

INTERNATIONAL STANDARD



Environmental considerations specific to insulated electrical power and control cables

IECNORM.COM : Click to view the full PDF of IEC 62125:2019



THIS PUBLICATION IS COPYRIGHT PROTECTED

Copyright © 2019 IEC, Geneva, Switzerland

All rights reserved. Unless otherwise specified, no part of this publication may be reproduced or utilized in any form or by any means, electronic or mechanical, including photocopying and microfilm, without permission in writing from either IEC or IEC's member National Committee in the country of the requester. If you have any questions about IEC copyright or have an enquiry about obtaining additional rights to this publication, please contact the address below or your local IEC member National Committee for further information.

IEC Central Office
3, rue de Varembe
CH-1211 Geneva 20
Switzerland

Tel.: +41 22 919 02 11
info@iec.ch
www.iec.ch

About the IEC

The International Electrotechnical Commission (IEC) is the leading global organization that prepares and publishes International Standards for all electrical, electronic and related technologies.

About IEC publications

The technical content of IEC publications is kept under constant review by the IEC. Please make sure that you have the latest edition, a corrigendum or an amendment might have been published.

IEC publications search - webstore.iec.ch/advsearchform

The advanced search enables to find IEC publications by a variety of criteria (reference number, text, technical committee,...). It also gives information on projects, replaced and withdrawn publications.

IEC Just Published - webstore.iec.ch/justpublished

Stay up to date on all new IEC publications. Just Published details all new publications released. Available online and once a month by email.

IEC Customer Service Centre - webstore.iec.ch/csc

If you wish to give us your feedback on this publication or need further assistance, please contact the Customer Service Centre: sales@iec.ch.

Electropedia - www.electropedia.org

The world's leading online dictionary on electrotechnology, containing more than 22 000 terminological entries in English and French, with equivalent terms in 16 additional languages. Also known as the International Electrotechnical Vocabulary (IEV) online.

IEC Glossary - std.iec.ch/glossary

67 000 electrotechnical terminology entries in English and French extracted from the Terms and Definitions clause of IEC publications issued since 2002. Some entries have been collected from earlier publications of IEC TC 37, 77, 86 and CISPR.

IECNORM.COM : Click to view this IEC PDF on IEC 60125:2019

INTERNATIONAL STANDARD



Environmental considerations specific to insulated electrical power and control cables

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

ICS 29.060.20

ISBN 978-2-8322-7374-6

Warning! Make sure that you obtained this publication from an authorized distributor.

CONTENTS

FOREWORD.....	4
INTRODUCTION.....	6
1 Scope.....	7
2 Normative references	7
3 Terms, definitions and symbols.....	7
3.1 Terms and definitions.....	7
3.2 Symbols.....	9
4 General principles	11
5 Environmental checklist approach.....	11
5.1 What is the checklist approach?.....	11
5.2 Checklist.....	12
6 Life cycle assessment (LCA) of cables	12
6.1 General.....	12
6.2 Goal and scope.....	13
6.2.1 LCA study goal	13
6.2.2 Functional unit.....	13
6.2.3 Reference flow	14
6.2.4 System boundary.....	14
6.2.5 Cut-off criteria	15
6.2.6 Assumptions and limitations	15
6.3 Life cycle inventory (LCI)	15
6.3.1 General	15
6.3.2 Data collection.....	15
6.3.3 Data selection.....	16
6.3.4 Allocation procedure.....	16
6.4 Life cycle impact assessment (LCIA).....	16
6.5 Interpretation	17
6.6 Single environmental indicator approach.....	17
7 Environmental and energy cost-based conductor size optimization – ECSO	18
7.1 Overview.....	18
7.2 Basic rules.....	18
7.3 Factors	20
7.4 CO ₂ evaluation.....	20
7.4.1 General	20
7.4.2 CO ₂ emissions during manufacturing, transportation, installation and final disposal	20
7.4.3 CO ₂ emissions at the use phase	20
7.5 Calculation method	20
7.5.1 General	20
7.5.2 Calculation of initial cost.....	20
7.5.3 Calculation of running costs.....	21
7.5.4 Conductor resistance.....	21
7.5.5 Optimum current.....	21
7.5.6 Optimum conductor size	22
7.5.7 Energy reduction related to the use phase of the cable.....	22
7.6 Example.....	23

8	Environment-related communication	24
8.1	General.....	24
8.2	General principles.....	24
8.3	Composition and compliancy to legislation on substances.....	25
8.4	Life cycle assessment.....	25
8.5	End of life	25
Annex A	(informative) Checklist for the checklist approach	26
A.1	Preliminary considerations	26
A.2	Design considerations.....	26
A.3	Production considerations.....	26
A.4	Considerations for use and end of life phase.....	27
Annex B	(informative) Example for ECSO	28
B.1	General.....	28
B.2	Cable data	28
B.3	Calculation condition.....	28
B.4	Initial cost	29
B.4.1	Initial investment	29
B.4.2	Conversion of CO ₂ emissions during material/cable production, removal, transportation and disposal to cost	29
B.4.3	Initial cost (sum).....	29
B.4.4	Conductor resistance.....	30
B.5	Calculation of running costs.....	30
B.5.1	Costs for Joule losses during anticipated life time.....	30
B.5.2	Costs for CO ₂ emission during anticipated life time	30
B.6	Life cycle cost.....	31
B.7	Optimum current.....	31
B.8	Efficiency.....	32
B.8.1	Calculation of energy efficiency	32
B.9	Life cycle cost versus service life.....	33
Annex C	(informative) Example of environmental communication.....	34
Bibliography	35
Figure 1	– Life cycle phases	13
Figure 2	– Life cycle costs for conductor size for a certain current	19
Figure 3	– Optimum current range for minimizing life cycle cost.....	19
Table B.1	– Life cycle cost versus service life.....	33
Table B.2	– Life cycle cost versus service life, relative to 3C 70 mm ²	33

INTERNATIONAL ELECTROTECHNICAL COMMISSION

**ENVIRONMENTAL CONSIDERATIONS SPECIFIC TO
INSULATED ELECTRICAL POWER AND CONTROL CABLES**

FOREWORD

- 1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
- 2) The formal decisions or agreements of IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested IEC National Committees.
- 3) IEC Publications have the form of recommendations for international use and are accepted by IEC National Committees in that sense. While all reasonable efforts are made to ensure that the technical content of IEC Publications is accurate, IEC cannot be held responsible for the way in which they are used or for any misinterpretation by any end user.
- 4) In order to promote international uniformity, IEC National Committees undertake to apply IEC Publications transparently to the maximum extent possible in their national and regional publications. Any divergence between any IEC Publication and the corresponding national or regional publication shall be clearly indicated in the latter.
- 5) IEC itself does not provide any attestation of conformity. Independent certification bodies provide conformity assessment services and, in some areas, access to IEC marks of conformity. IEC is not responsible for any services carried out by independent certification bodies.
- 6) All users should ensure that they have the latest edition of this publication.
- 7) No liability shall attach to IEC or its directors, employees, servants or agents including individual experts and members of its technical committees and IEC National Committees for any personal injury, property damage or other damage of any nature whatsoever, whether direct or indirect, or for costs (including legal fees) and expenses arising out of the publication, use of, or reliance upon, this IEC Publication or any other IEC Publications.
- 8) Attention is drawn to the Normative references cited in this publication. Use of the referenced publications is indispensable for the correct application of this publication.
- 9) Attention is drawn to the possibility that some of the elements of this IEC Publication may be the subject of patent rights. IEC shall not be held responsible for identifying any or all such patent rights.

International Standard IEC 62125 has been prepared by IEC technical committee 20: Electric cables.

