
**Environmental life cycle assessment
and recycling of ductile iron pipes for
water applications**

*Evaluation du cycle de vie environnemental et recyclage des tuyaux
en fonte ductile utilisés pour l'eau*

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ISO copyright office
CP 401 • Ch. de Blandonnet 8
CH-1214 Vernier, Geneva
Phone: +41 22 749 01 11
Email: copyright@iso.org
Website: www.iso.org

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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).

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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 5, *Ferrous metal pipes and metallic fittings*, Subcommittee SC 2, *Cast iron pipes, fittings and their joints*.

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

The growing awareness of the importance of environmental protection, and the possible impacts associated with products, both manufactured and consumed, has increased interest in the development of methods to better understand and address these impacts. One of the techniques developed for this purpose is the environmental life cycle assessment (E-LCA).

E-LCA can assist in

- identifying opportunities to improve the environmental performance of products at various points in their life cycle;
- informing decision-makers in industry, government or non-governmental organizations (e.g. for the purpose of strategic planning, priority setting, product or process design or redesign);
- the selection of relevant indicators of environmental performance, including measurement techniques;
- marketing (e.g. implementing an ecolabelling scheme, making an environmental claim, or producing an environmental product declaration).

The concept of reference service life (RSL) is defined according to ISO 15686-1:2011 which identifies and establishes general principles for service- life planning and a systematic framework for undertaking service- life planning of a planned construction work throughout its life cycle.

This document is mainly focused on CO₂ emissions. The methods can be applied also to other environmental factors, e.g. other greenhouse gases emissions, natural resources consumption, water consumption.

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Environmental life cycle assessment and recycling of ductile iron pipes for water applications

1 Scope

This document specifies the evaluation method of the environmental life cycle assessment (E-LCA) of ductile iron (DI) pipes used for water applications as specified in ISO 2531 and ISO 16631. This evaluation method, applicable to ductile iron pipe products, is based on concepts and methods developed in ISO 14040 and its application guidelines in ISO 14044.

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 2531:2009, *Ductile iron pipes, fittings, accessories and their joints for water applications*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 2531 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 environmental life cycle assessment E-LCA

compilation and evaluation of the inputs, outputs and the potential *environmental impacts* (3.2) of a product system

Note 1 to entry: Environmental life cycle assessment and environmental life cycle analysis are synonymous.

[SOURCE: ISO 14040:2006, 3.2, modified — The term has been changed from "life cycle assessment" to "environmental life cycle assessment"; "throughout its life cycle" at the end of the definition has been removed. Note 1 to entry has been added.]

3.2 environmental impact

change to the environment, whether adverse or beneficial, wholly or partially resulting from an organization's activities, products or services

[SOURCE: ISO 14001:2015, 3.2.4, modified — "environmental aspects" has been replaced by "activities, products or services".]

3.3 CO₂ emissions

release of equivalent CO₂ as greenhouse gases into the atmosphere over a specified area and period of time

3.4

service life

period of time after installation during which a facility or its component parts meet or exceed the performance requirements

[SOURCE: ISO 15686-1:2011, 3.25]

3.5

functional unit

quantified performance of a product system for use as a reference unit

[SOURCE: ISO 14040:2006, 3.20]

3.6

reference service life

RSL

service life (3.4) of a product, component, assembly or pipeline which is known to be expected under a particular set, i.e. a reference set, of *in-use conditions* (3.7) and which can form the basis for estimating the service life under other in-use conditions

[SOURCE: ISO 15686-1:2011, 3.22, modified — "system" has been replaced by "pipeline".]

3.7

in-use condition

any circumstance that can impact on the performance of a pipeline, or a part thereof, under normal use

[SOURCE: ISO 15686-1:2011, 3.10, modified — "a building or a constructed asset" has been replaced by "a pipeline".]

4 Basic concept of environmental life cycle assessment (E-LCA)

4.1 General

Studies on environmental impacts are important for utility decision-makers as they seek to balance budget concerns over immediate and long-term needs across acquisition, operation and maintenance, and planned end-of-life. For authorities and engineers designing pipeline systems, E-LCA serves as a tool to study various scenarios to determine the right solution for site-specific conditions and community values, as well as provide the necessary data to support those decisions.

