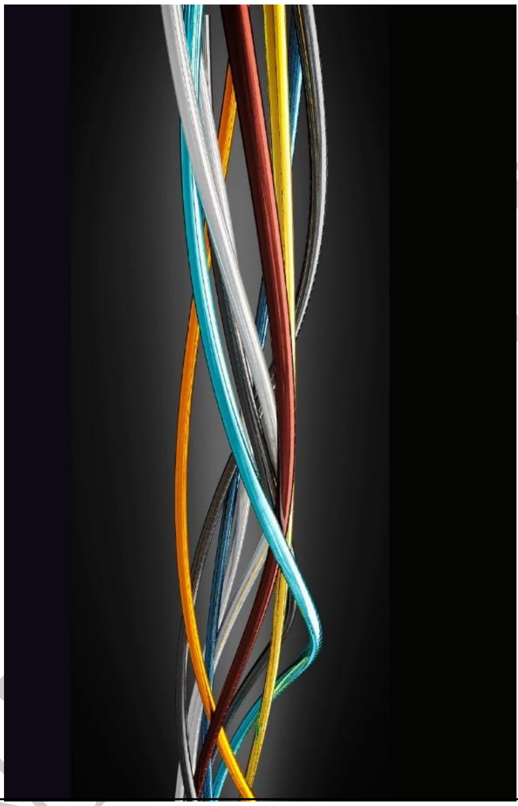

Comparative Life Cycle Assessment of two elbow connectors

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Executive summary

Context and objectives

Electrical grids (or networks) enable the delivery of electricity from suppliers to consumers. Electricity distribution is ensured by energy cables which are interconnected with joints and connected to equipments (e.g. transformers) with connectors. Therefore, connectors are essential items of the global energy network.

Nexans, as one of the leaders in the cable industry, also manufactures power accessories in order to provide to its clients a complete solution to build energy networks. Within Nexans, one of the power accessory manufacturers is Euromold division. Euromold is specialized in rubber connectors, epoxy bushings and coldshrinkable terminations/joints and one of the factories is located in Erembodegem (Belgium).

In 2014, Euromold has launched a redesign project on the elbow connector 158LR (interface A) in order to decrease product cost and also improve environmental performances. A life cycle assessment (LCA) of the elbow connector was performed to inform the redesign process with the significant environmental aspects of this product life cycle.
In 2017, the design of the new connector, named 200LR, was finalized. Erembodegem development team used the results of the LCA (results and data available in the report DT-ENV-MEM-061) to inform the design process of the new connector. Therefore, the objective of this study is to compare the environmental performance over the product lifecycles to see if the new design, 200LR is an improvement on the 158LR.

The specific goals of this study are as follow:
- Make an accurate environmental profile of the new connector;
- Evaluate potential improvements and/or deterioration of the 200LR life cycle compared to the 158LR;
- Support environmental claims for the marketing campaign of the new connector.

Methodology

In this study, the functional unit used as a reference for evaluating the products on a common basis is:

"Connect energy cables to equipment, expressed for one packaging unit, in the same use conditions as the cables: 100A (or 10A) over 40 years and used 100% of its life, and fulfilling the appropriate standards".

The study assesses connectors' life cycles from the extraction and processing of all raw materials up to the end-of-life. The system is divided into the following life cycle stages:
- Manufacturing: extraction, transportation and processing of raw materials and chemicals used to manufacture the connector;
- Distribution: transport of the connector to the installation place;
- Installation: management of the end-of-life of installation parts and packaging;
- Use: operation of the connector under normal conditions, representing the Joule losses during the product lifetime;
- End-of-life: collection and waste treatment processes.

Primary data have been collected in collaboration with Erembodegem plant (raw material nature/mass, energy consumption of manufacturing equipment).
For the 158LR, data used in DT-ENV-MEM-061 was used.
For the 200LR, design information and data collection on new equipments have been used.
All life cycle inventory data are taken from Nexans-2017-06 database implemented in the software EIME v5.7.0.2.

Impact assessment methods used are the one recommended by PEPecopassport® program, which is a reference in Electric and Electronic industry. 11 environmental aspects including Global Warming (expressed in kg CO_2-eq), Energy Depletion (expressed in MJ), Abiotic Depletion of Resources (in kg Sb-eq) and Water Depletion (dm^3) were evaluated in this study.

Results

When comparing the product life cycles of the 158LR with the new 200LR from an environmental impact perspective, the redesign product 200LR fulfils the functional unit with significantly less environmental impacts, for the two use scenarios analysed in this study.
The use phase environmental impact is reduced by 51% for the 200LR connector.
The impact of the manufacturing phase has been reduced by:

- 55% on global warming potential;
- 44% on abiotic depletion of resources;
- 58% on total primary energy use;
- 65% on net fresh water use.

The contribution pattern for the 200LR accessory is similar to the one of the 158LR, when selecting the use scenario of 100A. The two main contributors are:

- The use phase;
- The manufacturing phase.

For the manufacturing phase, two groups of components are standing out:

- The connector body, with all its elastomeric parts and;
- The metallic parts of the product (like the ground cable and the clamping system).

Conclusions

Based on the results of the comparative life cycle assessment, it can be concluded that the **ecodesign efforts** put on the redesign project of the elbow connector 158LR were **beneficial**. The new version of the product, 200LR, improves significantly the two first contributors to the environmental impact of an electric accessory for MV network life cycle, without any impact transfers to other life cycle stages:

- <u>Use phase:</u> thanks to a shorter length of conductor in the product, the energy losses have been cut by two.
- <u>Manufacturing</u>: thanks to a more compact design, with a better process-ability, less material use and energy efficiency improvements of the machinery, the impacts of manufacturing have been reduced.

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ABBREVIATIONS AND ACRONYMS

A	Ampere
A	Acidification potential of soil and water
ADPe	Abiotic Depletion (resources)
ADf	Abiotic Depletion (fossil fuels)
AP	Air Pollution
CO_2	Carbon dioxide
EP	Eutrophication
FW	Fresh water aquatic ecotoxicity
GWP	Global Warming
I	Intensity (current)
J	Joule
kg	Kilogram
kg.km	Kilogram.kilometer
km	Kilometer
kV	Kilovolt
kWh	Kilowatt-hour
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
MV	Medium Voltage
MJ	Mega Joule
ODP	Ozone Layer Depletion
Ω.km	Ohm.Kilometer, unit of measure for linear resistivity
P	Power
PCR	Product Category Rules
POCP	Photochemical oxidation
PSR	Product Specific Rules
TPE	Total Primary Energy
W	Watt
WP	Water pollution

I. Introduction

Electrical grids (or networks) enable the delivery of electricity from suppliers to consumers. Electricity distribution is ensured by energy cables which are interconnected with joints and connected to equipment (e.g. transformers) with connectors. Therefore, connectors are essential items of the global energy network.

Nexans, as one of the leaders in the cable industry, also manufactures power accessories in order to provide to its clients a complete solution to build energy networks. Within Nexans, one of the power accessory manufacturers is Euromold division. Euromold is specialized in rubber connectors, epoxy bushings and coldshrinkable terminations/joints and one of the factories is located in Erembodegem (Belgium).

In 2014, Euromold has launched a redesign project on the elbow connector 158LR (interface A) in order to decrease product cost and also improve environmental performances.
In 2017, the design of the new connector, named 200LR, was finalized. Erembodegem development team used the results of the LCA (results and data available in the report DT-ENV-MEM-061) to inform the design process of the new connector.
Therefore, the objective of this study is to compare the environmental performance over the product lifecycles to see if the new design, 200LR is an improvement on the 158LR.

II. Goal of the study

II.1 Objectives

The objectives of this study are to assess the potential environmental impacts of the 200LR elbow connector and to compare it to the potential environmental impacts of the 158LR, the previous version of this product, studied in 2014 (data and results are compiled in DT-ENV-MEM-061).

The study gives an overview of the environmental impacts of the connector only. The medium voltage cable used to transmit energy is not taken into account.

II.2 Intended audience and application

The study report is intended to point out any advantages/drawbacks of the 200LR over the 158LR and to provide clear results on environmental impacts of the connector to:

- Euromold Technical Management;
- Nexans Technical Management;
- Marketing teams.

The results of this study are going to be used by the marketing team to communicate with Nexans clients in a Business to Business context.

II.3 Disclosures and declarations

Nexans seeks to evaluate the environmental performance of the connector described below. It is not intended to be compared with any competing connector. A critical review has been commissioned on this study.

III. Scope of the study

III.1 General description of the product studied

Elbow connectors are designed to connect polymeric insulated cables to equipments (such as transformers or switchgears) in both indoor and outdoor applications. The connectors under study are designed for medium voltage applications, with a current intensity up to 250A. Its jacket is made of EPDM (ethylene-propylene-diene monomer) material.

Figure 1: Elbow Connector 158LR (on the left) and Elbow connector 200LR (on the right)

The commercial description of the products are available by visiting the following weblinks:

- 200LR: https://200-lr.com/
- 158LR: https://www.nexans.be/Belgium/2018/CP%20AC3010-ENG-158LR.pdf

III.2 Function and functional unit

Life Cycle Assessment (LCA) relies on a functional unit as a reference for evaluating the components within a single system on a common basis. In this study, the functional unit is:

"Connect energy cables to equipment, expressed for one packaging unit, in the same use conditions as the cables: 100A (or 10A) over 40 years and used 100% of its life, and fulfilling the appropriate standards"

The main purpose of the functional unit is to provide a reference to which the input and output data are related. This reference is necessary to ensure comparability between LCA results in the case of a comparison (e.g. environmental impact comparison between old connector design and new connector design).
To define this functional unit, the Product Specific Rules-PSR for Cables, Wires and Accessories from the ecodeclaration program PEPecopassport ® were used [1]. The only adjustment made was on the intensity for the use of the junction. The PSR uses an intensity of 1A to facilitate the calculations of power losses during use phase, but this intensity is not realistic. In this case, the intensity is established based on the average constrains that the junction will endure during its lifetime. The constrain is different if the cables connected are copper cables (10A) or aluminum cables (100A).
The functional unit refers to the quantity of product in one packaging units (in our case 3 connectors) because:

- To be aligned with the product specific rules of the PEPecopasport ® program requirements for power accessories, the content of one unit of packaging should be considered and;
- Most medium voltage cables are installed in a "trefoil configuration", ie. with three cables at the same time meaning that the connection of MV cables to another part of the grid needs to be done three times. This means that, most of the time, for a connection point on the grid three connectors (ie. The quantity of products in one unit of packaging) is needed. The figure below shows a trefoil configuration for MV cables

Figure 2: Medium voltage cables in a trefoil configuration

III.3 Reference flow

The reference flow for this study is a package that contains 3 connectors with a kit of elements for installation.

The reference flow covers the following elements for both cables:

- A packaging, including:
  - A cardboard box that contains all the elements listed below;
  - Plastics bags used for keeping kitting elements together;
  - A pair of gloves;
  - Wipers;
  - Installation instructions
- Installation auxiliaries (included in the product weight):
  - A tube of grease;
  - A Water sealing mastic;
  - An adhesive tape and;
- 3 connectors (ie. products), each of them composed of:
  - 1 conductor contact;
  - 1 pin contact and 1 hex key;
  - 1 bail restraint;
  - 1 connector housing;
  - 1 cable reducer.

For the 158 LR, reference flow also includes the elements presented in the following figure, 3 times: Connector housing, conductor contact, pin, hex key, bail restraint and cable reducer. These 6 elements are what form the product after its installation.

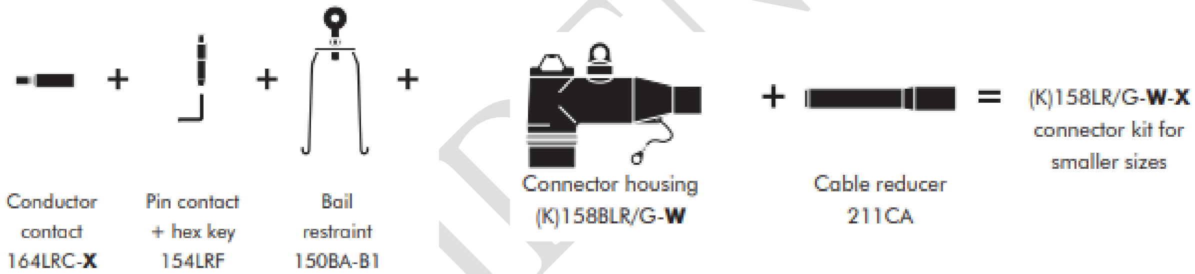


Figure 3: Content of a package of 158LR

For the 200LR, the reference flow also includes the elements presented in the following figure, 3 times: Connector housing, conductor contact, pin, hex key, bail restraint and cable reducer. These 6 elements are what form the product after its installation.

