption, as well as replacement parts.

- f) Sludge management, including sludge treatment and disposal, refers to all processes and activities carried out to handle and dispose of generated primary and/or secondary sludge. It can include stabilization and dewatering or just hauling off-site for treatment elsewhere, according to design.

Sludge processing is typically associated with a cost and is targeted at reducing the volume of remaining sludge to be disposed of at a higher cost. For example, a sludge management plan could comprise accumulation and occasional disposal by hauling off-site at a high cost or it could comprise thickening, stabilization and dewatering to a smaller volume with little additional processing requirements.

Sludge treatment is usually a multistage process, generally including thickening, stabilization and dewatering:

- Thickening can be by gravity or by mechanical thickeners.
- Stabilization can be by aerobic, anaerobic or chemical processes. Aerobic sludge digestion has a major OPEX item in power consumption for aeration, whereas anaerobic digestion typically has

a higher OPEX item in labour and maintenance (replacement parts). Anaerobic digestion can have a negative OPEX item through sales of biogas or electricity or steam.

Chemical stabilization uses mixing of thickened sludge with a chemical such as lime, usually with another inert powder, both of which are usually OPEX items.

- Dewatering is carried out using different types of suitable electromechanical equipment, such as a centrifuge, a belt press or a multi-disc screw. Dewatering usually requires a combination of electrolytes and polymers for coagulation and flocculation. Thus, the OPEX items of dewatering shall include power consumption and chemicals. In addition, there are typically high operator costs and high maintenance costs for replacement parts that contribute to the OPEX.

Typically, a centrate stream, which is the filtrate from sludge dewatering, is generated from dewatering. All costs for treatment of the centrate stream (sidestream) shall be included in the cost of dewatering, for example chemical dosing for phosphorous or struvite removal or a biological treatment process such as anammox.

- Dewatered stabilized sludge is disposed of or treated to comply with higher requirements by means such as heating, composting or other processes. As a result, the disposal costs will possibly be lower or even negative (an income). The cost of energy and chemicals to obtain this higher sludge quality (known in some places as “class A” sludge) shall be included in the OPEX. In addition, the projected cost of disposal or the income from selling the sludge shall be included in accordance with [Clause 6](#).

NOTE 1 The replacement of UV lamps, membranes and pump components is covered in [Clause 6](#).

NOTE 2 All components of the system have maintenance costs associated with them.

For a summary of treatment process units along with their associated cost items, see [Annex C](#) and [Table C.1](#).

5.5 Effluent reuse management

Reuse can involve any aspect of the transportation and storage of treated water, including an operational volume, pumping stations, effluent piping (“purple” pipes) and water reservoirs, such as seasonal reservoirs.

All elements of the water reuse systems within the scope of the plan will be considered for their cost, including energy consumption for pumping, chemical dosing and/or aeration in the reservoir.

6 Cost items to be considered in economic life cycle analysis calculations

6.1 General

Each of the components of the water network should account for both their OPEX and CAPEX.

6.2 Investment cost (C_I) or CAPEX items

6.2.1 General

Primarily, the basis for estimation of the investment cost of each item should be the same for every degree of distribution. For example, prices of certain items (such as pipes) are taken from price tables for all plans being compared. Alternatively, the same pricing key, such as a price per unit, is applied in all plans for a certain item. For example, in pipes it could be price per unit length and per unit diameter (\$/m/mm).

The total investment cost is the sum of the costs of the components or items included in the plan for each degree of distribution, as defined in [Formula \(1\)](#).

$$C_I = \sum_i C_{I,i} \quad (1)$$

where

C_I is the total investment cost;

$C_{I,i}$ is the cost of item i ;

I A, B, C, D, E or F, corresponding to [6.2.2](#) to [6.2.7](#).

6.2.2 Sewer collection piping, $C_{I,A}$

A complete and real cost of a plan should include all levels of the collection piping, starting with lateral sewers from the sources or households, gradually converging into larger and fewer collectors that eventually direct the sewage to treatment plants.