This first edition cancels and replaces IEC TR 62125, published in 2007. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to IEC TR 62125:2007:

- a) development of the document from TR to international standard;
- b) inclusion of a methodology for LCA;
- c) inclusion of a methodology for conductor size optimization.

The text of this standard is based on the following documents:

FDIS	Report on voting
20/1876/FDIS	20/1881/RVD

Full information on the voting for the approval of this standard can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC web site under "<http://webstore.iec.ch>" in the data related to the specific publication. At this date, the publication will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

A bilingual version of this publication may be issued at a later date.

IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

IECNORM.COM : Click to view the full PDF of IEC 62125:2019

INTRODUCTION

The cable sector has, for many years, considered the impact of electric cables on the environment with respect to their operating conditions. Transmission system operators, distribution system operators, manufacturers, installers/contractors, users and authorities have considerably increased their requirements to take into account the environmental impact of electric cables.

IEC TC 20 regularly reviews its approach to the incorporation of environmental aspects into standards for electric cables and their components. Environmental considerations should be included in both design and redesign work with respect to the raw materials used, energy consumption, emissions and generation of waste during production, end of life recycling or disposal, and in-service performance.

This document supersedes IEC TR 62125 published 2007, which intended to give assistance to writers of standards within IEC Technical Committee 20, to take into account the relevant environmental aspects that are specific to electric cables in normal use.

This document is addressed to writers of standards, manufacturers and users of power cables to provide guidance when evaluating:

- the qualitative environmental impact (checklist approach), or
- the quantitative environmental impact (LCA approach), and
- the environmental and energy cost-based conductor size optimization (ECSO).

IECNORM.COM : Click to view the full PDF of IEC 62125:2019

ENVIRONMENTAL CONSIDERATIONS SPECIFIC TO INSULATED ELECTRICAL POWER AND CONTROL CABLES

1 Scope

This document provides methodologies addressing environmental evaluation and communication related to cables in normal use.

It includes an environmental checklist for power cables, the method for life cycle assessment (LCA) and a methodology for conductor size optimization.

The results obtained by applying such methodologies can be used for external communication. Environmental communication can also include other topics, such as material declaration.

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.

IEC 60287-3-2:2012, *Electric cables – Calculation of the current rating – Part 3-2: Sections on operating conditions – Economic optimization of power cable size*

ISO 14040:2006, *Environmental management – Life cycle assessment – Principles and framework*

ISO 14044:2006, *Environmental management – Life cycle assessment – Requirements and guidelines*

3 Terms, definitions and symbols

3.1 Terms and definitions

3.1.1

life cycle assessment

LCA

compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle

[SOURCE: ISO 14040:2006, 3.2]

3.1.2

life cycle inventory

LCI

phase of life cycle assessment involving the compilation and quantification of inputs and outputs for a product throughout its life cycle

[SOURCE: ISO 14040:2006, 3.3]

3.1.3
life cycle impact assessment
LCIA

phase of life cycle assessment aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts for a product system throughout the life cycle of the product

[SOURCE: ISO 14040:2006, 3.4]

3.1.4
life cycle thinking
LCT

consideration of all relevant environmental aspects during the entire lifecycle of products

[SOURCE: IEC 62430:2009, 3.11]

3.1.5
reference flow

measure of the outputs from processes in a given product system required to fulfil the function expressed by the functional unit

[SOURCE: ISO 14040:2006, 3.29]

3.1.6
functional unit

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

[SOURCE: ISO 14040:2006, 3.20]

3.1.7
environment

surroundings in which a product or system exists, including air, water, land, natural resources, flora, fauna, humans and their interrelation

Note 1 to entry: "Environment" in this document means ecological environment. It does not refer to surrounding factors influencing the cable (such as humidity or temperature), nor to the business environment.

[SOURCE: IEC Guide 109:2012, 3.3, modified – Note 1 to entry has been added.]

3.1.8
life cycle

consecutive and interlinked stages of a product system, from raw material acquisition or generation from natural resources to final disposal

[SOURCE: ISO 14040:2006, 3.1]

3.1.9
environmental impact of a product

change to the environment, whether adverse or beneficial, wholly or partially resulting from the life cycle of a product

3.1.10
unit process

smallest element considered in the life cycle inventory analysis for which input and output data are quantified

[SOURCE: ISO 14040:2006, 3.34]

3.2 Symbols

α_{20}	temperature coefficient of conductor resistance at 20 °C (for copper: 0,003 93, for aluminium: 0,004 03)	1/K
θ	maximum rated conductor operating temperature	°C
θ_a	ambient average temperature	°C
θ_m	mean operating conductor temperature	°C
$\Delta\theta$	temperature rise of conductor $\Delta\theta = (\theta_m - 20 \text{ °C})$	°C
μ	loss load factor, see IEC 60853-1	–
C_{af}	cost for ancillary materials and installation materials (like conduits)	cu/km
C_C	cable cost including transportation	cu/km
C_I	initial cost of the cable being considered	cu/km
$C_{I(\text{CO}_2)}$	cost for CO ₂ emission during mining, manufacturing, transportation, installation and final disposal for a certain conductor size	cu/km
C_{I1}	initial cost of the next smaller standard size of conductor	cu/km
$C_{I1(\text{CO}_2)}$	cost for CO ₂ emission during mining, manufacturing, transportation, installation and final disposal for the next smaller size of conductor	cu/km
C_{I2}	initial cost of the next larger standard size of conductor	cu/km
$C_{I2(\text{CO}_2)}$	cost for CO ₂ emission during mining, manufacturing, transportation, installation and final disposal for the next larger size of conductor	cu/km
C_J	present value of the cost of joule losses during N years	cu/km
$C_{J(\text{CO}_2)}$	present value of the costs for CO ₂ emission during anticipated life time due to Joule losses	cu/km
C_L	cable installation (including laying, removal and disposal) cost	cu/km
C_T	life cycle cost	cu/km
C_{T1}	life cycle cost for the next smaller size of conductor	cu/km
C_{T2}	life cycle costs for the next larger size of conductor	cu/km
cu	arbitrary currency unit	
E_{CONV}	CO ₂ emission of the cable of conventional size per year during use phase	CO ₂ -kg/year

E_{OPTI}	CO ₂ emission of the cable of optimum size per year during use phase	CO ₂ -kg/year
F	auxiliary quantity defined by Formula (8)	cu/W
f_1	load factor	
f_2	power factor (= $\cos \varphi$, φ being the phase angle between voltage and current)	
I_{max}	maximum load current	A
I_{upper}	upper limit of I_{max}	A
I_{lower}	lower limit of I_{max}	A
I_Z	CO ₂ emissions during mining, manufacturing, transportation, installation and final disposal	CO ₂ -kg/km
K	CO ₂ emission for generation of unit power to be adjusted to the national situation	CO ₂ -kg/kWh
k_w	Coefficient based on wiring system, e.g. 3 phase-3 wire $k_w = \sqrt{3}$, for DC cables $k_w = 1$	
L	cable length	km
M	coefficient for converting CO ₂ emissions to cost to be adjusted to the national situation	CO ₂ -cu/kg
N	service life, a synonym (anticipated life time)	year
N_p	number of loaded phase conductors	–
P	cost of one kilowatt-hour at relevant voltage level	cu/kWh
R	conductor resistance of conductor per length (considered to be a constant value at an average operating temperature)	Ω/km
R_1	conductor resistance per length of the next smaller standard conductor size	Ω/km
R_2	conductor resistance per length of the next larger standard conductor size	Ω/km
R_{20}	conductor resistance at 20 °C per length, (ohm/km)	Ω/km
R_{conv}	AC resistance per length of the cable with conventional size for AC system and DC resistance per length of the cable with conventional size for DC system	Ω/km
R_{opti}	AC resistance per length of the cable with optimum size for AC system and DC resistance per length of the cable with optimum size for DC system	Ω/km
S	cross-sectional area of a cable conductor	mm ²

S_1	cross-sectional area of the next smaller standard conductor size	mm ²
S_2	cross-sectional area of the next larger standard conductor size	mm ²
U	system voltage	V
W	amount of power consumption per year	kWh/year
W_{conv}	distribution losses with the cable of conventional size	kWh/year
W_{opti}	distribution losses of the cable with optimum size	kWh/year
Y	annual operating days	days

4 General principles

The environmental impact of an electric cable shall be considered throughout all life cycle phases: from design till end of life. This is called the concept of life cycle thinking.