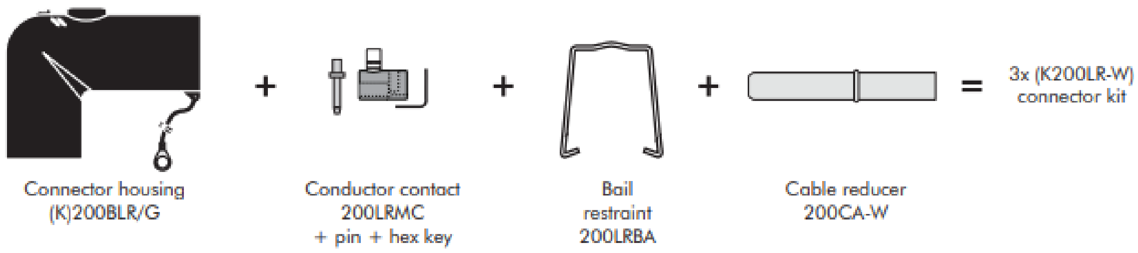


Figure 4: Content of a package of 200LR

III.4 System boundaries

The system boundaries identify the life cycle steps, processes and flows considered in the LCA and should include all relevant activities in order to attain the study objectives. Based on PEPecopassport® program rules (PEP-PCR-ed3-EN-2015 04 02 [2] and PSR-0001-ed3-EN-2015 10 16 [1]), the system was grouped into the following principal life cycle stages:

- **Manufacturing**: it includes raw material extraction, transportation of raw materials to the production facility, product manufacturing and transportation to the last logistic warehouse of the manufacturer;
- **Distribution**: it considers product transportation from the last logistic warehouse of the manufacturer to the use place;
- **Installation**: it is limited to the management of the packaging and installation part end-of-life due to a lack of information on installation of such products;
- **Use**: it reflects the operation of the product under normal conditions, which means the energy consumption during the product lifetime;
- **End-of-life**: it includes the transportation to the end-of-life facilities and the landfill of the components.

N.B: the current intensity is not 1A as mentioned in PEPecopassport® program because this study is realized under more realistic use conditions in order to assess precisely the environmental impact of the connector and identify eco-design opportunities.

The following approaches are applied in this study for the two systems, according to the PEPecopassport® program reference document [3]:

- Modularity principle: that means manufacturing scraps are considered treated at manufacturing stage and packaging end-of-life is taken into account at installation stage;
- Cut-off approach or "stock method": that means recovered materials after end-of-life treatments are made available for further use through a virtual "stock" (see Figure 5);

No credit or environmental benefit is attributed to the products when constituting materials are recycled or use for energy production at the end of their life. This approach has been chosen because the uncertainty is high on what is going to happen at the end-of-life of the product, in our case 40 years from now. The market demand for this type of materials might be completely different, so to consider it as a stock frees us from the uncertainty of the future market demand.
This also means that the impact of waste management operations is considered up to the point of substitution, i.e. up to the point where the material can be considered as a "stock" to be used in future applications.
The point of substitution describes the moment in end-of-life management process when the material that is obtained can substituted a virgin material. For example, the point of substitution for copper from cable waste management is when it is separated from the other elements of the cable (insulation, screen, sheath…). This means that the waste management operations that leads to a copper fraction free of other elements has to be allocated to the cable that is being managed at its end-of-life.
This also means that the environmental impact of a product that uses recycled materials covers all the operations after the point of substitution, ie. after the material is taken out of the stock.

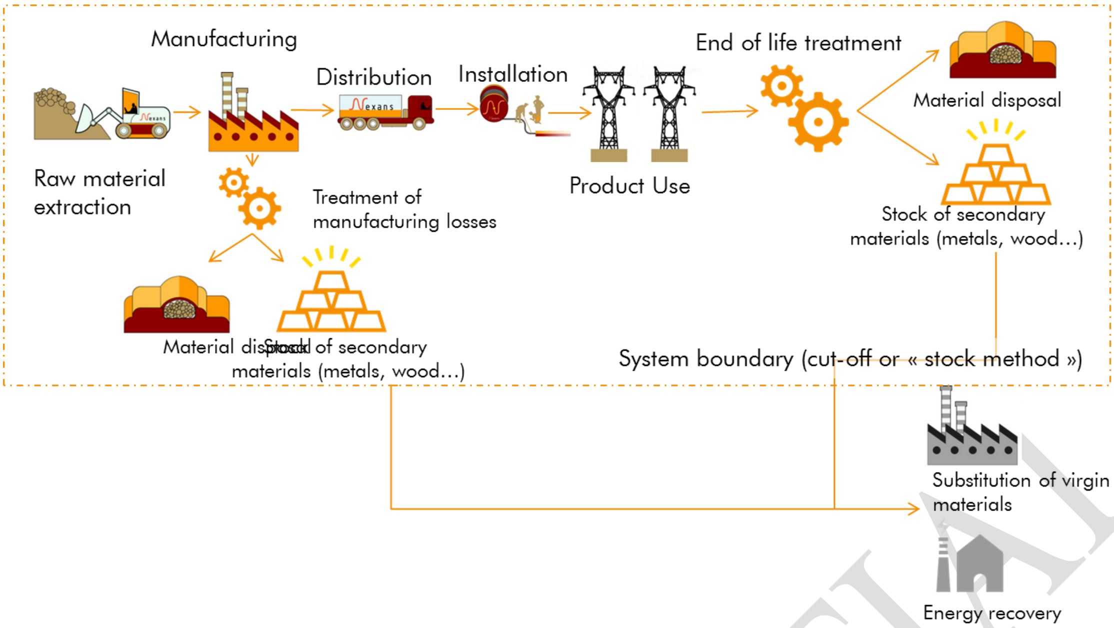


Figure 5: Steps considered in the cut-off approach or "stock method" in the study

III.5 Temporal and geographic boundaries

This study is representative of elbow connectors produced in Erembodegem (Belgium) and sold in Germany at the time the study is conducted for the 200LR connector (2017). For the 158LR, design data was collected in 2014 but the life cycle inventories used for modeling the system were updated to reflect a manufacturing in 2017.
Data and assumptions are intended to reflect current equipments, processes and materials. However, it should be noted that some processes within the system boundaries might take place anywhere.

III.6 Cut-off criteria

All flows that can be identified within the scope of this study must be assessed. If data are not available, the following cut-off rule applies: the sum of the intermediate flows mass that are not collected must be less than or equal to 5% of the mass of the reference flow corresponding to the functional unit.
For the 200LR, no intermediate flows of materials that have been identified during data collection were cut-off and 0.1% of the 158LR mass of elements were not considered in the study.

Also, processes may be excluded if their contributions to the total system's environmental impact are less than 5%. All product components are included when the necessary information is readily available or a reasonable estimate can be made.

The following elements are excluded from the system boundaries due to lack of data. It is not possible to determine the effects of the inclusion of these elements on the results. However, as these elements are similar for the three systems under study, their omission should not likely influence the results:

- Raw material packaging;
- Transport of manufacturing scraps to treatment facility;
- Treatment of scraps from packaging production;

- Transport of the building machine to the installation site;
- Maintenance of the accessories;
- Workers commuting;
- Tertiary activities
- R&D activities.

III.7 Impact assessment method and indicators

Impact assessment classifies and combines the flows of materials, energy and emissions into and out of each system by the type of impact their use or release has on the environment. The environmental impact categories used here are taken from the PEPecopassport® program, known as a reference in the cable industry. The common rules of the PEPecopassport® program define the environmental impact indicators to be disclosed. They are divided into 2 categories:

- Mandatory indicators;
- Optional indicators.

For this LCA study, all of the mandatory indicators have been calculated with the addition of water pollution and air pollution. The calculation methodology for each environmental indicator is detailed in the PEPecopassport® PCR (PEP-PCR-ed3-EN-2015 04 02). The indicators are presented in Table 1 and are described in Appendix 1.

Table 1: Impact indicators list

Initials	Impact indicator	Unit	Characterization method
GWP	Global warming	kg CO_2 eq.	IPCC2007 via CML
ADPe	Abiotic depletion elements	kg Sb eq.	CML - IA Version 4.1, October 2012, Baseline
TPE	Total Primary Energy	MJ	
FW	Net use of freshwater	m3	
ODP	Ozone layer depletion	kg CFC-11 eq.	CML - IA Version 4.1, October 2012, Baseline
A	Acidification potential of soil and water	kg SO2 eq.	Huijbregts
EP	Eutrophication	kg PO43- eq.	CML - IA Version 4.1, October 2012, Baseline
POCP	Photochemical oxidation	kg C_2H_4 eq.	
ADPf	Abiotic depletion fossil	MJ	
WP	Water Pollution	m3	DHUP, detailed with AIMCC reccomendations
AP	Air pollution	m3	

To further investigate the impacts of the accessories, the indicators set is narrowed down to four indicators for the detailed contribution analysis. The following indicators are selected: Global Warming- GWP; Abiotic depletion of minerals resources- ADPe, Total Primary Energy – TPE and Water Depletion- WD
The limited indicator set was selected because they represent the main challenges that a cable manufacturer is likely to face in the upcoming years.

Global Warming and Total Primary energy are aligned with the objective of the European Union climate and energy package. This package is pushing to decrease global warming emissions and improve energy efficiency and renewable energy production. Specific actions have been targeting utilities, Nexans main clients for this type of product.
Abiotic depletion of minerals resources reflects the challenge of the electric and electronic industry confronted to the exhaustion to its primary raw materials sources. Decreasing this environmental impact is also aligned with the objective to move towards a circular economy.
Water depletion is a proxy to reflect the consumption and contamination of water resources. A growing concern from the civil society and industrial stakeholders is focus on water management and water scarcity. Even though cable related products, including cable accessories, do not consume water strictly speaking, it is important to focus on this type of impact because water is used in the processes that make it possible to fulfill the product function.
A focus on ozone depletion potential is also made for the contribution analysis of the product design because it is an environmental impact that is do not directly linked to the energy mix used.

IV. Inventory data

IV.1 Life cycle inventory data

The quality of LCA results are dependent on the quality of the data used in the evaluation. In this study, life cycle inventory (LCI) data collection concerns the materials used and the energy consumed by each process included in the system boundaries.

All LCI data sources for secondary data come from Nexans-2017-06 database. It should be noted that most, though not all, of the data are of European origin and developed to represent European industrial conditions and processes.

In order to keep this report as clear as possible, the full LCIs are presented in the appendixes for each product:

- Appendix 3 for the 158LR
- Appendix 2 for the 200LR

IV.1.1 Manufacturing

The manufacturing phase covers the product life cycle from cradle (raw material extraction) to the gate of Nexans last logistical platform. In this study, the main manufacturing plant is Euromold, located in Erembodegem, Belgium, where they manufacture the connector body.
In Erembodegem, the product is packed in a cardboard box along with the installation elements.
The last logistic platform before supplying the client is the actual manufacturing plant.

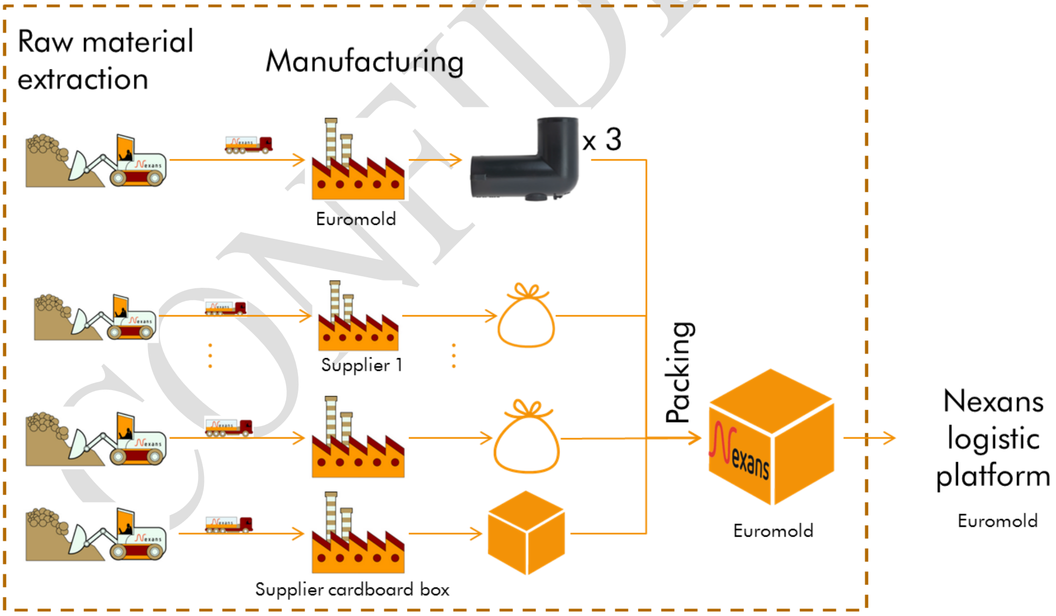


Figure 6: Schematic system boundaries of the manufacturing phase

IV.1.1.1 Product architecture

The main element of a junction is a connector body. Others small elements like conductor contact, pin, hex key, bail restraint and cable reducer are assembled during the installation phase.