For the purpose of comparison between two or more plans, the common part of the sewer system may be eliminated. For example, if the two alternatives described in Clause 4 are compared, the cost comparison may include only piping starting from the locations of the decentralized plants of the distributed design, up to which both systems are identical, i.e. the piping cost for comparison may exclude the common sections of the two plans.

The total installed cost of the collection piping should be taken for $C_{I,A}$. If no piping is installed, such as in the case of non-sewered systems or an on-site treatment system, the total installed cost of the collection piping will be zero.

6.2.3 Pumping stations, $C_{I,B}$

The cost of pumping stations shall include all related civil and infrastructure, such as concrete construction works, fence and electricity connection (installed cost). The cost may be obtained through specific pricing or through published correlations or even proprietary correlations. However, the same methodology should be applied to all plans being compared. For the sake of clarity, if there are no pumping stations, such as in the case of decentralized or on-site treatment system, the cost of pumping stations shall be zero.

6.2.4 The treatment plant, $C_{I,C}$

The cost of the complete treatment plant requires some level of process design in order to define the type of process and its main units. For the purpose of cost comparisons, the costs of different plant sizes may be estimated in any of the following methodologies (as long as all degrees of distribution follow the same methodology):

- offers or price lists from contractors or suppliers (usually will require some level of equipment sizing);
- scale-up rules based on known prices for a similar scope, such as capacity-ratio exponents;^[18]
- published or proprietary correlations, such as shown in [Annex B](#), for which more detail can be found at the referenced source; however, the use of any published or proprietary correlations should be exercised at the discretion of a professional with understanding of their applicability to the case.

The effluent quality requirements and the intended reuse application can be different for small local plants and large centralized plants. These conditions may be considered in the design of the treatment systems for each case, so a different process and technology may be chosen for different degrees of distribution.

In some cases, landscaping or other development work is required from a local small plant located close to the source. The cost of this mandatory requirement, which may be different between small, local systems and larger, remote systems, should be included as part of $C_{1,C}$.

6.2.5 Effluent distribution piping, $C_{1,D}$

Treated water distribution can be different for different degrees of distribution. The plans should specify the reuse destinations and quantify the water distribution or discharge piping.

The distribution piping pricing, $C_{1,D}$, shall be for the installed cost and should follow the same principals for the different degrees of distribution being compared, preferably based on the same sources.

If the treated water distribution is not part of the plan due to ownership or scope by others, it may be excluded from pricing.

6.2.6 Effluent pumping stations, $C_{1,E}$

The cost of pumping stations shall include all related civil and infrastructure works, such as concrete construction, fence and electricity connection (installed cost).

The cost may be obtained through detailed itemized pricing or through published or proprietary correlations. In any case, the same pricing methodology should be applied to all degrees of distribution being compared.

If effluent pumping is not within the scope of the plan, it may be excluded from pricing.

6.2.7 Treated water reservoirs, $C_{1,F}$

If treated water reservoirs are within the scope of the plan, their cost shall be included as part of the total CAPEX. Sizing of the reservoirs should match the reuse purpose and destination, which does not have to be the same for different degrees of distribution. Land cost consideration may be taken into account, preferably representing a real expense and not the potential value.

The basis for pricing may be according to detailed itemized costs or based on published or proprietary correlations.

6.3 Operating cost (C_0) OPEX items

6.3.1 General

Operating cost correlations could be available (see [Table B.1](#)) and generally include all of the cost items in this subclause in one formula. Such correlations may be used as long as they are applied to all compared plans of different degrees of distribution. These correlations calculate C_0 directly.

If a correlation for C_0 is not applicable or available, each of the cost items, $C_{0,i}$, should be accounted for in accordance with this subclause. The total operating cost is obtained using [Formula \(2\)](#):

$$C_0 = \sum_i C_{0,i} \quad (2)$$

where

C_0 is the total operating cost;

$C_{0,i}$ is the operating cost of item i ;

i A, B, C, D, E or F, corresponding to [6.3.2](#) to [6.3.7](#).