There are various tools for the environmental evaluation of the products, for example:

- a checklist approach, which is a qualitative consideration of the environmental aspects related to the life cycle steps of the product, i.e. use of the checklist in accordance with Clause 5 and Annex A, that is based on IEC Guide 109 and specifically focused on power cables;
- life cycle assessment (LCA), which is a scientific tool providing a quantitative evaluation of the environmental impact occurring during the whole life cycle of the product, i.e. use of the life cycle assessment in accordance with Clause 6 for assessment of the environmental impacts of a product.

The use of LCA methodology is recommended, as it provides quantified and detailed information on product environmental impact. Nevertheless, considering the knowledge and resources required to perform LCA studies, the checklist might be acceptable, for instance if certain aspects are considered without determining the complete environmental impact. This choice has to be made depending on objectives and knowledge and resources available.

Apart from life cycle thinking, other approaches can be used, such as:

- ECSO, a tool (described in Clause 7) to evaluate and optimize the conductor size by combining environmental and energy costs. ECSO is the optimization of the conductor size so that the sum of the total costs and the conversion costs of CO₂ emissions throughout the life phases (defined in 6.2.4) of the cable is minimized.

Environmental improvement shall be balanced against other factors, such as product function, performance, health and safety, cost, marketability and quality, legal and regulatory requirements and other standards.

5 Environmental checklist approach

5.1 What is the checklist approach?

The checklist approach is a simple method without quantification of the complete environmental impact. It is a working aid to evaluate the cable design and the cable choice for a certain application so as to find environmentally related aspects that may require consideration. The lists in 5.2 and Annex A address key factors that have an impact on the environment.

It should be noted that considerations of the points in 5.2 and Annex A do not always lead to reduction of the adverse environmental impact of the product throughout its lifetime: any decision to improve one environmental indicator can impact negatively another indicator. A possible way to confirm and quantify the environmental improvement is the use of the LCA methodology described in Clause 6.

5.2 Checklist

The following list, which is in accordance with IEC Guide 109:2012, Annex A, addresses key factors that may have an impact on the environment. Determine whether cable design and cable choice for the application consider the following aspects:

- material conservation:
 - minimal material content in the product;
 - minimal material content in the packaging;
 - minimal number of different materials;
 - maximum separability of different materials;
 - maximum recyclability of used materials;
 - reusability of product parts and components;
 - reusability and upgradability of the product as a whole;
 - possibility of using recycled materials;
 - possibility of using refurbished product parts and components;
 - minimal size of product;
 - minimal mass of product.
- energy conservation:
 - minimal energy consumption during the product's manufacture and operation;
 - power management, e.g. automatic switch to standby mode.
- pollution prevention:
 - avoidance of hazardous substances;
 - avoidance of substance emissions into the environment (air, water, soil);
 - avoidance of other releases, e.g. radiation, noise, dust.
- avoidance of waste:
 - modularity allowing multiple use of components (e.g. common chargers for different applications).

This list is not exhaustive; more items could be added for specific reasons. Not every item on the list will apply to every situation. Some more specific guidance related to electric cables is given in Annex A.

6 Life cycle assessment (LCA) of cables

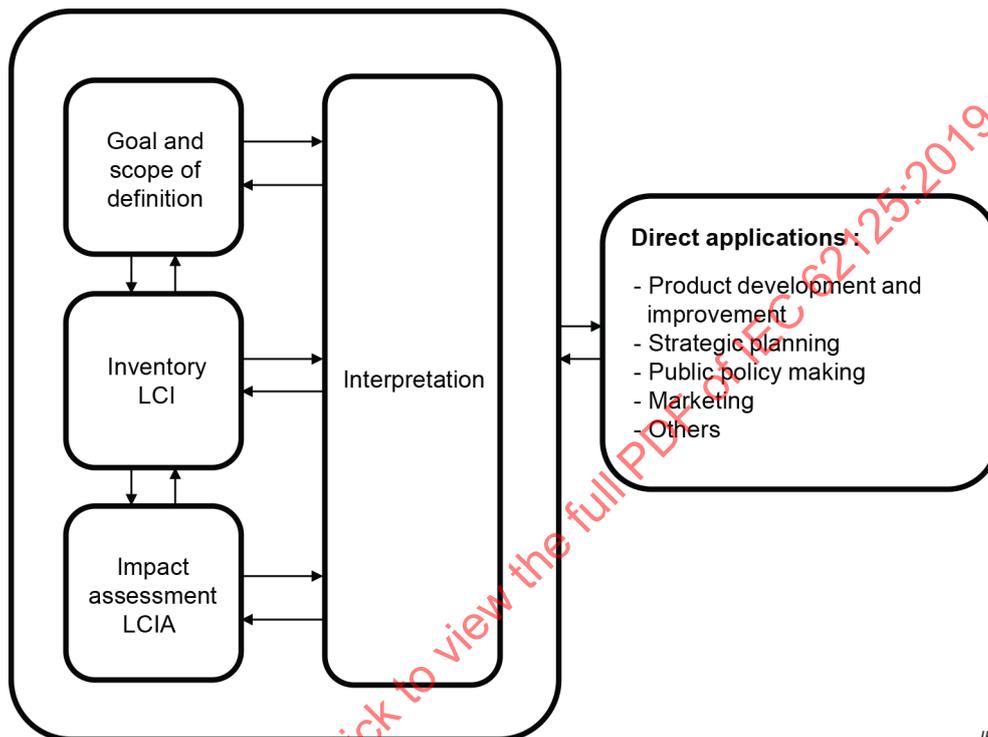
6.1 General

As recommended by IEC Guide 109, the basis of the assessment of product-related environmental impact is life cycle thinking. The environmental impact of a product needs to be evaluated by taking into account its whole life cycle, and by evaluating various environmental indicators. LCA is a tool covering all life cycle stages (cradle to grave).

Figure 1 illustrates the elements in an LCA. An LCA shall be carried out in accordance with the methodology of life cycle assessment (LCA) specified in ISO 14040 and ISO 14044.

Some basic steps to conduct this life cycle assessment of power cables are described in 6.2 to 6.6.

It has to be noted that an environmental optimum may not coincide with the economical optimum. LCA has to be seen as an evaluation tool to quantify the environmental impact and is not related to economic aspects. Regarding economic consideration, other methodologies can be applied, such as environmental life cycle cost (monetary expression, i.e. monetization of environmental indicators) or ECSO (see Clause 7), which combine environmental and economic aspects.



IEC

Figure 1 – Life cycle phases

6.2 Goal and scope

6.2.1 LCA study goal

The goal and scope of the LCA study should be clearly defined and be consistent with the intended application of the LCA.

The following items shall be unambiguously stated:

- the intended application;
- the decision context (reason for carrying out the study);
- the intended audience, i.e. to whom the results of the study are intended to be communicated.