The connector body is the heaviest part for both products. The following figure shows a transversal view of the connector architecture, the global overview of the product is similar.

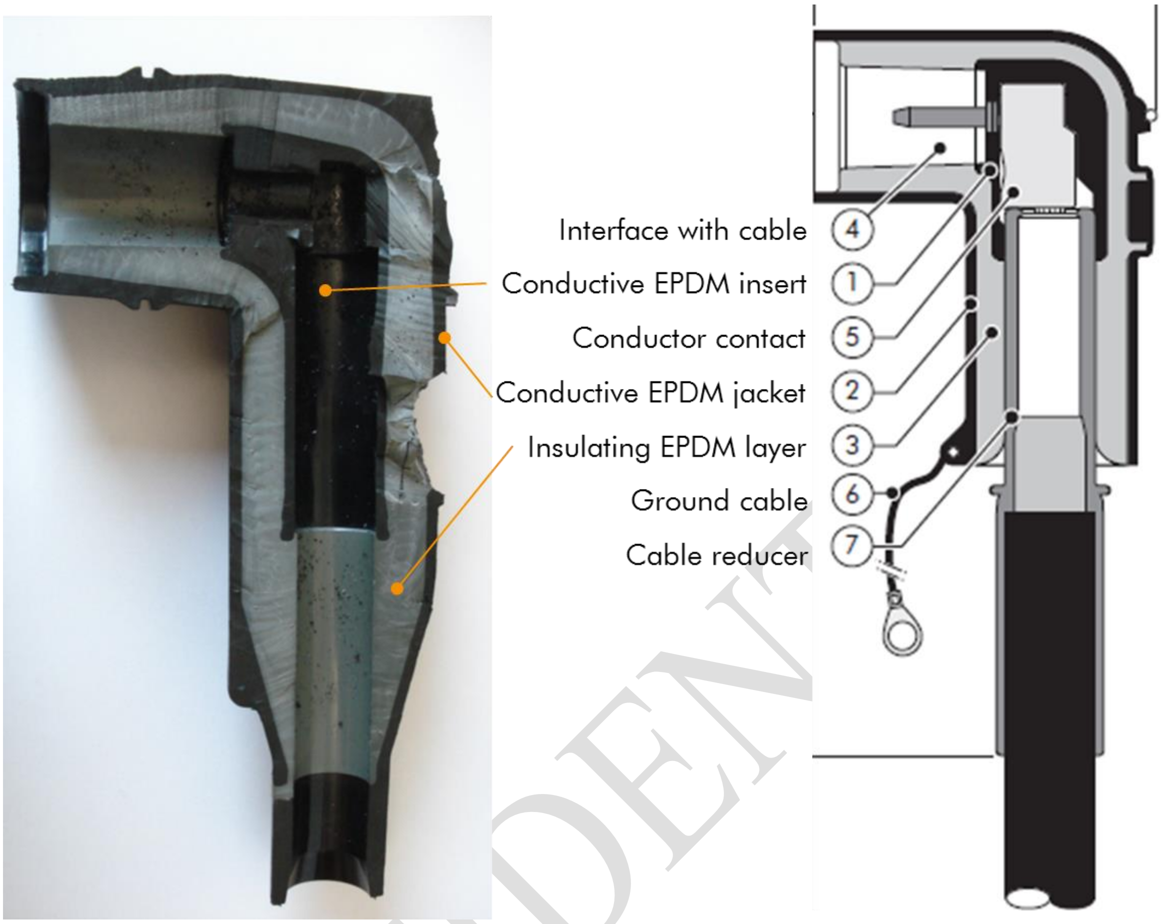


Figure 7: Junctions architecture (Left: elastomeric parts of the 158LR- Right: schematic representation of the 200LR assembled connector)

The redesign process has not affected the elements of the product, nor the materials composition of the product (see appendix 2 and 3 for more details on material composition of the products). The main difference is that the new design allows for a reduction of mass of the product, as the table below shows.

Table 2: Comparison of the two products architecture

		158LR (in kg)	200LR (in kg)
Connector housing x 3	Conductive EPDM insert	0.196	0.144
	Insulating EPDM layer	1.33	0.702
	Conductive EPDM jacket	0.609	0.369
	Ground cable lead	0.108	0.108
Conductor contact (including pin and hex key) x3		0.369	0.14
Other small parts (bail restraint, cable reducer, grease, sealing mastic and adhesive tape) x3		1.269	0.447
Total (3 connectors)		3.88	1.91
Packaging and consumables x1		0.32	0.37
Total for the reference flows (3 connectors in their packaging)		4.2	2.28

IV.1.1.2 Processes

The main activity regarding the Erembodegem plant for this product is related to the injection molding of the connector body. For these processing steps, the environmental impact is based on the energy consumption monitored directly in the plant.
Energy consumption of equipment in Nexans is assessed by:

- Monitoring the power level of the equipment in the different modes (set-up and producing)
- Multiplying it by the production time for one unit of product and by dividing the energy consumption of the set-up time by the number of product units for that is produced after this set-up time.

This evaluation is done for costing purposes and the procedure is standardized in Nexans Industrial Costing Excellence document.
The following devices are used in Erembodegem and their energy consumption was measured, and used in the assessment:

- Injection molding equipment;
- Robots that handle the transfer of product from one step to the other (only for 200LR);
- Deflashing of the finalized product to get the appropriate surface quality.

To the best of our knowledge, these devices do not emit substance into the environment. The legal monitoring of on-site emissions does not show any releases of substances of concerns in the environment, so no additional emissions to air or water has been added to the product manufacturing phase.
The only water that is needed in the manufacturing of the connector is used for cooling and all Nexans plants are equipped with a close-loop reused system for cooling water. , no water consumption was added to the analysis.

For all other steps that happen outside of Nexans plant, secondary life cycle inventory datasets were used. It includes:

- For plastic compounds: Compounding and extrusion;
- For metallic parts:
  - Casting and drawing for the conductors;
  - Turning and plating for others metallic parts. Three type of plating are used depending on the parts of the junction: Tin, Nickel and Zinc.

IV.1.1.3 Raw material supply

There is no internal statistics readily available on transport distances between Nexans and its suppliers. In addition, some suppliers are not direct suppliers of raw materials. They make compounds or masterbaches used afterwards in cable manufacturing. Thus, as no specific data were available, transportation distances and loading for raw material supply are generic data in accordance with the PEPecopassport® program reference document [3]:

- 19000 km by boat (freight, transoceanic ship) + 1000 km by truck (freight, lorry 16-32t, EURO5) for metals;
- 3500 km by truck for other materials (freight, lorry 16-32t, EURO5).

Most of the modules used to model the upstream processes of material production are representative of a production in Europe. The 3500 km hypothesis is used to represent an average distance of supply from a site in Europe to the production plant. Even though the dataset used for metals are average value for Europe, it was decided to add a transportation scenario from overseas. Nexans is sourcing most of its metals from overseas, especially materials for conductors, but has limited information on the exact location of the production sites, so an average scenario has been selected.

IV.1.1.4 Manufacturing scraps

Manufacturing scraps have been added to the study. The scrap is likely smaller for the new version of the product but the same scrap rate was kept for both products: 1% based on Erembodegem plant feedback.
This percentage is based on the plant waste monitoring for this production line over one month. The short sampling period is due to the fact that the 200LR is produced on a new line that has been operated for less than two month at the time of the study
Scraps processing includes: grinding and sorting of product wastes, recycling of metallic fractions and landfill of all other fractions.
The product mass repartition of metals and other type of materials has been used to describe the composition of the manufacturing scrap.

IV.1.2 Distribution

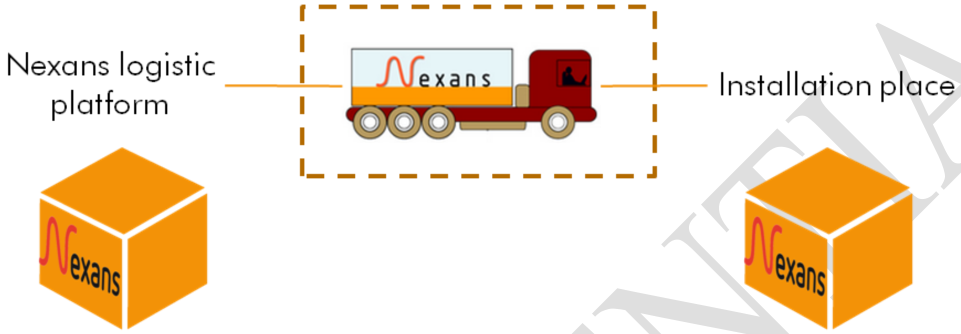


Figure 8: Boundaries of the distribution phase

In this study, it is assumed that the connector is sold to the German market. As a baseline assumption regarding PEPecopassport® hypotheses, transportation distance from manufacturing facility to the use place is set at 1000 km, using heavy truck (27t).

IV.1.3 Installation

Based on the PEPecopassport ® rules and the modularity principle, the installation phase for electric accessories should at least take into consideration end-of-life of:

- Packaging: cardboard box, paper wrappers and plastic bags and ;
- Installation parts: instruction leaflet, gloves, paper wipes, polyethylene net.

Installation is done by Nexans clients so we have limited information on the processes that take place at this stage. So the life cycle inventory of installation is limited to:

- Transportation of packaging and installation parts to waste treatment facility (1000km by 27t truck)
- Recycling of metallic parts of packaging and installation parts. Since there is no metallic parts in the packaging and installation parts, there is no recycling of metals included in the study.
- Landfill of all other parts of packaging and installation parts.

Since the installation process is similar for both products, that will likely have a limited influence on the conclusions of the comparative study. Yet, this limitation should be taken into consideration when analyzing the results of the individual product life cycles.

The following figure provides a simplified view of the installation processes included in the system boundaries.

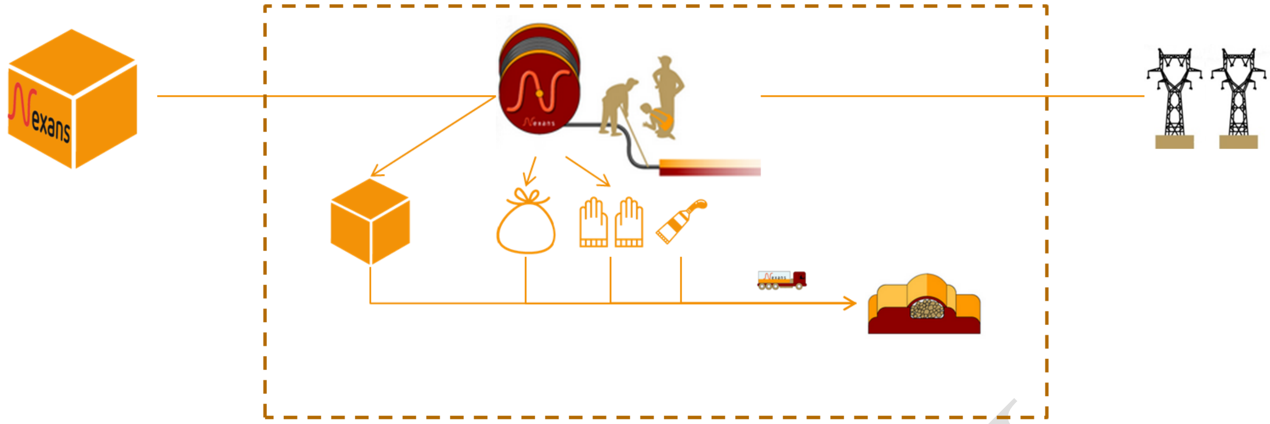


Figure 9: Boundaries of the installation phase

IV.1.4 Use

Use phase often appears to be a key parameter in Nexans LCA studies due to electric losses. Indeed, electric losses can lead to a significant environmental impact over the total life cycle of a product.