4.2 Definition of environmental life cycle assessment (E-LCA)

E-LCA is a technique used to assess environmental impacts through all the stages of product and service life. The environmental impact associated with the consumption of natural resources or energy and waste disposal can be quantitatively estimated as the amount of CO₂ emissions.

Total CO₂ emissions is calculated using [Formula \(1\)](#) as a total amount of CO₂ emissions through all life cycle stages such as acquisition stage, operation stage, maintenance stage and end-of-life stage.

$$E_T = E_A + E_O + E_M + E_E \quad (1)$$

where

E_T is the total CO₂ emissions through all life cycle stages;

E_A is the CO₂ emissions at acquisition stage;

E_O is the CO₂ emissions at operation stage;

E_M is the CO₂ emissions at maintenance stage;

E_E is the CO₂ emissions at end-of-life stage.

4.3 Calculation method of CO₂ emissions

The total amount of CO₂ emissions is calculated using [Formulae \(2\)](#) to [\(4\)](#) by totalizing all the CO₂ emissions in a period of analysis.

Case 1: $t_n < t_m$

$$E_T = E_A + \sum_{t=1}^{t_n} (E_{O,t} + E_{M,t}) \quad (2)$$

Case 2: $t_n = t_m$

$$E_T = E_A + \sum_{t=1}^{t_n} (E_{O,t} + E_{M,t}) + E_E \quad (3)$$

Case 3: $t_m < t_n < 2 \times t_m$

$$E_T = 2 \times E_A + \sum_{t=1}^{t_n} (E_{O,t} + E_{M,t}) + E_E \quad (4)$$

where

E_T is the total CO₂ emissions;

t is the time in years;

t_n is the period of analysis;

t_m is the service life;

E_A is the CO₂ emissions at acquisition stage;

$E_{O,t}$ is the CO₂ emissions at operation stage in the t^{th} year;

$E_{M,t}$ is the CO₂ emissions at maintenance stage in the t^{th} year;

E_E is the CO₂ emissions at end-of-life stage.

4.4 Other impacts

Environmental impacts can also be evaluated in other categories which are listed below.

- impact on the environment:
 - climate change;
 - air, water and soil pollution;
 - ozone depletion;
 - eutrophication;
 - acidification;

- reduction of biological diversity;
- impact on human health:
 - hazardous substance emissions;
 - smog formation;
- impact on natural resource consumption:
 - depletion of resources.

5 Breakdown of CO₂ emissions

5.1 CO₂ emissions at acquisition stage

CO₂ emissions at acquisition stage is calculated using [Formula \(5\)](#) as a total of CO₂ emissions with pipe manufacture, construction material production, construction machine operation, transportation and regeneration treatment of excavated soil.

$$E_A = E_{AP} + E_{AC} + E_{AO} + E_{AT} + E_{AR} \quad (5)$$

where

- E_A is the CO₂ emissions at acquisition stage;
- E_{AP} is the CO₂ emissions with pipe manufacture (e.g. raw material procurement, transportation to the factory, manufacturing);
- E_{AC} is the CO₂ emissions with construction material production (e.g. asphalt pavement materials, road bedding materials, sand);
- E_{AO} is the CO₂ emissions with construction machine operation for pipe laying work (e.g. installation of pipes and valves by crane, crush and loading of existing pavement by backhoe, excavation and loading of soil by backhoe, backfilling by backhoe, compaction by tamper, road bedding by tamper or vibratory roller, asphalt paving work by vibratory roller or vibratory compactor);
- E_{AT} is the CO₂ emissions with transportation of construction materials, construction machines, excavated soil, ground-improved soil and construction waste;
- E_{AR} is the CO₂ emissions with regeneration treatment of excavated soil.

NOTE The calculation methodology for CO₂ emissions with provision for scrap recycling in ductile iron pipe production is given in [Annex A](#).

5.2 CO₂ emissions at operation stage

Annual CO₂ emissions at operation stage is calculated using [Formula \(6\)](#) as a total of CO₂ emissions with pump operation. Calculation method of CO₂ emissions with pump operation is given in [Annex B](#).

$$E_{O,t} = E_{OP,t} \quad (6)$$

where

- $E_{O,t}$ is the CO₂ emissions at operation stage in the t^{th} year;
- $E_{OP,t}$ is the CO₂ emissions with pump operation in the t^{th} year.