6.2.2 Functional unit

The functional unit defines the quantification of the identified functions (performance characteristics) of the product being considered. The purpose of the functional unit is to provide a reference to which the inputs and outputs are related. This reference is necessary to ensure comparability of LCA results.

The functional unit shall mention:

- the main function delivered to the user;
- the quantified level of performance to be achieved by the main function.

For example, for a standard functional unit of power cables:

- "To transmit energy expressed for x A over a distance of y km during n years at a b % use rate, in accordance with the relevant standards...." or
- "To transmit energy of x kWh over a distance of y km during n years at a b % use rate, in accordance with the relevant standards...."

NOTE Use rate represents the operating time per year and can be expressed as

- the % of annual operating days (in %);
- the number of operating hours per year (in hours);
- the number of operating days per year (in days).

Other functional units can be defined depending on the goal of the LCA and the intended application.

6.2.3 Reference flow

Each functional unit corresponds to a reference flow. This reference flow describes all the needed flows to fulfil the functional unit and includes at least a reference power cable.

The reference flow shall include:

- the quantification of the reference product and its mass (kg), used to fulfil the functional unit;
- the additional materials not found in the reference product that include waste and discarded materials generated at each life cycle stage (manufacturing process, cutting, installation, etc.);
- elements, flows and processes required to distribute, install, use (maintenance, repairs, replacements...) remove, dismantle and treat the reference product.

6.2.4 System boundary

The system boundary describes the unit processes that are included in the LCA. Concerning power cables, the main impacting life phases are known to be the manufacturing (of the raw materials) and the use phases of the cables.

The life phases include:

- the **manufacturing phase** with:
 - **raw material extraction and processing**, transport of raw materials to the cable manufacturer;
 - **cable manufacturing**;
- the **transportation phase** with the transportation of the power cable from the manufacturer to the installation place;
- the **installation phase** including processes, components and energy accounted for the installation phase. Owing to the wide range of possible installation of these products, it may be decided to exclude the installation phase from the life cycle assessment's perimeter;
- the **use phase** with the energy consumption related to cables losses and other impacts, if any. The impact of the use phase will clearly describe the scenario used, such as cable lifetime, cable load factor, conductor resistivity and current load of the conductor;

- the **end of life phase**, including cable removal and transportation, as well as end-of-life treatment (grinding, separation, landfill, recycling, energy recovery, etc.).

The LCA has to be composed by all the life cycle steps. The LCA methodology could be used in some cases and for some reasons (for example, if it is required by a customer) to analyze just some phases, for instance "cradle to gate" analysis that only takes into consideration raw materials and cable manufacturing. This approach does not result in an LCA as such.

6.2.5 Cut-off criteria

Criteria for the exclusion of inputs and outputs shall not be applied to hide data. Any application of the criteria for the exclusion of inputs and outputs shall be documented. The cut-off criteria depend on the goal and scope definition and the boundary setting. Various cut-off criteria may be used to decide inputs and outputs to be included in the assessment, such as weight, energy and environmental influence. The total of neglected input flows (for example, raw materials to manufacture the cable) shall be clearly identified. Moreover, particular care should be taken to include material and energy flows known to have the potential to cause significant emissions into air, water and soil in relation to the environmental indicators of this document.

As an example, the following cut-off criteria can be applied:

- the mass of intermediate flows not taken into account shall be less than or equal to 5 % of the mass of the elements of the reference product corresponding to the functional unit;
- the energy flows not taken into account shall be less than or equal to 5 % of the total use of primary energy during the life cycle of the reference product corresponding to the functional unit.

6.2.6 Assumptions and limitations

Every assumption made – if necessary because of, for example, lack of data impossible to retrieve – should be clearly specified.

6.3 Life cycle inventory (LCI)

6.3.1 General

The life cycle inventory includes the collection of input data about resources, products or energy entering into the process, as well as output data about product, material or energy flow that leaves a process.

6.3.2 Data collection

The data to be included in the LCA study shall be obtained for each process included in the system boundary. For each unit process within the system boundaries, inputs and outputs related to the reference flow shall be collected including:

- consumption of materials, energy, water;
- emissions to air, water, soil;
- waste from the processes analysed.

The data gathered, whether they are measured, calculated or estimated, shall be used to quantify the inputs and output flows of a process. If data cannot be collected directly on-site (primary data), data can be obtained from high-quality and well-recognized databases (secondary data).

Secondary data shall be identified and consistent with the scope of the study in terms of time-related, geographic and technologic coverage. The databases used for the LCA shall be mentioned in the LCA report.

NOTE Examples of public database are:

- Ecoinvent database [1]¹;
- European Life Cycle Database (ELCD) [2];
- U.S. Life Cycle Inventory Database (USLCI) [3].

6.3.3 Data selection

Specific or average data derived from specific production processes shall be the first choice as a basis for the LCA study of power cables.

It is recommended that:

- the collected flows should be averaged over a sufficiently long period, preferably over a year, to even out any seasonal peaks;
- the collected data should be representative of a current scenario in terms of geographic coverage and technologic coverage. When data are collected from several sites, the data should be collected from representative sites. The method used to aggregate the multi-site data (i.e. measurements taken on each site) and the rules applying to the creation of data sources should be documented in the LCA report.

6.3.4 Allocation procedure

Most industrial processes produce more than the intended product. Normally, more than one input is needed to produce one product and sometimes products are co-produced with other products. When dealing with systems involving multiple products, allocation rules need to be set up to share the inputs and outputs to each product. Several methods are described in ISO 14044.

To allocate the consumptions of energy, materials, and water and emissions in air, water, soil and waste, it is necessary to apply a physical allocation rule being representative for the parameter, which shall be allocated to the functional unit.

The physical parameter of assignment of input and output flows may be for example mass, surface, or the number of units produced according to what is suitable for the system of production. Allocation should be considered carefully and should be justified.

6.4 Life cycle impact assessment (LCIA)

It includes the assignment of the LCI results to the selected impact categories and the potential environmental impacts in each category.

The impact assessment methodology used to carry out the LCA should be clearly described.

The impact assessment is carried out preferentially following the ILCD (International Reference Life Cycle Data System) recommendations given in the ILCD handbook [4].

Regarding the global warming potential, this can be expressed in two possible ways:

- a) by quantifying its impact with the "CO₂ equivalent" units, intended as the "mid-point category" as potential direct impact to the environment;
- b) by quantifying its impact up to the final damage to the "endpoint categories", for example: damage to human health, environment, resource depletion.

The same two approaches can be followed for any other impact category used to evaluate the LCA impact of the cable.

¹ Numbers in square brackets refer to the Bibliography.

6.5 Interpretation

The LCA interpretation shall include:

- a) an interpretation starting with the identification of significant issues;
- b) a description of the completeness (taking into account system boundaries and cut-off criteria);
- c) sensitivity and consistency checks.

The result should be interpreted taking into account the initial aim of the study.

If the aim of the study is the comparison between alternative cables, the results interpretation should be focused on the differences of the cables, not on their common properties.

Whilst if the aim of the study is the identification of the main impact elements of a cable in order to improve its environmental design (for example: what is the most impacting raw material? what is the most impact life cycle step – production, use or other? Etc.), the conclusions should be structured consequently.

This means that a strong result interpretation implies focusing on the elements relevant for the product to be analyzed and for the objectives of the LCA.

For this reason, the interpretation is also feedback about the quality of the LCA performed, since it can make evident the need to review the study before releasing the definitive results, allowing for possible significant elements to be included in the LCA that could have been neglected at first.

The interpretation should also be carried out with the purpose of identifying the main conclusions to communicate in the LCA report.