Electric losses are mainly dependent on two parameters: the resistance of the connector and the current intensity. Following PEPecopassport® indications regarding power accessories, electric losses are calculated as follow for one connector:

$$E = R * I^2 * \Delta t$$

With:
E: energetic consumption (J);
R: resistance of the connector related to the reference flow (Ω);
I: current intensity (A);
Δt: use time (s).

In order to determine precisely the electric losses due to the connector, it is necessary to:

- Assess the connector electric resistance;
- Determine the loading rate of the connector in term of current intensity.

IV.1.4.1 Connector electric resistance:

In order to determine specifically the electric resistance of the connector, data from electric tests following the standard IEC 61238-1 was used. The IEC 61238 standard, entitled "Compression and mechanical connectors for power cables for rated voltages up to 30 kV", defines the type of assembly and the different heat cycle tests that have to be completed in order to determine the connector resistance.

Thus, measurements of electrical resistance shall be made throughout the different tests as defined in the 61238-1 standard. The tests on the connector consist in several heat cycles. After each series of heat cycles, a resistance factor k is determined. As seen in Figure 10, the k factor is the ratio between the resistance of a known length of a reference conductor and the connector resistance. The test reports provided only give the k factor. Then, the connector resistance has to be calculated.

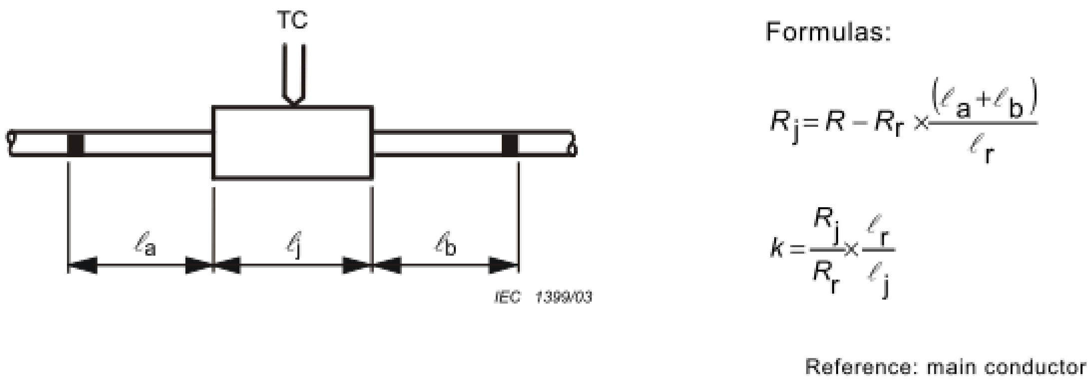


Figure 10: Definition of *k* factor (IEC 61238-1)

Parameters presented in Figure 10 are:

- R_j: connector resistance;
- L_j: connector length;
- L_a and L_b: lengths of the connector assembly associated with the measurement points;
- R_r: reference conductor resistance for the length between measurement points;
- L_r: length of the reference conductor between measurement points.

Two test reports were provided in order to conduct the study on 158LR. Indeed, calculations of *k* factor were first made on the conductor contact and then on the pin contact.
Table 3 and Table 4 below presents the assemblies for the two series of tests and the conductor resistance calculations for the 158LR and the 200LR respectively.

Table 3: Test assemblies and resistance measurement for the 158LR

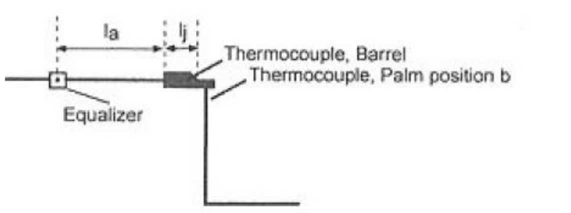
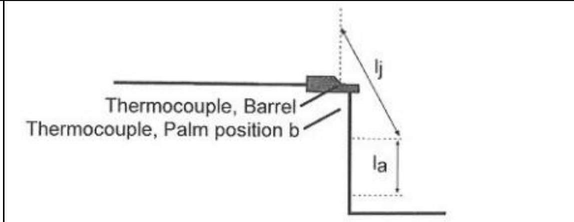
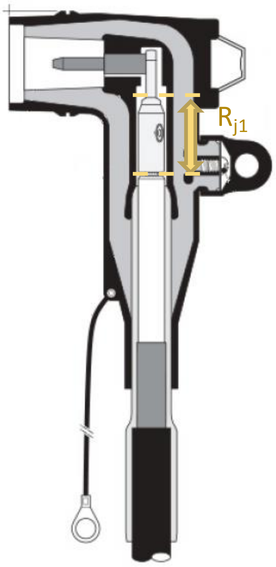
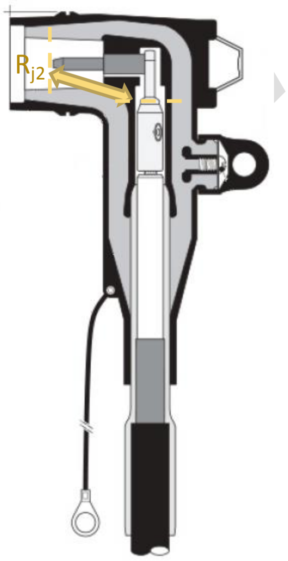
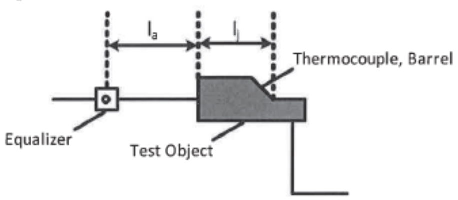
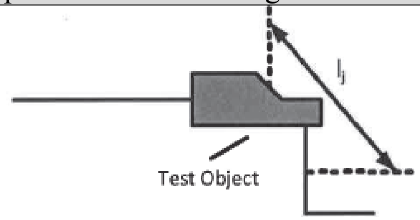
	Test series 1 (report GTR_2008-166-1)	Test series 2 (report GTR_2008-166-2)
Measurement points		
Measured resistance illustration		
k factor	$k = 0.8$	$k = 1.1$
Resistance calculations	$R_{j1} = \frac{0.8 * 0.000148 * 54}{463} = 1.38E^{-5}\ \Omega$	$R_{j2} = \frac{1.1 * 0.000148 * 71.7}{463} = 2.52E^{-5}\ \Omega$
158LR resistance	$R_j(158\ LR) = R_{j1} + R_{j2} = 3.9E^{-5}\ \Omega$	

Table 4: Test assemblies and resistance measurement for the 200 LR

	Test series 1 (report Ohne Zeichnung 2016-84-1)	Test series 2 (report Ohne Zeichnung 2016-84-2)
Measurement points		
k factor	$k = 1$	$k = 0.7$
Resistance calculations	$R_{j1} = \frac{1 * 0.000166 * 22}{520} = 7.04E^{-6}\ \Omega$	$R_{j2} = \frac{0.7 * 0.000048 * 58.5}{150} = 1.31\ E^{-5}\ \Omega$
200 LR resistance	$R_j(200LR) = R_{j1} + R_{j2} = 2.01E^{-5}\ \Omega$	

IV.1.4.2 Calculations of electric losses overall the connector life cycle

In the PEPecopassport® program, the current intensity is set at 1A to cover the wide application range of power accessories and to ensure the comparability between eco-declarations. However, the objective of this study is to assess the environmental impact of the connector under realistic use conditions in order to identify environmental hotspots and decrease the environmental impact of the next generation of connectors. Thus, a 1A current intensity is not appropriate.

Regarding the two types of cables that can be connected thanks to the 158LR connector and the 200LR, two use scenarios were identified in accordance with Erembodegem. The two different cables used with these connectors, along with the appropriate loading rate, are:

- Aluminum core cable, section 95mm², loading rate: **100A**;
- Copper core cable, section 16mm², loading rate: **10A**.

The connector is designed for energy distribution networks (medium voltage applications), which means, according to PEPecopassport® program:

- Connector lifetime is 40 years;
- Connector use rate is 100%.

The connector is designed to last for as long as the cable that it is connected to. Cables for medium voltage network are installed for at least 40 years and no maintenance operations are necessary if no accident occurs. So the lifetime of the connector is considered to me 40 years.

Therefore, the electric losses are calculated with the following parameter:
Δt = 40*365*24= 1.26E09 hours of use.

Finally, Table 5 below presents the calculations of electric losses for the two use scenarios identified in this study and for the two connectors:

Table 5: Use scenarios for 3* units of 158LR and 200 LR connectors

Scenario		Unit	158 LR	200 LR	Improvements
1-	Losses (Al 95²)	kWh	410,62	211,75	48%
2-	Losses (Cu 16²)	kWh	4,11	2,12	48%

* The reference flow for this study represents the quantity of products packaged in one packaging unit. In this specific case, each package of product contains 3 junctions so the power losses have to be calculated for the 3 junctions.

The electricity life cycle inventory used to model the electricity losses are modelled as a consumption of electricity from the German Medium Voltage grid.
N.B.: ERDF data from Sycabel project (report DT-ENV-MEM-035) were used to calculate the average loading rate of medium voltage cables over a year. It appeared the average current intensity is around 100A (with a 95mm² aluminum core cable), which corroborates the connector use phase hypotheses.

IV.1.5 End-of-life

As mentioned in PEPecopassport® program, the end-of-life steps for accessories include:

- The separation between the accessory and the connected cable,
- Transportation, assuming a local transport,
- Landfilling of all materials.

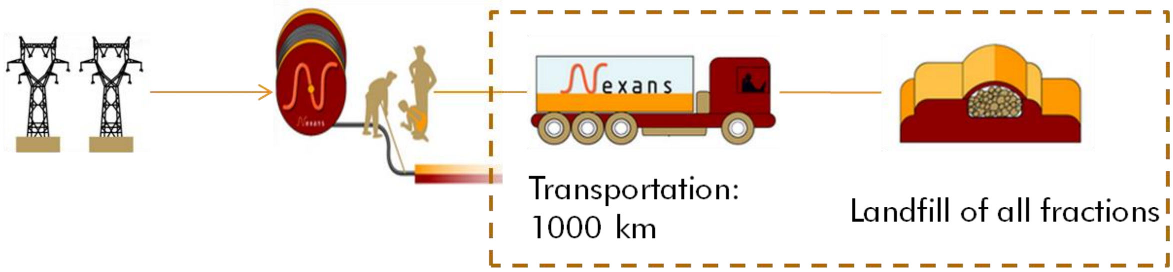


Figure 11: Boundaries of the end-of-life phase

IV.2 Data quality

Reliability of results and conclusions of this study depends on the quality of inventory data. It can be ensured that data were selected with care, regarding both the quantification of flows and the choice of processes. Besides, secondary data quality directly depends on CODDE LCI data quality and should be assessed module by module.
The database selected for this study is Nexans-2017-06 that includes the database CODDE-2016-11, with the addition of life cycle inventory specific to Nexans activities.
A complete data quality analysis is available in Appendix 5: Data quality assessment.

IV.3 Contribution analysis

Contribution analyses are performed to determine the extent to which each process modeled contributes to the overall impact of the systems under study. Indeed, lower quality data may be suitable in the case of a process whose contribution is minimal.

In this study, the contribution analysis is a simple observation of the relative importance of the different life cycle steps to the overall potential impact. A specific contribution analysis is also made on the manufacturing phase.

IV.4 Sensitivity analysis

The parameters, methodological choices and assumptions used when modeling the systems present a certain degree of uncertainty. It is important to evaluate whether the choice of parameters or assumptions significantly influences the study conclusions and to what extent the findings are dependent to certain conditions.
In this study, two sensitivity analyses were performed, one on the hypothesis made for modelling complex chemicals during manufacturing and one on the use phase scenario.
The results are available in paragraph VII.

IV.5 Peer review

As the results of this study are intended to support the development of environmental claims for the general public, a critical review has been commissioned to Julie Orgelet (DDemain), LCA expert independent from the study and external from Nexans. The critical review process ensures that:

- The methodology used by Nexans is:
    - Consistent with the requirements provided in the ISO 14040-44 standard series;
    - Valid from a technical and scientific perspective;

  - Relevant and reasonable regarding the study objective.
- Nexans interpretation reflects the limitations identified and the study objective.
- The detailed report is transparent and consistent.