NOTE The operating costs (C_0) are expressed and directly related to unit treated (such as $\$/m^3$) and the expenses are distributed over time, as opposed to the investment costs, which are a singular event expressed per unit capacity [e.g. $\$/m^3/d$]. Guidelines for amortization of distributed expenses to present value for expression in the same terms of a singular expense, and vice versa, are provided in [Clause 7](#).

6.3.2 Electricity, $C_{0,A}$

Power consumption for sewage pumping is typically estimated according to distance and elevation (head or discharge pressure) for each branch of pressure sewer.

Wastewater treatment plant energy consumption may be estimated according to published^[19] or proprietary values for each type of process, in terms of kWh/m^3 . The processes selected may vary between different plans but the methodology to attribute an energy consumption and the cost per unit energy should be the same for all plans being compared.

Distribution of water for reuse, if within the scope of the plans being compared, may be estimated according to distance and elevation (head or discharge pressure) for each branch of effluent distribution.

Calculation of the annual energy cost should typically follow these steps:

- the total power consumption of a plan should be obtained in units of power, such as kW;
- a price for electricity should be assigned in terms of currency per unit energy, such as $\$/kWh$;
- the power consumption should be multiplied by the price to obtain cost per unit time (like cash flow), such as $\$/h$;
- the cash flow should be converted to the time scale of the amortization, such as $\$$ per year, by multiplying the cost per time (e.g. $\$/h$) by time per year (e.g. 8 700 h/year).

6.3.3 Labour, $C_{0,B}$

The cost of labour shall be included in the operating cost. Typically, labour is required for sampling, analysis, measurements, data collection and documentation, reporting, changing process conditions and housekeeping. The operation of pumping stations is included in the labour cost of the plan.

NOTE Different degrees of operation and different plans typically require different levels of operator skills and attention. These could be reflected in a different hourly cost and different number of hours per month for different plans.

Calculation of the annual cost of labour should typically follow these steps:

- estimate or budget the hours per week or per month for both operator and technician and calculate the hours per year;
- assign an hourly rate for each worker category or an average hourly rate for all workers categories;
- multiply the hours per year by the hourly rate to obtain the annual labour cost.

6.3.4 Chemicals, $C_{0,C}$

The cost of all chemicals used in all operations of the entire plan is included in the operating costs. Chemicals are mostly used in the treatment plant for flocculation and coagulation, phosphorous removal, disinfection and cleaning of membranes and filters. In ponds and lagoons, chemicals are sometimes used for algae control.

The calculation relating specifically to chemical costs shall follow [Formula \(3\)](#) and [Formula \(4\)](#):

$$C_i = c_i \cdot Q_i \quad (3)$$

$$C_{0,C} = \sum_i C_i \quad (4)$$

where

C_i is the annual expense for each chemical (such as \$ per year of chemical i);

c_i is the cost per unit of each chemical (such as \$ per kg of chemical i);

Q_i is the annual quantity of each chemical (such as kg per year of chemical i);

$C_{0,C}$ is the annual cost of chemicals (such as \$ per year).

Sacrificial electrodes, such as in electrocoagulation systems, are accounted for as a chemical which is consumed continuously and purchased periodically, similar to a batch of chemicals, in which case the cost of the electrodes will be included in $C_{0,C}$. Alternatively, the cost of sacrificial electrodes may be considered a replacement part and included in C_M .

6.3.5 Sludge disposal, $C_{0,D}$

Any sludge or trash disposed at a cost shall be included in the operating cost under $C_{0,D}$. Sludge is typically produced in the course of water and wastewater treatment processes. The sludge can be treated to different levels to comply with a category or requirement and to reduce its quantity, all of which influence the disposal price in many places. The sludge treatment costs, such as electricity, chemicals and labour, are included in the different cost items together with the rest of the plan, while $C_{0,D}$ only relates to the cost of the disposal, also referred to as “tipping fee”.

6.3.6 Services, $C_{0,E}$

Regular services not included in labour or other C_0 items are commonly provided as part of operation, such as water sampling and analysis, trash disposal, cleaning, safety inspections, consulting or software licenses. Any such budgeted expenses shall be included in $C_{0,E}$.