As a matter of fact, the LCA results (after the "impact assessment" step) are represented by one or more numbers and charts, indicating how much the cable life cycle impacts on the environment. Those numbers are often not very clear to non-expert readers. Therefore, they should be translated into final conclusions by putting them through the "interpretation" step. Such conclusions – in order to be communicated to the public – should be defined consistently with the basic aim of the study.

6.6 Single environmental indicator approach

Usually, the single environmental indicator is obtained by weighting the resulting impacts (of an LCA) and adding them up. The weighting process consists in giving a weight of importance to each impact, but this procedure is subjective, both political and scientific (for example: stating that the impact "global warming" is more important than "ozone depletion" is to a certain extent subjective). Therefore, it is not recommended to evaluate or communicate on a single environmental indicator as the comparison of single indicators between products can lead to limited conclusions and promotion of products with a higher impact for a certain environmental indicator that is considered less important at the moment, but that could become more important in the future.

Nevertheless, if it is wished to consider and communicate a single environmental indicator, it is necessary to evaluate the global environmental impact of the power cables by following a full life cycle assessment methodology as described above, and to make a good interpretation analysis to be aware of what the single indicator means. This will provide better knowledge on the product and on its environmental impacts, and can avoid false conclusions on environmental improvements between products.

Moreover, the evaluation and communication of a single environmental indicator shall take into account all life cycle stages to avoid pollution transfer between phases. When comparing products, comparison should be made between at least the total life cycle and not only one specific life phase.

Finally, when communicating on a single environmental indicator, an organization should try its best to avoid misleading the public or customers.

7 Environmental and energy cost-based conductor size optimization – ECSO

7.1 Overview

Environmental and energy cost-based conductor size optimization takes into account the cable's life phases' costs and the reduction in power loss costs during the use phase, and the related costs of CO₂ compared to the conventional sizing of highly loaded cables with significant energy losses.

ECSO takes specifically into account:

- initial cost of investment including manufacturing, transportation, installation and final disposal costs;
- cost for CO₂ emission during manufacturing, transportation, installation and final disposal;
- costs for Joule losses during anticipated lifetime;
- costs for CO₂ emission during anticipated lifetime.

At the time of writing of this document, the cost of CO₂ emissions might not adequately reflect the environmental effect of those emissions. It is recommended that the customer provide the cost of CO₂ and Joule losses to be considered by the manufacturer when performing the ECSO analysis.

This method is not an environmental impact evaluation; it may be used in addition to the checklist or LCA approach.

7.2 Basic rules

ECSO is the conductor size optimization so that the total costs C_T (broadly based on IEC 60287-3-2 costs and the conversion costs of CO₂ emissions throughout the life of cable) are minimized.

The potential return/benefit (scrap value) for recycling conductor material is also worthy enough to be considered. It may be taken into account in the calculation of the initial cost depending on the local situation.

It is recommended that the customer provide the scrap values for recycled conductor material to be considered by the manufacturer when performing the ECSO analysis. Figure 2 shows the total cost for a certain current load and indicates that, for conventional sizing, the cost could be different to optimum sizing. Depending on the voltage range, conventional sizing can take into account factors such as maximum current load (maximum conductor temperature), voltage drop, and protection devices.

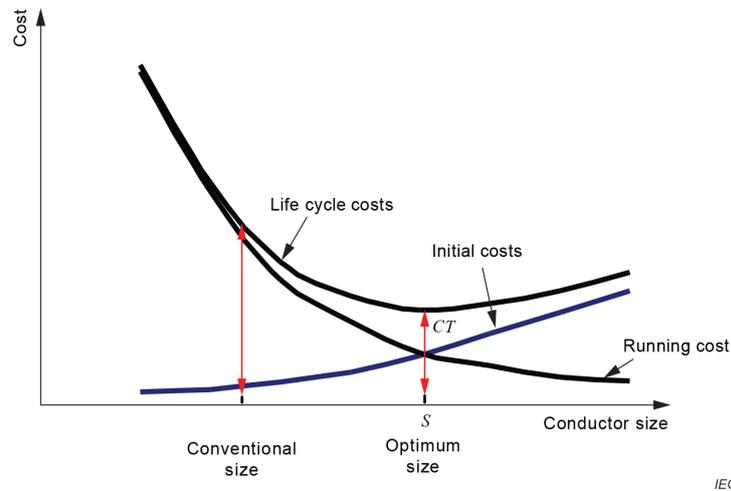
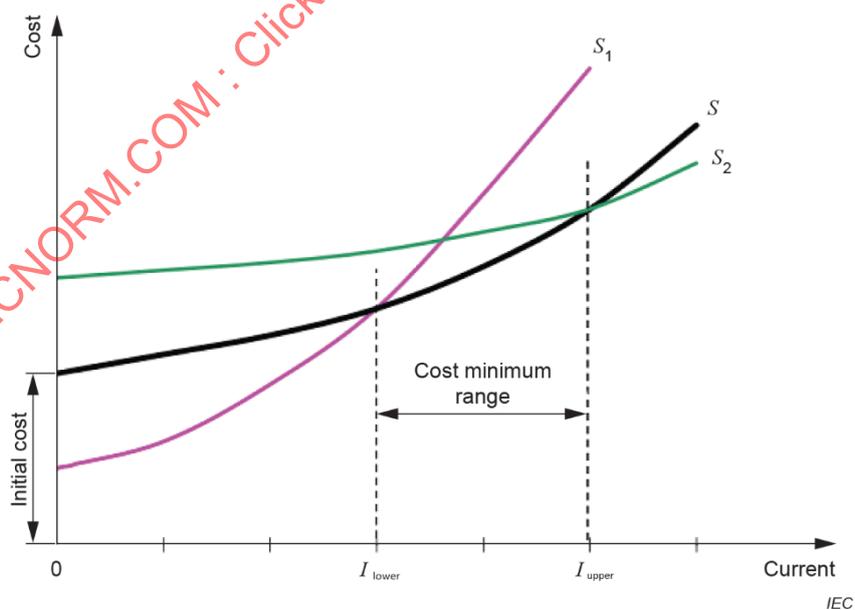


Figure 2 – Life cycle costs for conductor size for a certain current

The optimum current range (I_{lower} to I_{upper}) for a certain conductor size S , so that total cost $C_T = (\text{initial cost} + \text{running cost})$ (see Equation (1)) can become minimal, exists as per Figure 3 and is calculated in accordance with Equations (8) to (12). (Here life cycle cost includes the costs of converted CO_2 emission throughout the life of cable.)

$$C_T = C_I + C_{I(\text{CO}_2)} + C_J + C_{J(\text{CO}_2)} \quad (1)$$

I_{lower} can be determined by solving the equation for the intersection of both the life cycle costs of the conductor size S_1 and the conductor size S . In the same way, I_{upper} can be determined by solving the equation for the intersection of both the life cycle costs of the conductor size S and the conductor size S_2 .



Key

- S A certain conductor size
- S_1 the next smaller conductor size
- S_2 the next larger conductor size

Figure 3 – Optimum current range for minimizing life cycle cost

7.3 Factors

As described in 7.1 and 7.2, the optimum current range is influenced by many variable factors. The factors used for the calculations of optimum current include, for example, the price of conductor material, cable laying cost, service life, load factor, operating days, electricity charge. They differ from one country/region to another and can be variable in time. So the factors shall be determined carefully.

7.4 CO₂ evaluation

7.4.1 General

CO₂ emissions throughout the lifetime of the cable include all of those at each phase (raw materials, cable manufacturing, transportation, installation, use, removal and disposal).

7.4.2 CO₂ emissions during manufacturing, transportation, installation and final disposal

CO₂ emissions during manufacturing, transportation, installation and final disposal of each cable shall be calculated by using the LCA methodology of Clause 6, or by using publically available inventory data.