The critical review process is carried out in several steps:
- Review of the final report;
- Comments and answers from Nexans to points highlighted by the reviewer;
- Review of the updated report and final comments the reviewer.

The reviewer's comments, the answers from Nexans to the underlined points and the external critical review report are presented in the appendix 6 of this report.

IV.6 Model assumptions

As mentioned above, secondary data from Nexans-2017-06 database are used to model the systems under study. The modules used in this study are available in the confidential CONFIDENTIAL Appendix 2: Complete inventory data for 200LR connector life cycle) and CONFIDENTIAL Appendix 3: Complete inventory data for 158LR connector life cycle).

V. Impact assessment

EIME v5.7.0.2 software, developed by CODDE-Bureau Veritas, was used to assist LCA modeling. It links the reference flows with the LCI database and computes the complete LCI of the systems. This software is generally used by French Electric and Electronic products manufacturer and is specifically designed for this type of products. The calculations have been made according to the "PEPecopassport®" method for type III environmental declaration.
The database used for this assessment is Nexans-2017-06. This database includes most of the modules from the CODDE-2016-11 database with the additions of Nexans specific life cycle inventory. The description of the Nexans specific inventory used in this study can be found in CONFIDENTIAL Appendix 4.

VI. Results

The following sections present the study results in the following order:
- Environmental results for the 200 LR connector full life cycle and contribution analysis for its entire lifecycle and its manufacturing phase (use scenario 100A);
- Environmental results for the 158 LR connector full life cycle and contribution analysis through its entire lifecycle (use scenario 100A);
- Comparison of the 158LR life cycle with the 200LR life cycle (use scenario 100A);
- Comparison of the 158LR life cycle with the 200LR life cycle (use scenario 10A);
- Comparison of the 158LR manufacturing with the 200LR manufacturing.

VI.1 Environmental results for the 200 LR connector full life cycle and contribution analysis for its entire lifecycle and its manufacturing phase (use scenario 100A);

As mentioned in part IV, two use scenarios were evaluated in this study to take into account the different uses of this connector. For the life cycle evaluation of individual products, the hypothesis with a current intensity of 100A was chosen. Considering the study hypotheses, the figure below presents the environmental impact results for the connector under study, calculated with a LCA approach.

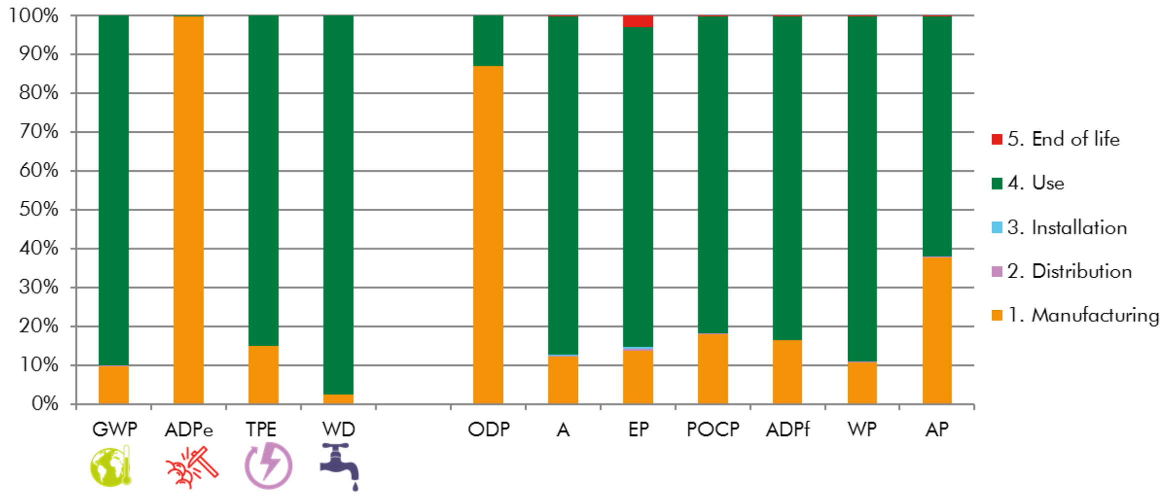


Figure 12: Life Cycle Contribution for the 200LR connector (current intensity in use 100A)

The table below provided the numerical value for the contribution of the different life cycle phases. It is clear that, based on the use scenario chosen, the main contributors to the environmental impact of the 200LR life cycle are:
- **The use phase**, first contributors to nine out of eleven indicators. Its contribution range from 0 % on abiotic depletion of resources –ADPe to 98% on water depletion
- **The manufacturing phase,** first contributor to two indicators out of eleven: Abiotic depletion of resources - ADPe and ozone depletion potential –ODP. Its smallest contribution is on water depletion – WD with 2% and its highest is on abiotic depletion of resources – ADPe with 100%.

Table 6: Contribution analysis for the 200LR life cycle (current intensity in use 100A)

	Manufacturing	Distribution	Installation	Use	End of life	Total (for 1 packaging unit with 3 connectors)
GWP (kg eq CO_2)	10%	0%	0%	90%	0%	1,42E+02
ADPe (kg eq Sb)	100%	0%	0%	0%	0%	4,22E-03
TPE (MJ eq)	15%	0%	0%	85%	0%	2,46E+03
WD (m^3 eq)	2%	0%	0%	98%	0%	3,12E+02
ODP (kg eq CFC-11)	87%	0%	0%	13%	0%	4,60E-06
A (kg eq SO_2)	12%	0%	0%	87%	0%	2,31E-01
EP (kg eq PO_4^{2-})	14%	0%	1%	82%	3%	2,70E-02
POCP (kg eq C_2H_4)	18%	0%	0%	81%	0%	1,64E-02
ADPf (MJ eq)	16%	0%	0%	83%	0%	1,53E+03
WP (m^3eq)	11%	0%	0%	89%	0%	7,54E+03
AP (m^3eq)	38%	0%	0%	62%	0%	5,79E+03

The use phase environmental impact can be traced back to the energy losses in use.
In order to identify the contributors to the manufacturing phase of the 200LR, the following graphics focuses on the contributors, by connector elements, to the manufacturing environmental impacts.
It can be seen that the elements of the connector body (insulation, insert and jacket) are big contributors to the environmental impacts of manufacturing. When their environmental impact is combined, it ranges from 72% contribution on water depletion to 32% on acidification.

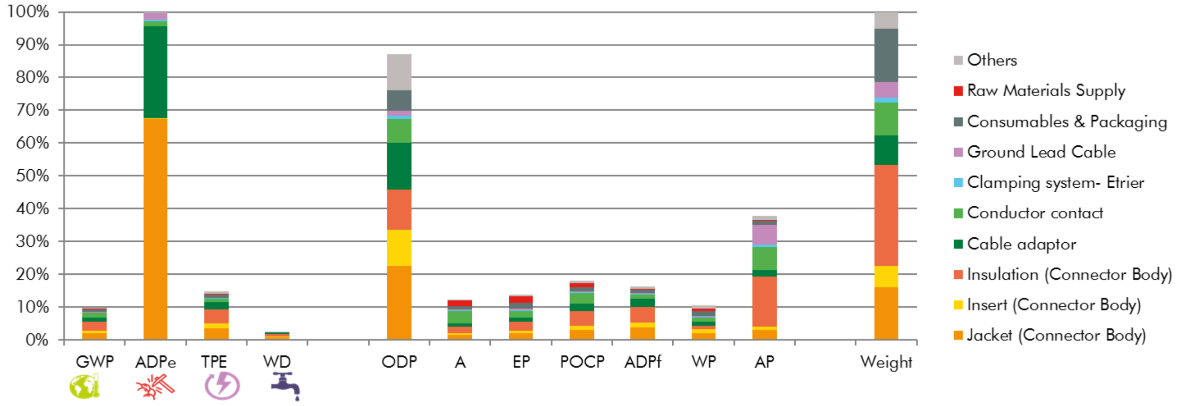


Figure 13: Contribution to the environmental impacts of the manufacturing phase considering the life cycle impact as a reference

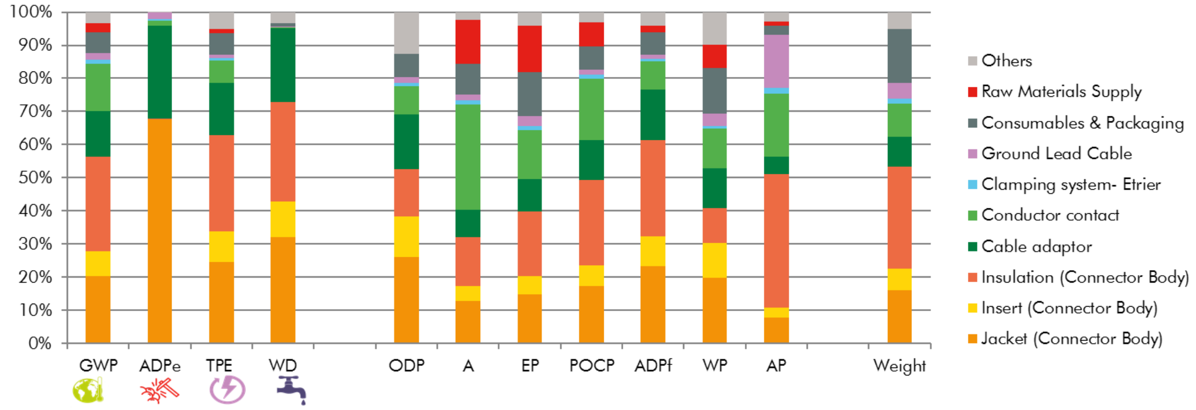


Figure 14: Contribution to the environmental impacts of the manufacturing phase considering the manufacturing impact as reference

To get a clearer contribution profile, the following paragraphs are detailing the contributors to global warming potential, abiotic depletion of resources, total use of primary energy and water depletion.

VI.1.1 Global warming

The following figure shows that, on global warming potential, the parts that are made out of elastomeric compounds (connector body and cable adaptor) are the first contributors. The other component that has an important contribution is the conductor contact.

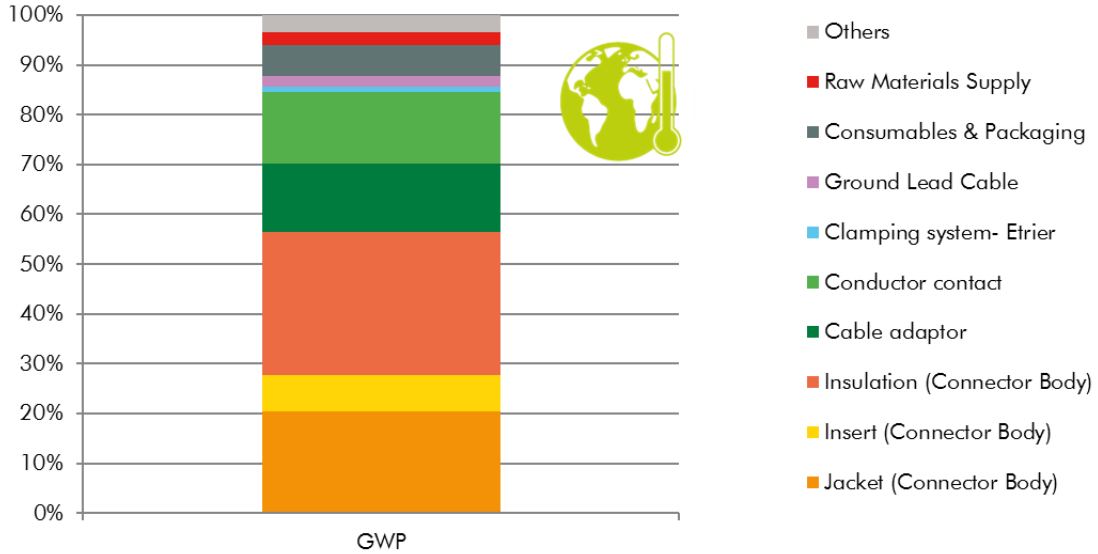


Figure 15: Global warming potential contributors for the manufacturing of 200LR

The following table shows the first contributors to global warming in parallel to their weight contribution to the product. It can be seen that the elastomeric parts have a contributions that is slightly different to their weight contribution, but in the same range:

- Insulation, with 29% of the impact while representing 26% of the product mass,
- Jacket, with 21% of the impact and 24% of the product weight
- Cable adaptor with 14% of the impact and 13% of the product weight.

For these three elements, the impact on global warming can be traced back to the processing of the parts in the Erembodegem plant and to the EPDM resin.