6.3.7 Others, $C_{0,F}$

Insurance, legal and accounting costs are typically not included in the OPEX. However, the inclusion of these costs may be decided by the planner, in which case the cost of these items shall be based on the same principles for all plans.

Additional recurring costs that are budgeted within the scope of the plans and do not belong to any of the categories in this subclause, $C_{0,A}$ to $C_{0,E}$, should be included in $C_{0,F}$.

NOTE In many cases, landscaping is required for decentralized systems that are located within or near residential or commercial areas. The costs of such landscaping activities are also included in $C_{0,F}$.

6.4 Maintenance cost items (C_M)

Estimation of maintenance cost, C_M , is characterized by higher uncertainty than CAPEX and OPEX, because it includes unexpected equipment failure at unexpected times. However, long-term experience with the processes involved in wastewater management for reuse allows for an acceptable level of confidence. A contingency component should be included in the C_M , although the same basis for contingency should be taken for all the plans of different degrees of distribution being compared.

C_M should include the following:

- a) replacement or repair of equipment (mechanical, electrical, electronic), such as pumps, blowers and measuring instruments;
- b) the cost of civil works repairs;

- c) spare parts kept in stock;
- d) labour, materials and external services;
- e) statutory periodic inspection costs as applicable.

Correlations for combined operation and maintenance (C_O+C_M) as shown in [Table B.1](#) may be used for any of the components of the network.

C_M as a percentage of equipment cost may be used for any of the plan components. For any component for which this cost estimation methodology is chosen, the methodology should be applied in all plans of all degrees of distribution compared.

The most accurate methodology for C_M estimation is detailed pricing based on the component replacement plan and allowance for contingencies. If such information is not available, C_M may be estimated as a fraction of the C_I , as in the following example:^[20]

- civil construction: 0,5 % to 2,0 % of C_I per year;
- renovations of civil construction: 2,0 % to 4,0 % of C_I per year;
- mechanical equipment: 2,0 % to 6,0 % of C_I per year;
- electrical and electronical equipment: 2,0 % to 6,0 % of C_I per year.

6.5 Income or revenue: negative cost items (C_N)

6.5.1 General

Reuse is associated with resource recovery, wherein water is one of the resources recovered but other resources such as energy or chemicals are also produced in some cases. In cases where recovered resources are planned to be sold, the outcomes should be included as an income to the net life cycle cost. The importance of accounting for this is that a plan for resource recovery facilities could be economically feasible in view of the life cycle net cost.

6.5.2 Income from selling treated water for reuse, I_w

The income from selling treated water is calculated according to [Formula \(5\)](#):

$$I_w = P_w \cdot Q_w \quad (5)$$

where

I_w is the annual revenue or income from selling water, such as \$/y;

Q_w is the annual quantity of water sold for reuse, such as m³/y;

P_w is the selling price of water per unit volume, such as \$/m³.

6.5.3 Income from biogas and its products, I_G

The income (I_G) from selling biogas, or electricity or heat generated from the biogas, should be calculated by [Formula \(6\)](#):

$$I_G = P_G \cdot f \cdot Q_G \quad (6)$$

where

I_G is the income from selling a resource generated from biogas, such as \$/year;

P_G is the selling price of the resource per unit, such as electricity energy units, heat energy units, biogas volume or treated biogas volume;

Q_G is the annual quantity of biogas produced;

f is the conversion factor of biogas to the resource planned to be sold, as shown in [Formula \(7\)](#):

$$f = \frac{Q_R}{Q_G} \quad (7)$$

where Q_R is the annual quantity of the resource produced from biogas.

6.5.4 Income from selling recovered products, I_S

The annual income from selling stabilized sludge or other recovered nutrients, such as ammonia, phosphorous or struvite, should be calculated according to [Formula \(8\)](#):

$$I_{S,i} = P_{S,i} \cdot Q_{S,i} \quad (8)$$

where

$I_{S,i}$ is the annual income or revenues from selling recovered product i ;

$Q_{S,i}$ is the annual quantity of each recovered product, such as tonne/year;

$P_{S,i}$ is the selling price per unit of the recovered product i .