7.4.3 CO₂ emissions at the use phase

CO₂ emissions at the use phase shall be calculated by using CO₂ emissions for the generation of unit power (CO₂-kg/kWh) in each country or state.

CO₂ emissions at the use phase are overwhelmingly dominant in comparison to those at the other phases for highly loaded cables.

NOTE According to experience in Japan, if CO₂ emissions corresponding to Joule losses in a cable over 20 years are equal to 100, CO₂ emissions during all the other stages/processes such as the extraction/processes/transportation of raw materials, cable manufacturing, transportation of the cable to the installation site, installation, and disposal is only 3 % in total. The weight % of the transportation is 2 % of the 3 % of the total, which is equal to 0,06 %. Thus, it is easily understood how big the weight of CO₂ to Joule losses is.

7.5 Calculation method

7.5.1 General

The calculation is a simplified method not taking into account inflation and discount rate.

7.5.2 Calculation of initial cost

7.5.2.1 Initial investment

The calculation of initial investment is uses Equation (2):

$$C_I = C_C + C_L + C_{af} \quad (2)$$

All costs need to be adjusted to the national situation or circuit condition.

7.5.2.2 Cost for CO₂ emissions during manufacturing, transportation, installation and final disposal

CO₂ emissions during manufacturing, transportation, installation and final disposal of each cable shall be calculated by using the LCA methodology of Clause 6, or by using publically available inventory data.

CO₂ emissions during manufacturing, transportation, installation and final disposal are converted to cost as given in in Equation (3);

$$C_{I(\text{CO}_2)} = I_Z \times M \quad (3)$$

7.5.3 Calculation of running costs

7.5.3.1 Costs for Joule losses during anticipated life time

The calculation of costs for Joule losses during the anticipated lifetime is as given in Equation (4):

$$C_J = N_p \times I_{\max}^2 \times R \times \mu \times 10^{-3} \times (24 \times y \times N) \times P \quad (4)$$

7.5.3.2 Costs for CO₂ emission during anticipated life time ($C_{J(\text{CO}_2)}$)

The calculation of costs for CO₂ during anticipated life time is given in Equation (5)

$$C_{J(\text{CO}_2)} = N_p \times I_{\max}^2 \times R \times \mu \times 10^{-3} \times (24 \times y \times N) \times K \times M \quad (5)$$

7.5.4 Conductor resistance

A simple formula for making an estimate of conductor operating temperature and hence its resistance is as follows. This is based on observations of typical calculations that the average operating temperature rise of an optimum size of conductor, taken over its economic life, is in the region of one-third of the rise occurring with its maximum permissible thermal rating that is basically following the calculation conditions of IEC 60287-3-2 (see Equation (6)).

$$\theta_m = (\theta - \theta_a) / 3 + \theta_a \quad (6)$$

The conductor resistance R is shown as given in Equation (7).

$$R = R_{20} \times (1 + \alpha_{20} \times \Delta\theta) \quad (7)$$

Methods for more refined estimation of conductor temperature and resistance are given in Annex B of IEC 60287-3-2:2012.

7.5.5 Optimum current

The calculation of the optimum current range is based on the considerations given in 7.2 using Formula (1) with reference to Figure 3. C_{T1} shall be related to I_{lower} , C_{T2} shall be related to I_{upper} .

Simplifying Formula (4) and Formula (5) by using Equation (8):

$$F = N_p \times \mu \times 10^{-3} \times (24 \times y \times N) \times (P + K \times M) \quad (8)$$

the calculation of C_{T1} and C_{T2} is given by Equation (9) resp. Equation(10):

$$\begin{aligned} C_{T1} &= C_{I1} + C_{I1(CO_2)} + C_{J1} + C_{J1(CO_2)} \quad (9) \\ &= C_{I1} + C_{I1(CO_2)} + N_p \times I_{lower}^2 \times R_1 \times \mu \times 10^{-3} \times (24 \times y \times N) \times (P + K \times M) \\ &= C_{I1} + C_{I1(CO_2)} + F \times I_{lower}^2 \times R_1 \end{aligned}$$

$$C_{T2} = C_{I2} + C_{I2(CO_2)} + F \times I_{upper}^2 \times R_2 \quad (10)$$

The lower limit I_{lower} is the current for which $C_T = C_{T1}$; the upper limit I_{upper} is the current for which $C_T = C_{T2}$.(see Equation (11) resp. Equation (12))

Therefore,

$$I_{lower} = \sqrt{\frac{C_{I1} + C_{I1(CO_2)} - (C_{I1} + C_{I1(CO_2)})}{F \times (R_1 - R)}} \quad (11)$$

$$I_{upper} = \sqrt{\frac{C_{I2} + C_{I2(CO_2)} - (C_{I1} + C_{I1(CO_2)})}{F \times (R - R_2)}} \quad (12)$$

The optimum current range for a conductor size S with resistance R is between I_{lower} and I_{upper} .

For MV and HV cables, the dielectric and metal sheath/screen losses have to be taken into account. Details are given in IEC 60287-3-2.

7.5.6 Optimum conductor size

The optimum current range is determined for all appropriate sizes in the product range greater than the conventional size. The optimum conductor size is the size for which the maximum load current I_{max} is within its optimum current range (between lower limit and upper limit of I_{max}).

7.5.7 Energy reduction related to the use phase of the cable

7.5.7.1 Calculation of reduction of energy consumption during use phase

7.5.7.1.1 General

The calculations by the application of the optimum size are given in 7.5.7.1.2 to 7.5.7.1.4.

7.5.7.1.2 Amount of power consumption per year

The amount of power consumption per year is given by Equation (13)

$$W = k_w \times U \times I_{\max} \times f_1 \times f_2 \times 10^{-3} \times 24 \times y \quad (13)$$

7.5.7.1.3 Distribution losses per year

a) Conventional size:

To determine conventional size, current ratio (= actual current / current rating) is needed. The value is to be adjusted to the circuit condition. The distribution losses of the cable with conventional size per year shall be calculated using Equation (14):

$$W_{\text{conv}} = N_p \times I_{\max}^2 \times R_{\text{conv}} \times L \times \mu \times 10^{-3} \times 24 \times y \quad (14)$$

b) Optimum size:

The distribution losses of the cable with optimum size per year shall be calculated using Equation (15):

$$W_{\text{opti}} = N_p \times I_{\max}^2 \times R_{\text{opti}} \times L \times \mu \times 10^{-3} \times 24 \times y \quad (15)$$

7.5.7.1.4 Reduction of energy consumption during use phase

Difference of distribution losses for transmitted electricity per specific period (%) is given in Equation (16):

$$\frac{(W_{\text{conv}} - W_{\text{opti}})}{W} \times 100 \% \quad (16)$$

7.5.7.2 Calculation of CO₂ emission

The calculations of CO₂ emission are given in Equation (17) and Equation (18);

a) Conventional size:

$$E_{\text{CONV}} = W_{\text{conv}} \times K \quad (17)$$

b) Optimum size:

$$E_{\text{OPTI}} = W_{\text{opti}} \times K \quad (18)$$

7.5.7.3 Reduction ratio CO₂ emissions during use phase

Reduction ratio of CO₂ emissions per year shall be calculated using Equation (19).

$$\left(1 - \frac{E_{\text{opti}}}{E_{\text{conv}}}\right) \times 100 \% \quad (19)$$

7.6 Example

An example for calculating ECSO is presented in Annex B.

NOTE Supportive software can be developed on the bases of the formulas given.