It is of interest to notice that the conductor contact, while contributing to only 8% of the product weight, contributes to 14% of the global warming potential. This is traced back to the aluminum alloy used for the conductor contact.

Table 7: Contribution to the global warming potential for 200LR

	GWP	Weight
Jacket (Connector Body)	20%	16%
Insert (Connector Body)	7%	6%
Insulation (Connector Body)	29%	31%
Cable adaptor	14%	9%
Conductor contact	14%	10%
Clamping system	1%	2%
Ground Lead Cable	2%	5%
Consumables & Packaging	6%	16%
Raw Materials Supply	3%	0%
Others	3%	5%

VI.1.2 Abiotic depletion of resources

The following figure shows that, on abiotic depletion of resources, the parts that are using TDEC are the first contributors (jacket and cable adaptor) and the parts that are partially made out of metals are the first contributors: conductor contact, ground lead cable and clamping system.
The high contribution of parts that includes TDEC – Tellurium diethyldithiocarbamate- to the impact is traced back to the tellurium flow that has been added to represent the use of this rare metal in the molecule used as a vulcanization agent in the rubber compound.

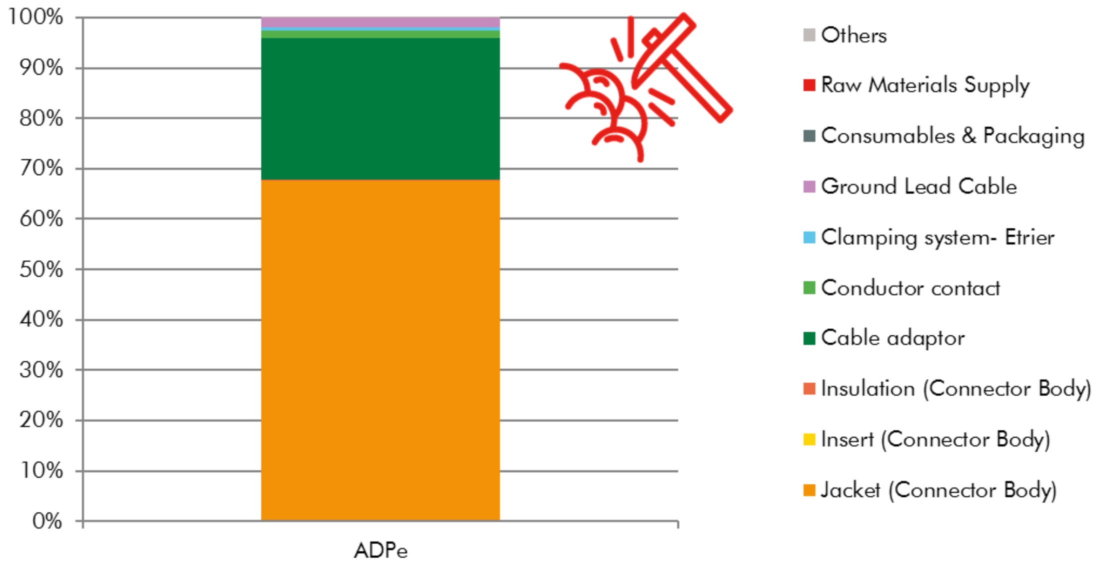


Figure 16: Abiotic depletion contributors for the manufacturing of 200LR

The first contributor to this impact, while only representing 24% of the product weight, is the jacket, with 68% of the impact. This is due to the use of TDEC in the rubber compound. The second contributor is the cable adaptor, also due to the use of TDEC in the rubber compound.

Table 8: Contribution to the abiotic depletion of resources for 200LR

	ADPe	Weight
Jacket (Connector Body)	68%	16%
Insert (Connector Body)	0%	6%
Insulation (Connector Body)	0%	31%
Cable adaptor	28%	9%
Conductor contact	2%	10%
Clamping system	1%	2%
Ground Lead Cable	2%	5%
Consumables & Packaging	0%	16%
Raw Materials Supply	0%	0%
Others	0%	5%

VI.1.3 Total use of primary energy

The following figure shows that on total use of energy the heaviest parts are the one that contribute the most to the environmental impact: jacket, insulation and cable adaptor.

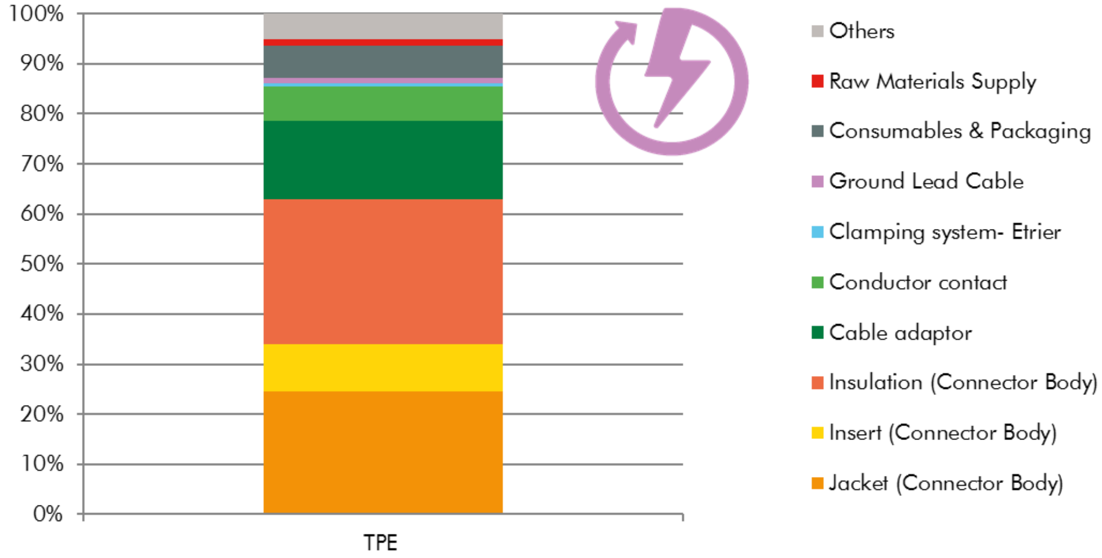


Figure 17: Total use of primary energy contributors for the manufacturing of 200LR

The following table gives confirmation that the heaviest parts are the one that contributes the most to this environmental impact. This can be traced back directly to the electricity consumption of the machinery used to process the different parts of the product. This consumption is proportional to the quantity of material processed.

Table 9: Contribution to the total use of primary energy 200LR

	TPE	Weight
Jacket (Connector Body)	25%	16%
Insert (Connector Body)	9%	6%
Insulation (Connector Body)	29%	31%
Cable adaptor	16%	9%
Conductor contact	7%	10%
Clamping system	1%	2%
Ground Lead Cable	1%	5%
Consumables & Packaging	7%	16%
Raw Materials Supply	1%	0%
Others	5%	5%

VI.1.4 Net fresh water use

The following figure shows that on net fresh water use only the elastomeric parts have a significant contribution: connector body elements and cable adaptor.

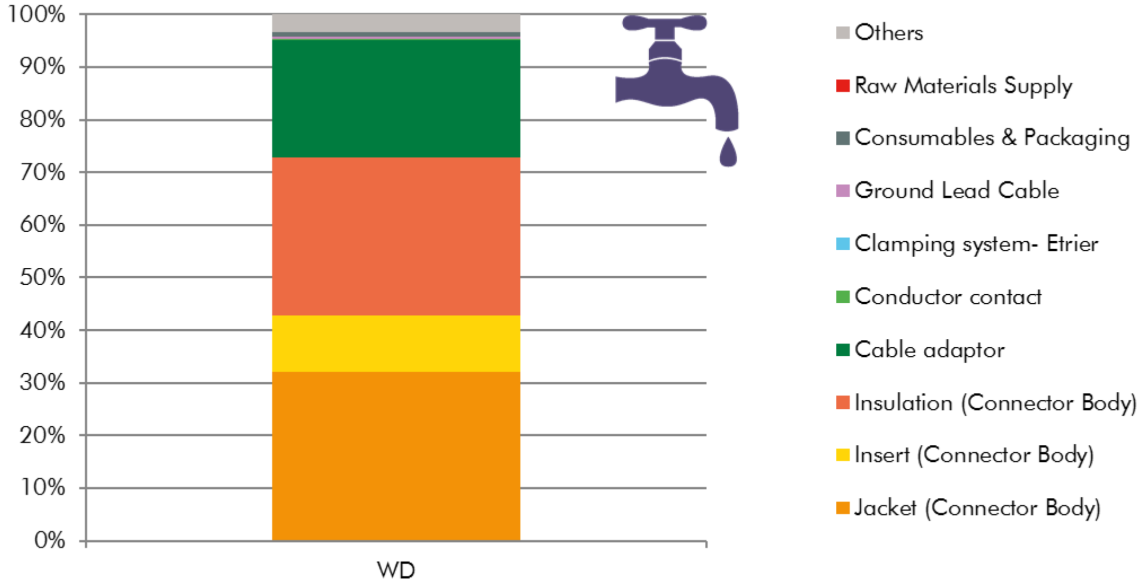


Figure 18: Net fresh water use contributors for the manufacturing of 200LR

The following table show that the elastomeric parts are the one that contributes the most to this impact. It is directly linked to the electricity consumption model used to represent Erembodegem plant activities (Medium voltage electricity from the Belgium grid).

Table 10: Contribution to the net fresh water use for 200LR

	WD	Weight
Jacket (Connector Body)	32%	16%
Insert (Connector Body)	11%	6%
Insulation (Connector Body)	30%	31%
Cable adaptor	22%	9%
Conductor contact	0%	10%
Clamping system	0%	2%
Ground Lead Cable	0%	5%
Consumables & Packaging	1%	16%
Raw Materials Supply	0%	0%
Others	3%	5%

VI.1.5 Ozone depletion potential

The following figure shows that on ozone depletion potential two main parts have an important contribution: the jacket and the cable adaptor.

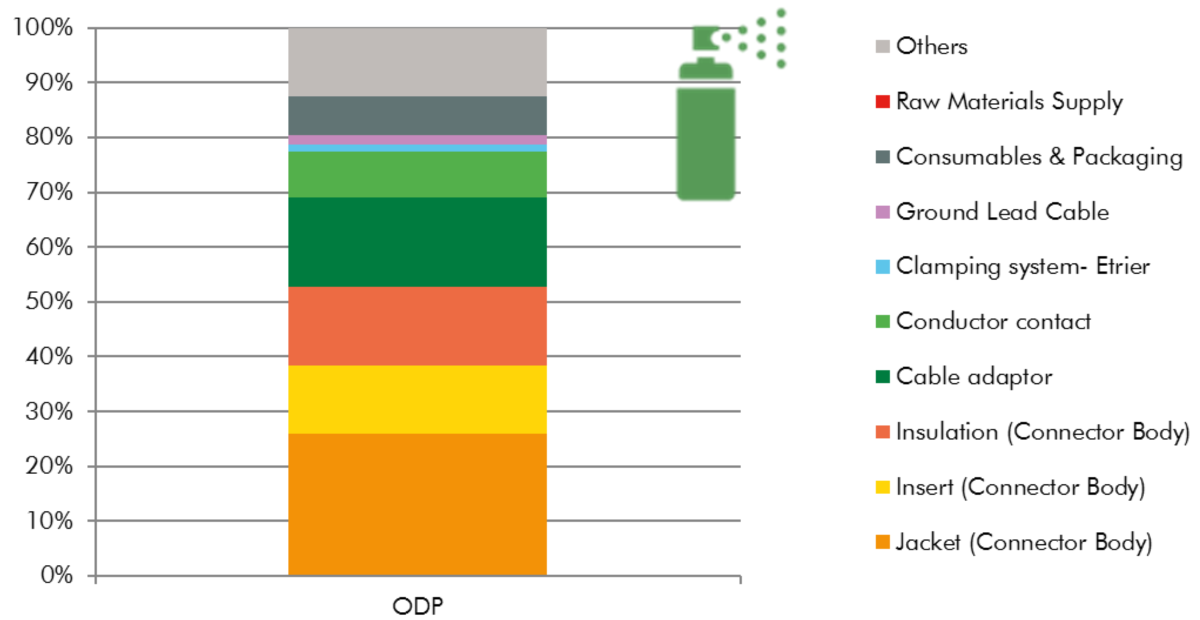


Figure 19: Ozone depletion potential contributors for the manufacturing of 200LR

The following table show that the jacket has an important contribution compared to its weight contribution. This is traced back to the use of carbon black.
It also shows that the cable adaptor has a significant contribution when compared to its weight contribution. This is traced back to carbon black use and energy consumption.
The contribution of the others part is linked to the mastic used, and especially to the use of nitrile rubber in the mastic.