[Annex C](#) gives information about the general relative high proportion of CO₂ emissions at operation stage.

5.3 CO₂ emissions at maintenance stage

Annual CO₂ emissions at maintenance stage is calculated using [Formula \(7\)](#) as a total of CO₂ emissions due to leakage, during machine operation for maintenance, production of restoration materials and during machine operation for restoration.

$$E_{M,t} = E_{ML,t} + E_{MM,t} + E_{MP,t} + E_{MR,t} \quad (7)$$

where

$E_{M,t}$ is the CO₂ emissions at maintenance stage in the t^{th} year;

$E_{ML,t}$ is the CO₂ emissions with leakage in the t^{th} year;

$E_{MM,t}$ is the CO₂ emissions with machine operation for maintenance (e.g. inspection, drainage, washing) in the t^{th} year;

$E_{MP,t}$ is the CO₂ emissions with production of restoration materials in the t^{th} year;

$E_{MR,t}$ is the CO₂ emissions with machine operation for restoration work in the t^{th} year.

5.4 CO₂ emissions at end-of-life stage

CO₂ emissions at end-of-life stage is calculated using [Formula \(8\)](#) as a total of CO₂ emissions with machine operation for existing pipeline dismantling, construction waste disposal, transportation of construction materials and reducing waste by recycling.

$$E_E = E_{EM} + E_{EC} + E_{ET} - E_{ER} \quad (8)$$

where

E_E is the CO₂ emissions at end-of-life stage;

E_{EM} is the CO₂ emissions with machine operation for existing pipeline dismantling;

E_{EC} is the CO₂ emissions with construction waste disposal;

E_{ET} is the CO₂ emissions with transportation of construction materials, construction machines, excavated soil and construction wastes;

E_{ER} is the decrease of CO₂ emissions with recycling of excavated pipes as raw materials.

Material recovery is considered to be applicable only to ductile iron pipes.

6 Key drivers for environmental impact reduction

6.1 Durability

6.1.1 Reference service life (RSL) of DI pipes

RSL is dependent on the properties of DI pipes and on the reference in-use conditions. It takes into account the components of a DI pipe that consists of pipe and fittings material, linings and coatings and assembling accessories.

One hundred years is commonly recognized as RSL for ductile iron pipes. Such an RSL refers to the declared in-use conditions stated in 6.1.2.

The expected service life can be forecasted by reducing or increasing the RSL, considering the local environmental features (e.g. hydrogeology, operation), the nature of the pipe coatings and the nature of the pipe linings.

Increasing the service life of the pipe system reduces the environmental impacts, because more frequent replacement/repair means additional consumption of natural resources and energy and extra waste. According to soil corrosivity, appropriate external protection can be selected to ensure the durability of pipeline.

6.1.2 In-use conditions

The RSL of a DI pipe is as shown in Table 1, including quantitative and qualitative data.

Table 1 — Set of in-use conditions

Technical characteristics of the pipe	According to ISO 2531, ISO 16631, ISO 8179-1, ISO 8179-2, ISO 4179 and ISO 16132
Appropriate code of designing	According to ISO 10803 and manufacturer's recommendations
Quality of installation	According to ISO 21051 and manufacturer's recommendations
Buried environment; corrosiveness of soil, with suitable external coatings	According to ISO 2531:2009, Annex A and the relevant soil survey
Fluid transported: water aggressiveness with suitable internal linings	According to ISO 2531:2009, Annex B
Typical service conditions	According to service pressure
Maintenance conditions	Sporadic

6.1.3 Service safety conditions

When evaluating the durability of pipelines, more specific conditions shall be taken into account.

The following service safety conditions can be normally considered by the user of a DI pipes as expected permanent performances in service (qualitative and quantitative) during the RSL: resistance to transient overpressure, resistance to vacuum ($-0,9 \text{ bar}^1$), resistance to corrosive soil (appropriate external protection), resistance to soil movements (flexibility of joints, ovalization), anti-permeation (against contaminated soil), fire resistance, impact resistance (robust over influence by other construction work), maintenance of water quality, resistance to external agent (e.g. traffic loads, surface loads).