8 Environment-related communication

8.1 General

Communications relating to the environmental aspects of products can cover various topics such as:

- the composition and compliancy to legislation on substances;
- the environmental impact of products (from the LCA results);
- treatment of products at the end of their life;
- information on the manufacturing process (existence of an environmental management system);
- the technical specifications of products related to their emissions (impact in case of fire, electromagnetic information).

An example of environmental communication related to the product, and covering some of the topics above, is provided in Annex C.

The communication of environmental aspects in the supply chain is interpreted and practised by the actors very differently. Nevertheless, some general principles can be standardized to achieve reliable environmental communications.

8.2 General principles

ISO 14020 provides general principles to apply in environmental communication on products in order to ensure reliable information to the customers. The basic principles that shall be applied are:

- environmental communication on products shall be:
 - truthful, accurate and non-misleading,
 - relevant to the particular product,
 - substantiated;
- environmental communication shall be based on comprehensive scientific methodology that produces results that are accurate and reproducible
- information concerning the procedure, methods and any criteria used should be made available;
- the meaning of any symbols or pictures shall be clear and relevant.

This implies that environmental claims that are vague and non-specific, such as "environmentally safe", "green" or "eco-friendly" shall not be used.

ISO 14020 is completed with additional standards that should be followed to ensure transparent and reliable environmental communication, such as:

- ISO 14021 on self-declared environmental claims (type II environmental labelling), which specifies requirements for self-declared environmental claims, including statements, symbols and graphics, regarding products. It further describes selected terms commonly used in environmental claims and provides a general evaluation and verification methodology for self-declared environmental claims.
- ISO 14024 on type I environmental labelling and the eco-logo. It establishes the principles and procedures for developing type I environmental labelling programmes, including the selection of product categories, product environmental criteria and product function characteristics, and for assessing and demonstrating compliance.

In any case, environmental claims shall comply with applicable laws and regulations. Various national or international guides have been developed to ensure reliable environmental communication and to respond to existing standards or legislation.

NOTE Examples of such guides are listed in the Bibliography [5], [6] and [7]:

8.3 Composition and compliancy to legislation on substances

Communication related to product composition (raw material, substances and concentration) shall remain limited to non-confidential and non-proprietary information.

The composition of the different cable parts can only be provided if it remains general. For instance, a cable can be described with the following information:

- aluminium or copper for the conductor;
- polyolefin, rubber and silicone for the insulation and sheath.

It is also possible to provide additional specific information that could be of interest for the customer, such as "halogen-free" for instance.

IEC 62474 deals with material declaration for products of, and for, the electrotechnical industry. It specifies the procedure relating to material declaration for products operating in and supplying the electrotechnical industry, as well as the list of substances to declare. As this document goes beyond legislative obligation (list of substances to be declared, reporting of substances mass and percent), and considering that, for cables, communication on substances is limited by confidential and proprietary information, IEC 62474 is not applicable or might not be recommended regarding material declaration.

Moreover, legislations (such as restrictions on hazardous substances) can require communication to customers on the presence of some specific substances and/or conformity to restrictions or bans on substances. Such declarations can be provided within the "composition" part of an environmental communication.

8.4 Life cycle assessment

The results and conclusions of the LCA should be reported in an adequate form to the intended audience, addressing the data, methods and assumptions applied in the study, and the limitations thereof. ISO 14040:2006, Clause 4 and ISO 14044:2006, Clause 5 provide information on LCA study reporting.

Specific requirements need to be fulfilled when LCA studies support comparative insertions intended to be disclosed to the public.

Moreover, a specific standard (ISO 14025) has been developed regarding type III environmental declaration related to the communication of LCA results. It specifies the program and process to develop for environmental product declaration (EPD) and requirements to communicate LCA results through EPD. To be compliant with ISO 14025, type III environmental declaration shall be based on product category rules (PCR) in order to ensure a harmonized life cycle assessment methodology. Some PCRs already exist or are under development for EEE products.

8.5 End of life

Environmental communication can focus on the information to provide to recyclers to ensure the proper treatment of the cables at the end of their life in order to limit their impact on the environment. IEC TR 62635 deals with end of life (EoL) information and provides a methodology for information exchange involving EEE manufacturers and recyclers to enable appropriate and optimized EoL treatment operations.

Annex A (informative)

Checklist for the checklist approach

A.1 Preliminary considerations

- 1) Has it been checked before that there is no possibility to adopt, with slight amendments, a cable design already existing, and for which environmental aspects have already been taken into consideration?
- 2) Has the raw material production been considered and evaluated for environmental constraints?

A.2 Design considerations

- 1) Has it been considered to choose a conductor with the lowest energy consumption and/or lowest CO₂ emission during manufacturing of the product?
- 2) Has the possibility to use recycled materials been considered, for instance as fillers? Has the consideration also taken into account the environmental impact of such recycling (parameters such as collection conditions, regeneration cycle, quality of the recycled material, losses, energy consumption, substitution rate) without affecting the cable safety, reliability and cost?
- 3) Has consideration been given to lists of internationally, regionally or nationally regulated substances, so that those for which restrictions apply can be avoided or reduced to a minimum within all parts and components of the cable?
- 4) Has it been checked that the components do not release hazardous substances into the environment during raw material production, manufacturing of the cable, cable in use and final disposal of the cable?
- 5) Has it been considered to select materials/components that can easily be separated from other cable components so that any available and ecologically efficient waste management option, including energy recovery, can be used?
- 6) Can the different components easily be identified?
- 7) Has it been considered to minimize the number of different materials in the cable design, without affecting the safe operation of the cable, its reliability and cost?

A.3 Production considerations

- 1) Has reference been made to the use of an environmental management system, such as ISO 14001, for production?
- 2) Has efficient use of energy and resources been considered?
- 3) Have measures for reduction of emissions and waste been considered?

A.4 Considerations for use and end of life phase

- 1) If a change in a product is also considered to give a change in the environmental constraint, have measures been taken to give information to the market regarding the constraints of the products already in stock or on the market?
- 2) Has information been given to the user on the fact that the choice of transmission/distribution voltage and the conductor cross-section will seriously influence the current transmission losses?
- 3) Has information been given how to recover/recycle the components/materials in the cable at end of life of the product (which may be many decades), including the possibility of energy exploitation?
- 4) Has consideration been given to waste management of any packaging associated with transportation of the cable, including the material and the size of cable drums?
- 5) Has consideration been given to minimize the energy with regard to cable transportation?

IECNORM.COM : Click to view the full PDF of IEC 62125:2019

Annex B (informative)

Example for ECSO

B.1 General

Annex B helps the user calculate ECSO. Please note that some assumptions are introduced. "cu" stands for an arbitrary currency unit.

B.2 Cable data

- a) Cable standard: IEC 60502-1
- b) 0,6/1kV XLPE insulated PVC sheathed power cable (3 cores)

B.3 Calculation condition

a) Installation	In air
b) Wiring system	3 phase – 3 wire
c) Ambient temperature (θ_a)	30 °C
d) Maximum load current (I_{max})	100A
e) Current ratio (maximum load current/current rating)	0,50
f) Loss-load factor (μ)	0,64
g) Load factor (f_1)	0,8
h) Power factor (f_2)	0,8
i) System voltage (U)	200 V
j) Max permitted conductor temperature (θ)	90 °C
k) Annual operating days (y)	300 (days)
l) CO ₂ emission for generation of unit power (K)	0,45 (CO ₂ -kg/kWh)
m) Electricity charge (P)	0,13 (cu/kWh)
n) Coefficient for converting CO ₂ emissions to cost (M)	0,010 (cu/CO ₂ -kg)
o) Cable length (l)	0,15 km
p) Frequency	50 Hz
q) Service life (N)	20 years

Country related figures are selected arbitrarily.