Table 11: Contribution to the ozone depletion potential for 200LR

	ODP	Weight
Jacket (Connector Body)	26%	16%
Insert (Connector Body)	12%	6%
Insulation (Connector Body)	14%	31%
Cable adaptor	16%	9%
Conductor contact	8%	10%
Clamping system	1%	2%
Ground Lead Cable	2%	5%
Consumables & Packaging	7%	16%
Raw Materials Supply	0%	0%
Others	13%	5%

VI.2 Environmental results for the 158 LR connector full life cycle and contribution analysis through its entire lifecycle (use scenario 100A);

The 158LR already has a dedicated LCA report in the DT-ENV-MEM-068 so this contribution analysis only aims at representing the contributors to the product environmental life cycle using the same product life cycle architecture and an updated life cycle inventory database, Nexans-2017-06. For detailed information on this product, the report DT-ENV-MEM-068 is available.

As mentioned in part IV, two use scenarios were evaluated in this study to consider the different uses of this connector. For the life cycle evaluation of individual products, the hypothesis with a current intensity of 100A was chosen. Considering the study hypotheses, the figure below presents the environmental impact results for the connector under study, calculated with a LCA approach. It can be seen that the contribution profile is similar to the 200LR.

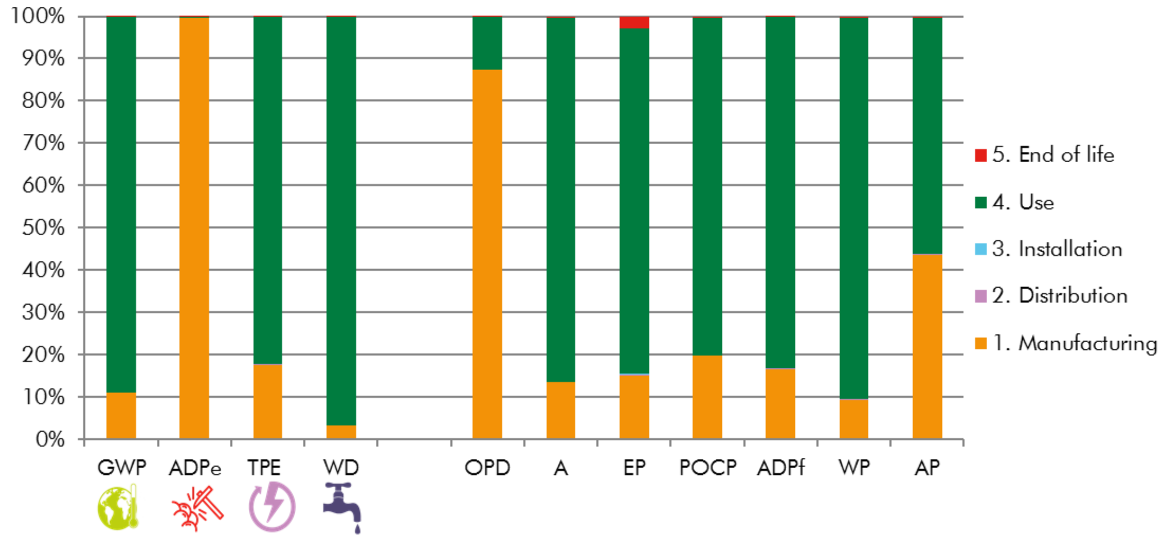


Figure 20: Life Cycle Contribution for the 158LR connector (current intensity in use 100A)

The table below provided the numerical value for the contribution of the different life cycle phases. It is clear that based on the use scenario chosen, the main contributors to the environmental impact of the 158LR life cycle are:

- The use phase, first contributors to nine out of eleven indicators. Its contribution range from 0 % on abiotic depletion of resources –ADPe to 97% on water depletion
- The manufacturing phase, first contributor to two indicators out of eleven: Abiotic depletion of resources - ADPe and ozone depletion potential –ODP. Its smallest contribution is on water depletion – WD with 3% and its highest is on abiotic depletion of resources – ADPe with 100%.

Table 12: Contribution analysis for the 158LR life cycle (current intensity in use 100A)

	Manufacturing	Distribution	Installation	Use	End of life	Total (for 1 packaging unit with 3 connectors)
GWP (kg eq CO_2)	11%	0%	0%	89%	0%	2,78E+02
ADPe (kg eq Sb)	100%	0%	0%	0%	0%	7,55E-03
TPE (MJ eq)	18%	0%	0%	82%	0%	4,94E+03
WD (m^3 eq)	3%	0%	0%	97%	0%	6,14E+02
ODP (kg eq CFC-11)	87%	0%	0%	13%	0%	9,13E-06
A (kg eq SO_2)	13%	0%	0%	86%	0%	4,55E-01
EP (kg eq PO_4^{2-})	15%	0%	0%	82%	3%	5,28E-02
POCP (kg eq C_2H_4)	20%	0%	0%	80%	0%	3,24E-02
ADPf (MJ eq)	17%	0%	0%	83%	0%	2,98E+03
WP (m^3eq)	9%	0%	0%	90%	0%	1,44E+04
AP (m^3eq)	44%	0%	0%	56%	0%	1,24E+04

The use phase environmental impact can be traced back to the energy losses in use.
In order to identify the contributors to the manufacturing phase of the 158LR, the following graphics focuses on the contributors, by connector elements, to the manufacturing environmental impacts.
It can be seen that the elements of the connector body (insulation, insert and jacket) are big contributors to the environmental impacts of manufacturing. When their environmental impact is combined, it ranges from 81% contribution on abiotic depletion of resources to 35% on acidification. One notable difference in the environmental profile of the 158LR is the contribution of the etrier made out of stainless steel. It should be noted that this part is 10 times lighter in the new product designed.

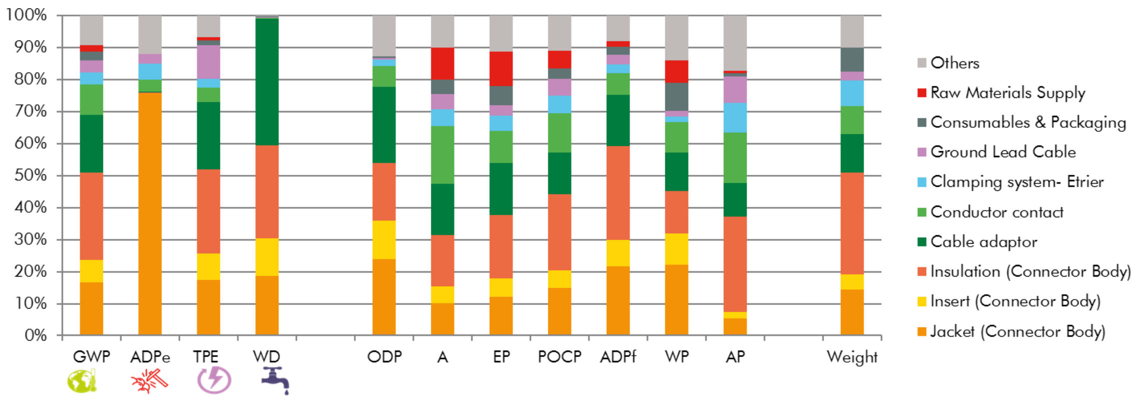


Figure 21: Contribution to the environmental impacts of the manufacturing phase

VI.3 Comparison of the 158LR life cycle with the 200LR life cycle (use scenario 100A)

Based on their compliance to the functional unit defined in III.2 and the use scenario with a current at 100 A, the comparison of the 158LR and 200LR is made.
The results of this comparison show that the 200LR **significantly improves the life cycle performance on all environmental indicators**, as illustrated by the following figure. The reduction varies from 53% less impact on air pollution-AP, to 44% on abiotic depletion of resources ADPe.
On all the other indicators, the reduction is between 50% and 48%.

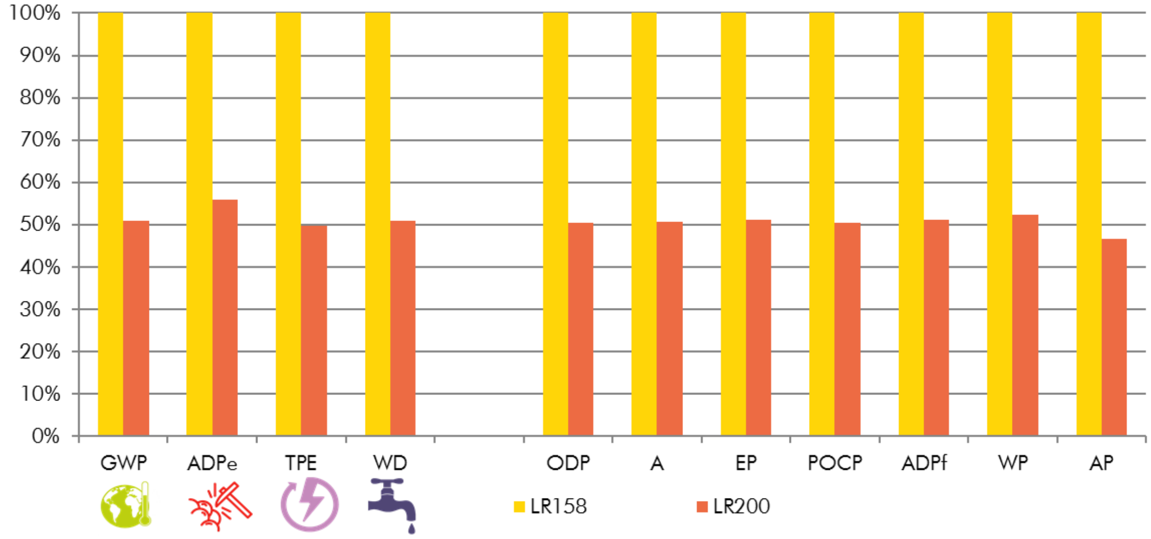


Figure 22: Comparison of the life cycles of 158LR with 200LR

Table 13: Comparison of the life cycles of 158LR with 200LR

	LR158	LR200	Improvements (for 1 packaging unit with 3 connectors)
GWP	100%	51%	- 49%
ADPe	100%	56%	- 44%
TPE	100%	50%	- 50%
WD	100%	51%	- 49%
ODP	100%	50%	- 50%
A	100%	51%	- 49%
EP	100%	51%	- 49%
POCP	100%	51%	- 49%
ADPf	100%	51%	- 49%
WP	100%	52%	- 48%
AP	100%	47%	- 53%

The next graphics are focusing on the four key indicators: global warming potential, abiotic depletion of elements, total primary energy use and net fresh water use.
The following figure shows that both the contributions of the use phase and the manufacturing phase have been reduced.

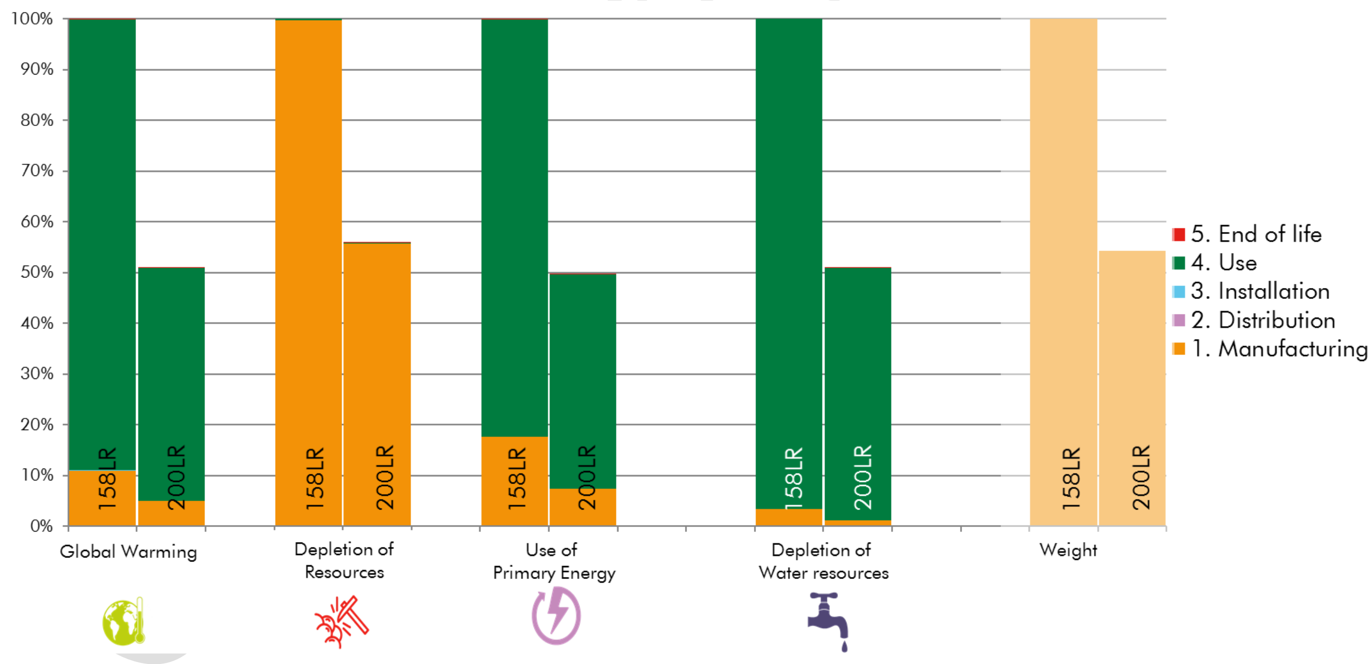


Figure 23: Comparison of the 158LR and 200LR life cycle contributions on the limited indicators set

Since the conductor length has been reduced in the 200LR, the power losses in use are reduced by 48%. So, for a scenario with a high intensity passing through the connector, like the one currently considered, the reduction of losses significantly improves the environmental performance. It should be noted that the impact of manufacturing is also reduced. A detailed comparison for this LCA phase is presented in VI.5.