Other conditions can also be considered as primordial according local issues (e.g. risk of attack, vandalism, damages from animals, frost resistance).

6.2 Leakage incident

Strong material properties and flexibility of joints contribute to preventing the leakage incident on buried ductile iron pipes. Low leakage incident rate leads to energy savings in the operation and maintenance stages.

Historically, cast iron pipes have been widely used in the world and in industrialized countries. The transition from grey cast iron material to ductile cast iron material began in 1950 and was achieved in 1970. Starting in the 1990s, China and India also adopted ductile cast iron pipes to build their large hydraulic infrastructure. In parallel, the socketed ductile cast iron pipe also adopted the elastomer ring seal for push-on joint (instead of the lead-poured joint), the cement internal lining against the aggressiveness of the waters and the zinc-based external coating against soil corrosiveness, which

1) $1 \text{ bar} = 0,1 \text{ MPa} = 10^5 \text{ Pa}$; $1 \text{ MPa} = 1 \text{ N/mm}^2$.

become the major components of ductile cast iron pipes. Studies on pipe network reliability and durability of pipe materials have developed worldwide very significantly in the recent years in order to improve sustainability of water pipe infrastructures to master environmental impact, efficiency and spending.

Some examples are published (see References [13], [14] and [15]) highlighting the actual performance of ductile iron networks in accordance with ISO 21053:2019, Annex C. The selected examples are for countries that use similar types of products based on ISO, JIS and EN standards. Only the criterion of the number of failures per year and per kilometre has been retained.

These studies should be read carefully in relation with their contexts: distinguishing grey cast iron and ductile iron, taking into account protective coatings, considering the water networks operating and the strategy of replacement.

6.3 Conveyance capacity

6.3.1 General

For a given nominal diameter, ductile iron pipes are duly designed with a large internal diameter in order to reduce head loss on energy pumping. Each head loss reduction leads to energy savings on the whole life cycle of the pipe. Formulae (B.4) and (B.5) show that the internal diameter is a more influent factor on the head loss than the surface roughness coefficient.

6.3.2 Functional unit of DI pipes

When using the pipes to convey water, the functional unit for DI pipes is commonly defined as transporting water in 1 m of DI pipes in a given hydraulic diameter with a speed of 1 m/s and service pressure P_s , for a 100 year (RSL), with the service safety conditions as stated in 6.1.3. In regards to the service conditions of a specific DI pipe, other water flow velocity may be used, when it is known.

6.4 Optimum pipe wall thickness

Optimum pipe wall thickness can be selected based on water pressure level, transportation and installation, leading to avoidance of unnecessary material usage and extra energy consumption.

6.5 Mechanical properties

Due to high mechanical properties of pipe material, excavated soil can be reused for bedding, surrounding or backfilling and ductile iron pipes can be installed with a narrow trench. This consequently brings several environmental benefits:

- to avoid using imported bedding material, such as sand, gravel, or concrete structure, resulting in depletion of natural resources;
- to avoid transportation of the above material to the job site and take away the natural soil, resulting in consumption of fuel and emissions of CO₂;
- to avoid creation of solid waste in case of making concrete structure.

6.6 Various pipe installation methods

Trenchless applications of ductile iron pipe systems include repair, renovation and replacement as well as new installation. These techniques are horizontal directional drilling, pipe bursting, casing, and pipe-jacking. Such installations are significantly useful to reduce traffic and construction waste.

6.7 Recyclability

Old cast or ductile iron pipes retrieved from the excavated trenches can be recycled as raw materials to manufacture new ductile iron pipes, leading to conservation of natural resources and reduction in waste.

Mechanical characteristics of DI material are permanent in time without degradation in reuse. It can be in use for decades or even for centuries. [Figure 1](#) summarizes the key drivers for environmental impact reduction.