Conventional size is 70 mm². To find the optimum size, the calculations in B.4 are carried out.

B.4 Initial cost

B.4.1 Initial investment

$$C_1 = C_C + C_L + C_{af} \text{ (cu/km)}$$

$$3C \ 70 \text{ mm}^2: C_1 = C_C + C_L + C_{af} \rightarrow 20\ 449 + 17\ 586 + 8\ 772 = 46\ 807 \text{ (cu/km)}$$

$$3C \ 95 \text{ mm}^2: C_1 = C_C + C_L + C_{af} \rightarrow 27\ 757 + 22\ 761 + 8\ 772 = 59\ 290 \text{ (cu/km)}$$

$$3C \ 120 \text{ mm}^2: C_1 = C_C + C_L + C_{af} \rightarrow 35\ 054 + 25\ 239 + 8\ 772 = 69\ 065 \text{ (cu/km)}$$

$$3C \ 150 \text{ mm}^2: C_1 = C_C + C_L + C_{af} \rightarrow 43\ 826 + 26\ 296 + 8\ 772 = 78\ 894 \text{ (cu/km)}$$

$$3C \ 185 \text{ mm}^2: C_1 = C_C + C_L + C_{af} \rightarrow 52\ 269 + 31\ 362 + 8\ 772 = 92\ 403 \text{ (cu/km)}$$

Assumption: the same ancillary material is used.

B.4.2 Conversion of CO₂ emissions during material/cable production, removal, transportation and disposal to cost

$$C_{I(\text{CO}_2)} = I_Z \times M \text{ (cu/km)}$$

$$3C \ 70 \text{ mm}^2: C_{I(\text{CO}_2)} = I_Z \times M \rightarrow 7\ 421 \times 0,010 = 74,21 \text{ (cu/km)}$$

$$3C \ 95 \text{ mm}^2: C_{I(\text{CO}_2)} = I_Z \times M \rightarrow 9\ 904 \times 0,010 = 99,04 \text{ (cu/km)}$$

$$3C \ 120 \text{ mm}^2: C_{I(\text{CO}_2)} = I_Z \times M \rightarrow 12\ 418 \times 0,010 = 124,18 \text{ (cu/km)}$$

$$3C \ 150 \text{ mm}^2: C_{I(\text{CO}_2)} = I_Z \times M \rightarrow 15\ 517 \times 0,010 = 155,17 \text{ (cu/km)}$$

$$3C \ 185 \text{ mm}^2: C_{I(\text{CO}_2)} = I_Z \times M \rightarrow 19\ 047 \times 0,010 = 190,47 \text{ (cu/km)}$$

B.4.3 Initial cost (sum)

$$3C \ 70 \text{ mm}^2: C_1 + C_{I(\text{CO}_2)} \rightarrow 46\ 807 + 74,21 = 46\ 881,21 \text{ (cu/km)}$$

$$3C \ 95 \text{ mm}^2: C_1 + C_{I(\text{CO}_2)} \rightarrow 59\ 290 + 99,04 = 59\ 389,04 \text{ (cu/km)}$$

$$3C \ 120 \text{ mm}^2: C_1 + C_{I(\text{CO}_2)} \rightarrow 69\ 065 + 124,18 = 69\ 189,18 \text{ (cu/km)}$$

$$3C \ 150 \text{ mm}^2: C_1 + C_{I(\text{CO}_2)} \rightarrow 78\ 894 + 155,17 = 79\ 049,17 \text{ (cu/km)}$$

$$3C \ 185 \text{ mm}^2: C_1 + C_{I(\text{CO}_2)} \rightarrow 92\ 403 + 190,47 = 92\ 593,47 \text{ (cu/km)}$$

B.4.4 Conductor resistance

$$\theta_m = (\theta - \theta_a) / 3 + \theta_a \rightarrow [(90 - 30) / 3 + 30] \text{ }^\circ\text{C} = 50 \text{ }^\circ\text{C}$$

$$\Delta\theta = \theta_m - 20 \text{ }^\circ\text{C} \rightarrow (50 - 20) \text{ }^\circ\text{C} = 30 \text{ }^\circ\text{C}$$

AC Conductor resistance:

$$3\text{C } 70 \text{ mm}^2: R = R_{20} \times (1 + \alpha_{20} \times \Delta\theta) \rightarrow 0,269 \times (1 + 0,003 \text{ } 93 \times 30) = 0,301 \text{ (ohm/km)}$$

$$3\text{C } 95 \text{ mm}^2: R = R_{20} \times (1 + \alpha_{20} \times \Delta\theta) \rightarrow 0,194 \times (1 + 0,003 \text{ } 93 \times 30) = 0,217 \text{ (ohm/km)}$$

$$3\text{C } 120 \text{ mm}^2: R = R_{20} \times (1 + \alpha_{20} \times \Delta\theta) \rightarrow 0,154 \times (1 + 0,003 \text{ } 93 \times 30) = 0,172 \text{ (ohm/km)}$$

$$3\text{C } 150 \text{ mm}^2: R = R_{20} \times (1 + \alpha_{20} \times \Delta\theta) \rightarrow 0,125 \times (1 + 0,003 \text{ } 93 \times 30) = 0,140 \text{ (ohm/km)}$$

$$3\text{C } 185 \text{ mm}^2: R = R_{20} \times (1 + \alpha_{20} \times \Delta\theta) \rightarrow 0,101 \times (1 + 0,003 \text{ } 93 \times 30) = 0,113 \text{ (ohm/km)}$$

B.5 Calculation of running costs

B.5.1 Costs for Joule losses during anticipated life time

$$3\text{C } 70 \text{ mm}^2: C_J \rightarrow 3 \times 100^2 \times 0,301 \times 0,64 \times 10^{-3} \times (24 \times 300 \times 20) \times 0,13 = 108 \text{ } 187 \text{ (cu/km)}$$

$$3\text{C } 95 \text{ mm}^2: C_J \rightarrow 3 \times 100^2 \times 0,217 \times 0,64 \times 10^{-3} \times (24 \times 300 \times 20) \times 0,13 = 77 \text{ } 995 \text{ (cu/km)}$$

$$3\text{C } 120 \text{ mm}^2: C_J \rightarrow 3 \times 100^2 \times 0,172 \times 0,64 \times 10^{-3} \times (24 \times 300 \times 20) \times 0,13 = 61 \text{ } 821 \text{ (cu/km)}$$

$$3\text{C } 150 \text{ mm}^2: C_J \rightarrow 3 \times 100^2 \times 0,140 \times 0,64 \times 10^{-3} \times (24 \times 300 \times 20) \times 0,13 = 50 \text{ } 319 \text{ (cu/km)}$$

$$3\text{C } 185 \text{ mm}^2: C_J \rightarrow 3 \times 100^2 \times 0,113 \times 0,64 \times 10^{-3} \times (24 \times 300 \times 20) \times 0,13 = 40 \text{ } 615 \text{ (cu/km)}$$

B.5.2 Costs for CO₂ emission during anticipated life time

$$3\text{C } 70 \text{ mm}^2: C_{J(\text{CO}_2)} \rightarrow 3 \times 100^2 \times 0,301 \times 0,64 \times 10^{-3} \times (24 \times 300 \times 20) \times 0,45 \times 0,010 = 3 \text{ } 745 \text{ (cu/km)}$$

$$3\text{C } 95 \text{ mm}^2: C_{J(\text{CO}_2)} \rightarrow 3 \times 100^2 \times 0,217 \times 0,64 \times 10^{-3} \times (24 \times 300 \times 20) \times 0,45 \times 0,010 = 2 \text{ } 700 \text{ (cu/km)}$$