The total revenues or income from selling recovered products should be calculated according to [Formula \(9\)](#):

$$I_S = \sum_i I_{S,i} \quad (9)$$

where

I_S is the total annual income or revenue from selling recovered products;

$I_{S,i}$ are the incomes or revenues from selling each product i .

6.5.5 Other income, I_0

Any planned recurring incomes, other than those detailed in [6.5.2](#), [6.5.3](#) and [6.5.4](#), should be accounted for as other income. A common example is acceptance of waste from sources, such as dairy farms or other food and beverage plants, that pay per batch delivered to the wastewater treatment plant. The calculation should be made according to [Formula \(10\)](#) and [Formula \(11\)](#):

$$I_{0,i} = P_{0,i} \cdot Q_{0,i} \quad (10)$$

$$I_0 = \sum_i I_{0,i} \quad (11)$$

where

$I_{0,i}$ is the annual income or revenue from source of income i ;

- $Q_{0,i}$ is the annual quantity of source of income i , such as truck loads per year;
- $P_{0,i}$ is the price per unit of the sources of income i , such as \$ per truck load;
- I_0 is the total income from all other sources.

7 Cost calculations, factoring and results integration

7.1 General

[Subclause 6.2](#) provides definitions and guidance on calculation of the total C_I , while [6.3](#), [6.4](#) and [6.5](#) provide the same for the annual costs C_0 and C_M , as well as for the annual income C_N . All of these values are eventually combined into a single result in [7.3](#). A calculation example of the steps described in this subclause is shown in [Table A.1](#) of [Annex A](#).

Two different ways to express the total plan cost are available according to relevance or preference:

- a) NPV, based on the sum of the investment and the amortization of net cost over the plan time period. The NPV is expressed in currency, such as \$. The calculations to express cost in terms of NPV are detailed in [7.2](#).
- b) Price per unit, based on the total net annual costs C_0 , C_M and C_N , combined with the annual amortized value of the investment, divided by the number of units per year. The result is expressed in cost per unit, such as \$/m³ or \$/PE. The calculations to express cost in terms of cost per unit are detailed in [7.3](#).

7.2 Conversion of all costs to present value

The following steps shall be followed for the calculation of the NPV of each plan. Express all recurring expenses (costs) and incomes (revenues) on an annual basis (per year).

- a) Sum up all annual recurrences costs and revenues, $C_0 + C_M + C_N$, to obtain the net annual OPEX (C_A).
- b) To amortize the cash flow over the plan time period with a constant interest, apply a spreadsheet function, such as PV, or use [Formula \(12\)](#):^[21]

$$C_{A,PV} = C_A \cdot \left(\frac{1 - (1+r)^{-n}}{r} \right) \quad (12)$$

where

- $C_{A,PV}$ is the PV of the cash flow;
- C_A is the payment per year or net annual cost, equal to $C_0 + C_M + C_N$;
- r is the interest per year;
- n is the number of years (term or time period of the plan).

- c) Sum up the PV of all the OPEX ($C_{A,PV}$) with the C_I to obtain the total PV of the plan, as shown in [Formula \(13\)](#):

$$X = C_{A,PV} + C_I \quad (13)$$

where X is the total NPV calculated by summation of $C_{A,PV}$ and C_I , expressed in currency such as \$.
\$ notations represent any currency of choice, as long as it is consistent throughout the calculations.

These steps should be followed for every plan (every degree of distribution) in the comparison, with the same interest and over the same term (time period).

7.3 Normalization of all costs per unit

The following steps should be used for the calculation of the total cost per unit:

- a) select an amortization term (time period) and the interest to apply to the C_1 in order to obtain its annual value;
- b) apply to the C_1 a worksheet payment calculation function (e.g. "PMT" function in spreadsheet software) or use [Formula \(14\)](#):^[21]

$$Y = C_1 \cdot \left(\frac{r}{1 - (1+r)^{-n}} \right) \quad (14)$$

where

Y is the amortized annual value of the C_1 ;

C_1 is the investment cost as defined and calculated in [Formula \(1\)](#);

r is the interest per year;

n is the number of years (term or time period of the plan).