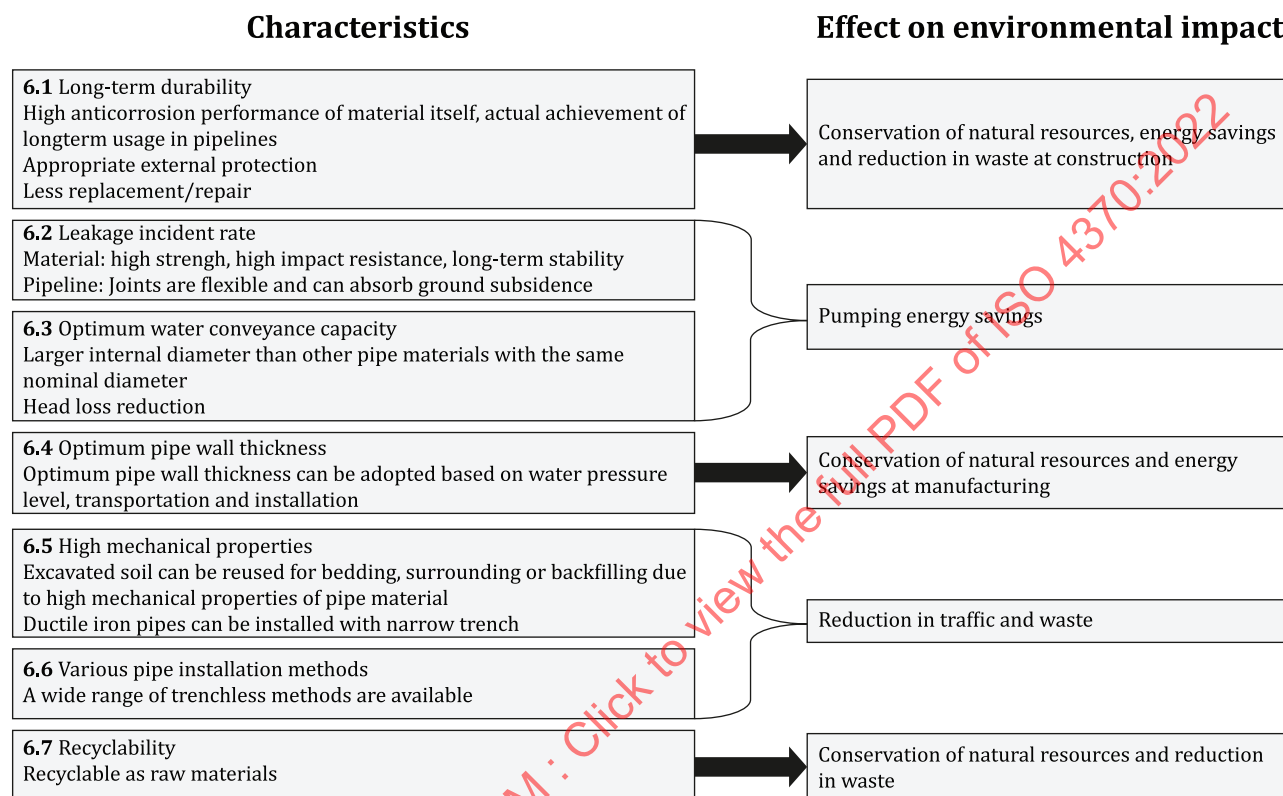


Figure 1 — Key drivers for environmental impact reduction

7 Recycling

Ductile iron pipes and fittings can be produced from two main sources of iron:

- iron ores with blast furnaces;
- ferrous scraps (e.g. steel scraps, cast iron scraps, ductile iron scraps) with cupolas or electric furnaces.

Old cast or ductile iron pipes can be recycled for re-use as raw materials and to produce new ductile iron pipe. They become secondary raw materials which prevents them from using virgin iron ore. Ductile iron pipes have also been made from the pipe's ferrous scraps. For making molten iron, recycling of iron scrap lowers coke consumption and CO₂ emissions compared to using virgin iron ore which has a reduction process.

Ductile iron pipes and fittings are easily 100 % recyclable over a long period, without degradation of the properties of the basic metal itself, and meet the performance and requirements of ISO 2531 after a long period of use.