- c) sum up the annual value of the investment cost Y with the net annual expenses C_A to obtain the total annual cost (Z);
- d) calculate the number of units for normalization of the cost (N_U), most commonly annual water volume treated or PE;
- e) calculate the cost per unit (C_U) by dividing the total annual cost (Z) by the normalization unit of choice (N_U) as shown in [Formula \(15\)](#):

$$C_U = \frac{Z}{N_U} \quad (15)$$

where

C_U is the cost per unit of choice, in units such as $\$/m^3$;

Z is the total annual cost obtained by summation of the investment cost Y with the net annual expenses C_A , expressed in $\$/y$;

N_U is the normalization unit of choice, such as m^3 of water or PE.

These steps should be followed for every plan (every degree of distribution) in the comparison, with the same interest and over the same term (time period).

8 Reporting on results of economic life cycle analysis calculations

The cost calculation results in all cases depend on the choice of term (time period) and interest selected for amortization. These values can influence the relative impact of the CAPEX and OPEX.

Results for all degrees of distribution shall be expressed in the same manner, either as NPV or as cost per unit for the same term of amortization.

The reporting on the normalized cost shall be done along with reporting on the depreciation period and interest rate used in the depreciation or amortization calculations as follows:

- a) the total NPV (Z) expressed in \$ or C_U , expressed in \$/unit;
- b) the term or time period n taken for design, costing and amortization, expressed in number of years;
- c) the interest r used for amortization.

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Annex A (informative)

Cost calculation example

The calculations in [Table A.1](#) correspond to the plan presented in [Figure A.1](#).

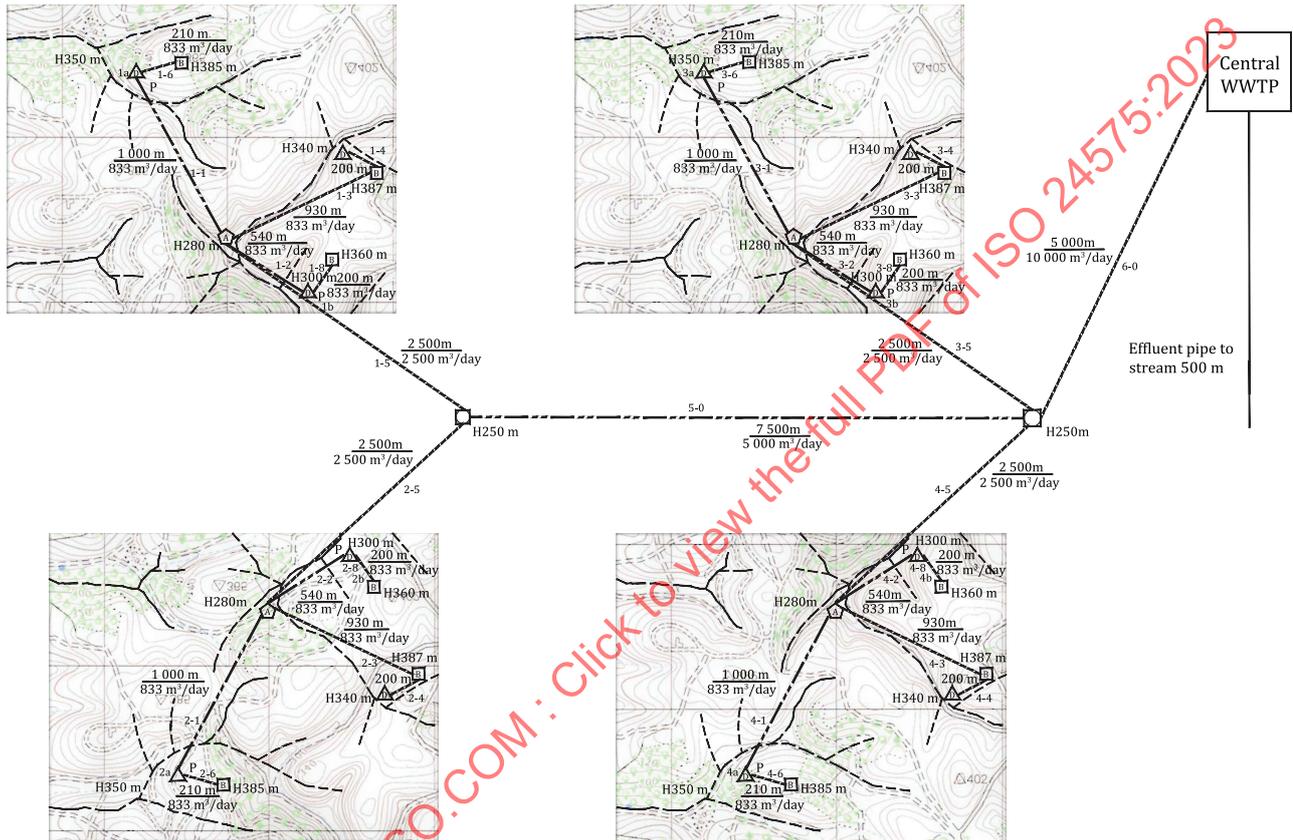
Table A.1 — Examples of cost calculation