The DI pipe industry takes advantage of an existing worldwide market organisation to collect, sort and reuse for the benefit of a circular economy. The recycling process of the cast or ductile iron pipe system

is simple, routine and organized by a worldwide network of scrap dealers and the quality of such scraps is monitored according to established manufacturer's standards.

The process and advantages of recycling of cast or ductile iron pipes are shown in [Figure 2](#).

The inert properties of ductile iron mean that pipe systems not in service can also be left unused and redundant in the ground with no adverse environmental impact.

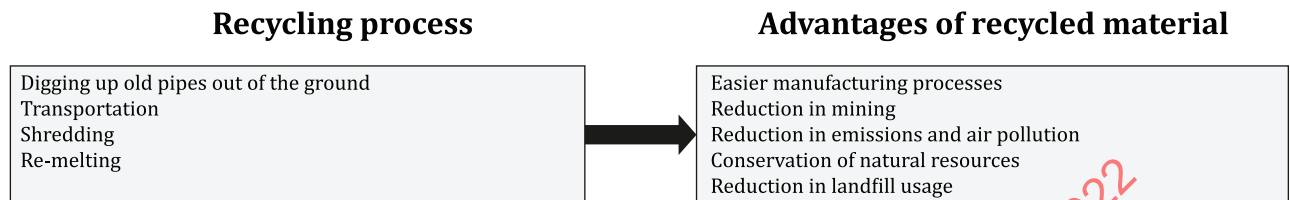


Figure 2 — Process and advantages of recycling of cast or ductile iron pipes

Annex A (informative)

Calculation methodology for CO₂ emissions with provision for scrap recycling in ductile iron pipe production

A.1 General

A plant manufacturing ductile iron pipe performs its calculations by carrying out the following steps.

- a) Clarify the quantity of annual ductile iron pipe production at the plant.
- b) Clarify the annual direct CO₂ emissions sources and upstream emissions sources based on raw materials, intermediate products and energy that the plant exports to outside users.
- c) Clarify the annual credit CO₂ emissions sources based on raw materials, intermediate products and energy that the plant exports to outside users.
- d) Calculate the annual CO₂ emissions and CO₂ intensity using the emissions factor.

A.2 Calculation procedure

A.2.1 Data collection of ductile iron pipe

A plant manufacturing ductile iron pipe records its annual production of ductile iron pipe (P).

A.2.2 Data collection of direct and/or upstream CO₂ emissions sources

A plant manufacturing ductile iron pipe records the quantities of raw materials, intermediate products, and energy that are imported from outside suppliers as the direct or upstream emissions sources according to ISO 14404-4:2020, Table 5.

A.2.3 Data collection of credit CO₂ emissions sources

A plant manufacturing ductile iron pipe records the quantities of raw materials, intermediate products and energy that are exported to the outside users as the credit CO₂ emissions sources according to ISO 14404-4:2020, Table 6.

A.2.4 Calculation

The annual CO₂ emissions ($E_{\text{CO}_2, \text{annual}}$) and CO₂ intensity (I_{CO_2}) are calculated from [Formulae \(A.1\)](#) and [\(A.2\)](#) using CO₂ emissions factors that correspond to the direct CO₂ emissions sources, upstream CO₂ emissions sources and credit emissions sources recorded as specified in [A.2.2](#) and [A.2.3](#).

$$E_{\text{CO}_2, \text{annual}} = \sum_{t=1}^N K_{t, \text{d}, \text{CO}_2} \times Q_{t, \text{d}, \text{CO}_2} + \sum_{t=1}^N K_{t, \text{u}, \text{CO}_2} \times Q_{t, \text{u}, \text{CO}_2} - \sum_{t=1}^N K_{t, \text{c}, \text{CO}_2} \times Q_{t, \text{c}, \text{CO}_2} \quad (\text{A.1})$$

$$I_{\text{CO}_2} = E_{\text{CO}_2, \text{annual}} / P \quad (\text{A.2})$$

where

$E_{\text{CO}_2, \text{annual}}$ is the annual CO₂ emissions;

K_{t,d,CO_2}	is the quantity of direct emissions source;
Q_{t,d,CO_2}	is the direct emissions factor for CO ₂ emissions source;
K_{t,u,CO_2}	is the quantity of upstream emissions source;
Q_{t,u,CO_2}	is the upstream emissions factor for CO ₂ emissions source;
K_{t,c,CO_2}	is the quantity of credit emissions source;
Q_{t,c,CO_2}	is the credit emissions factor for CO ₂ emissions source;
I_{CO_2}	is the CO ₂ intensity;
P	is the annual ductile iron pipe production.

An indication of emissions factors shown in ISO 14404-4:2020, Table 6 can be used if no other reliable data are available.

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Annex B (informative)

CO₂ emissions with pump operation

B.1 CO₂ emissions with pump operation

CO₂ emissions with pump operation is calculated using [Formula \(B.1\)](#).

$$E_{OP,t} = (E \times 365,25 \times Q_{E,CO_2}) \quad (B.1)$$

where

- $E_{OP,t}$ is the CO₂ emissions with pump operation in the t^{th} year;
- E is the daily pumping energy, in kWh/d;
- Q_{E,CO_2} is the emission factor for CO₂ emissions of electricity, in kg/kWh.

B.2 Daily pumping energy

The energy daily required for pumping is calculated using [Formula \(B.2\)](#).

$$E = \frac{\gamma \times Q \times H}{h_{\text{eff}} \times e_{\text{eff}}} \times d \quad (B.2)$$

where

- γ is the unit weight of pumping liquid, in kN/m³, defined as $\gamma = 9,81$;
- Q is the flow rate, in m³/s;
- H is the total head, in m;
- h_{eff} is the hydraulic efficiency (set as default 70 %);
- e_{eff} is the electricity efficiency (set as default 70 %);
- d is the daily pumping duration, in h/d.

B.3 Total head (H)

Required pump head called “total head” is calculated using [Formula \(B.3\)](#).

$$H = H_a + H_t + \frac{V_d^2}{2 \times g} + \frac{1\,000 \times (P_d - P_s)}{\gamma} \quad (B.3)$$

where

- H_a is the actual head, in m;
- H_t is the total head loss, in m;

V_d is the flow velocity, in m/s;

g is the gravitational acceleration, in m/s², defined as $g = 9,81$;

P_d is the pressure exerted on the discharge water surface, in MPa;

P_s is the pressure exerted on the suction water surface, in MPa.

Total head loss is calculated using [Formula \(B.4\)](#). Head loss is hydraulic energy loss essentially caused by the water viscosity and its friction against the pipe walls. The effect is an increase in energy consumption in a pipeline.

The Darcy formula is the general formula for calculation of friction head loss of the pipeline H_p .

$$H_t = H_p + H_o = j \times L + H_o = \frac{8 \times \lambda \times Q^2}{\pi^2 \times g \times I_D^5} \times L + H_o \quad (B.4)$$

where

H_p is the friction head loss of the pipeline, in m;

H_o is the head loss of the pipeline except for friction head loss, due to bend, valve, flowing into pipe, in m;

j is the hydraulic gradient, in m/m;

L is the pipeline length, in m;

λ is the head loss coefficient determined using the Colebrook-White formula (dimensionless);

I_D is the internal pipe diameter, in m.

The internal diameter is a more influent factor on head loss than the head loss coefficient λ .

The Colebrook-White formula, shown as [Formulae \(B.5\)](#) and [\(B.6\)](#), is used for determining the head loss coefficient λ .

$$\frac{1}{\sqrt{\lambda}} = -2 \times \log \left[\frac{2,51}{Re \times \sqrt{\lambda}} + \frac{k}{3,71 \times I_D} \right] \quad (B.5)$$

$$Re = \frac{4 \times Q}{\pi \times I_D \times \mu} \quad (B.6)$$

where

Re is the Reynolds number (dimensionless);

k is the pipe surface roughness, in m (see [Table B.1](#));

μ is the Kinematic viscosity of the fluid at the operating temperature, in m²/s. Here the fluid considered is water and the kinematic viscosity is set to $1,01 \times 10^{-6}$ m²/s.

In the Colebrook-White formula, the first term in the logarithmic function corresponds to the portion of head loss due to the liquid own internal friction acting upon itself. The second term corresponds to the portion of head loss caused by the friction of the liquid against the pipe wall.