Name	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Calculation basis and remarks
Number of plants	1	4	12	2 500	–
Flow per plant, m ³ /d	10 000	2 500	833	4	Total flow divided by equally sized plants
C _{I,A} – collection sys	4 967 918	1 026 691	112 878	0	Basis: 611 \$/m(diameter)/m(length), excluding gravity laterals
C _{I,B} – pump stations	1 125 611	521 571	0	0	Proprietary correlation for pumping station cost by pump power
C _{I,C} – treatment plants	5 732 257	7 315 151	9 574 923	57 299 528	Published correlation for CAS ^[9]
C _{I,D} – discharge piping	225 801	195 549	84 658	0	Same as sewer pipes
C _{I,E} – discharge pump	383 013	0	0	0	Same as sewage pumping stations
C _{IF} – reservoirs	0	0	0	0	Direct discharge to the environment
C _I (present value)	12 434 600	9 058 963	9 772 459	57 299 528	Sum of C _{I,i}
C _{O,A} – electricity	300 853	31 612	0	0	Each pump power calculated, 0,12 \$/kWh
C _{O,B} – labour	0	0	0	0	Included in CM for all piping and pumping
C _{O,C} – chemicals	0	0	0	0	Included in C _{O,F}
C _{O,D} – sludge dis- posal	0	0	0	0	Included in C _{O,F}
C _{O,E} – services	0	0	0	0	Included in C _{O,F}
C _{O,F} – other	280 793	331 390	386 117	1 223 773	Published correlation for MBR ^[9] divided by two
C _O \$/y	581 646	363 002	386 117	1 223 773	Sum of C _{O,i}
C _M \$/y	125 266	36 141	2 469	0	4 % of equipment and 1,25 % of civil works per year
Total PV of annual payments	8 809 693	4 974 204	4 842 645	15 250 913	Rate 5 % and term 20 years
Total PV of scenario	21 244 292	14 033 166	14 615 104	72 550 441	
Annual value of investment	997 784	726 915	784 167	4 597 862	Rate 5 % and term 20 years
NOTE 1 Plan design flow 10 000 m ³ /d.					
NOTE 2 All costs in US\$ unless otherwise noted.					

Table A.1 (continued)

Name	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Calculation basis and remarks
Total annual expense \$/y	1 704 697	1 126 058	1 172 754	5 821 635	
Specific cost per m ³	0,47	0,31	0,32	1,59	Total annual cost divided by annual quantity

NOTE 1 Plan design flow 10 000 m³/d.
 NOTE 2 All costs in US\$ unless otherwise noted.



- Key**
- B buildings
 - D decentralized WWTP
 - A areal WWTP
 - P pumping station
 - ← stream
 - ← pressure line
 - ← gravitational line
 - 1 000 m distance (m)
 - 833 m³/day flow (m³/day)
 - H300 m height (m)

Figure A.1 — Reference plan for cost calculations