The following paragraph is considering a use scenario with a smaller intensity passing through the connector (10A).

VI.4 Comparison of the 158LR life cycle with the 200LR life cycle (use scenario 10A)

Both connectors can be used to connect aluminum cables or copper cables. In the previous paragraph, the connexion was made between aluminum conductor cables with a cross-section of $95mm^2$. In this paragraph, the focus is made on the connexion of copper conductor cables.

The conclusion made in the previous paragraph are still valid: the life cycle environmental impacts of the 200LR are **significantly lower** than the one of the 158LR. The biggest reduction of impact is found on water depletion (61%) and the smallest on abiotic depletion of resources (40%).

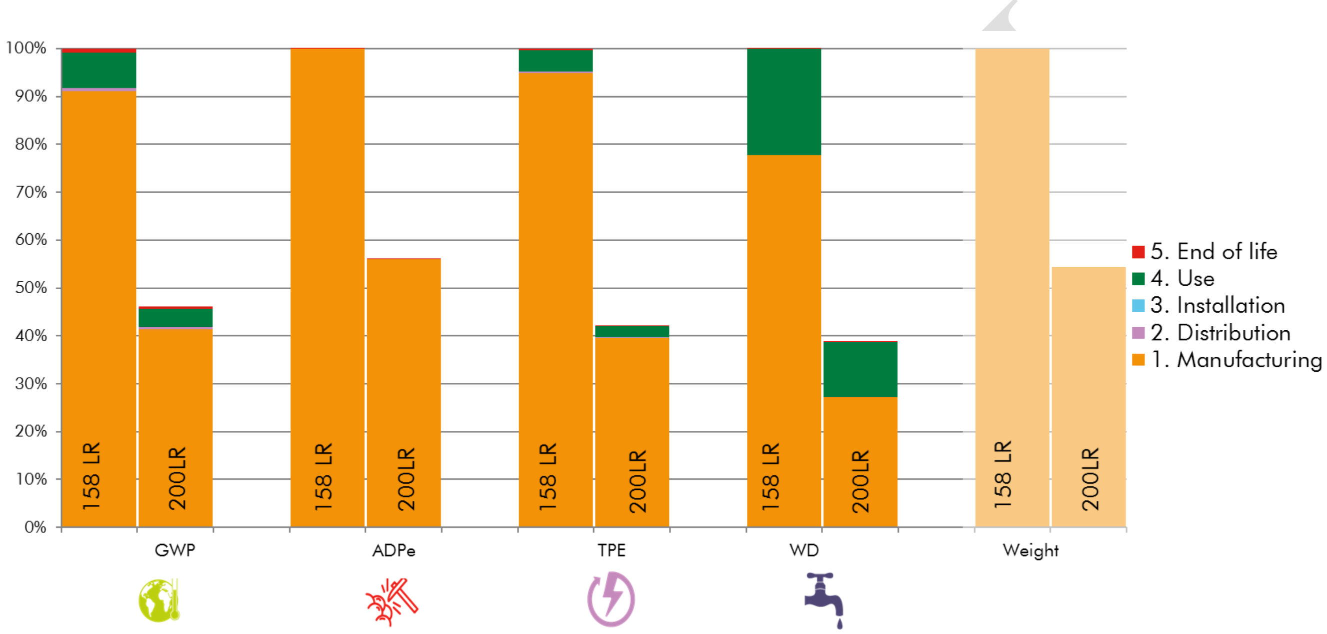


Figure 24: Comparison of 158LR and 200LR life cycles with a use scenario at 10A

It should be noted that in this configuration of connector use, the first contributor to the environmental impacts of the product life is the manufacturing phase, the use phase has a smaller contribution in this case. This conclusion is aligned with the conclusion of the report DT-ENV-MEM-038.

Table 14: Comparison of the life cycles of 158LR with 200LR

	LR158	LR200	Improvements (for 1 packaging unit with 3 connectors)
GWP	100%	46%	- 54%
ADPe	100%	56%	-44%
TPE	100%	42%	-58%
WD	100%	39%	-61%
ODP	100%	50%	-50%
A	100%	47%	-53%
EP	100%	49%	-51%
POCP	100%	47%	-53%
ADPf	100%	51%	-49%
WP	100%	59%	-41%
AP	100%	41%	-59%

It has been noted that the global environmental performance of the 200LR is significantly better than the 158LR. The improvement in use phase is traced back to a smaller length of conductor.

To further investigate the source of this improved environmental performance for the 200LR, the following paragraph provides a comparison of the contributors to the manufacturing phase for the connector.

VI.5 Comparison of the 158LR manufacturing with the 200LR manufacturing

For the manufacturing phase, the following graphic presents the difference in contribution for the two products.
First, it should be noted that **the reduction of impacts** of the manufacturing phase thanks to the new design on the four key indicators is **higher than the weight reduction**. The 200LR is 46% lighter than the 158LR and the smallest reduction of impact achieved on manufacturing is 41%, on water pollution -WP and the highest reduction is on Water depletion -WD with a decrease of 65%.

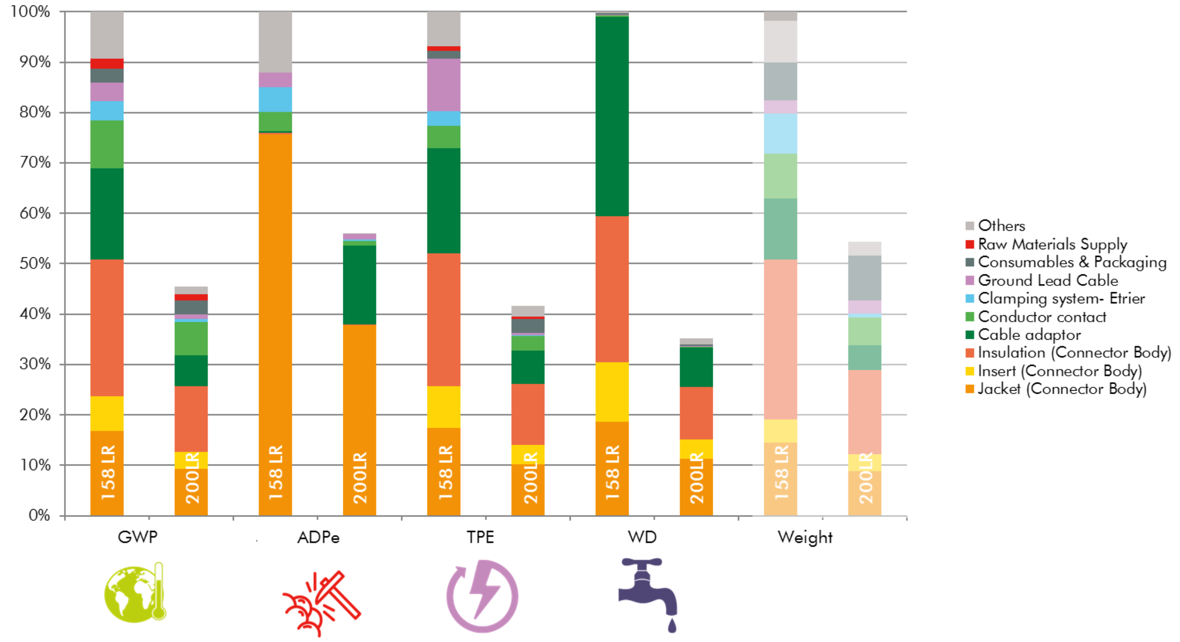


Figure 25: Comparison of the contributors to the environmental impact of the manufacturing phase for the 158LR and 200LR connectors

Table 15: Comparison of the life cycles of 158LR with 200LR

	LR158	200 LR	Improvements (for 1 packaging unit with 3 connectors)
GWP	100%	45%	- 55%
ADPe	100%	56%	- 44%
TPE	100%	42%	- 58%
WD	100%	35%	- 65%
ODP	100%	50%	- 50%
A	100%	46%	- 54%
EP	100%	47%	- 53%
POCP	100%	46%	- 54%
ADPf	100%	50%	- 50%
WP	100%	59%	- 41%
AP	100%	40%	- 60%

When focusing on climate change, it can be seen in the following graphic that the redesign effort to reduce both the quantity of materials and to invest in more efficient machinery, thus reducing energy consumption, is reducing significantly the impact of the manufacturing phase.

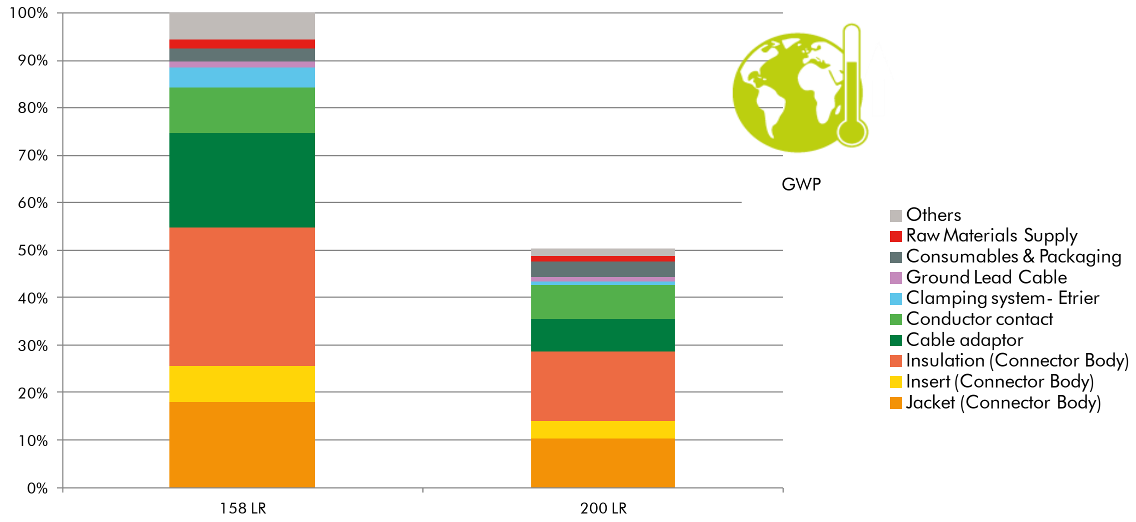


Figure 26: Comparison of the contributors to the global warming potential of the manufacturing of 158 LR and 200LR

The same conclusions can be reached for total use of primary energy and water depletion. As mentioned in VI.1.3 and VI.1.4 respectively, the reduction in electricity consumption in Erembodegem plant thanks to new machinery and better process-ability of the connector is reducing significantly the impact.

Looking now at the indicator abiotic depletion of resources, the reduction of impact of the 200LR can be traced back to different elements: the reduction of the quantity of rubber compound that uses TDEC as an additive and the reduction of copper conductor length and the reduction of the stainless steel used in the clamping system.
The new design for the clamping system, especially the bail/etrier part, has enabled significant weight reduction. The bail design for the 200LR is being patented by the Erembodegem plant.

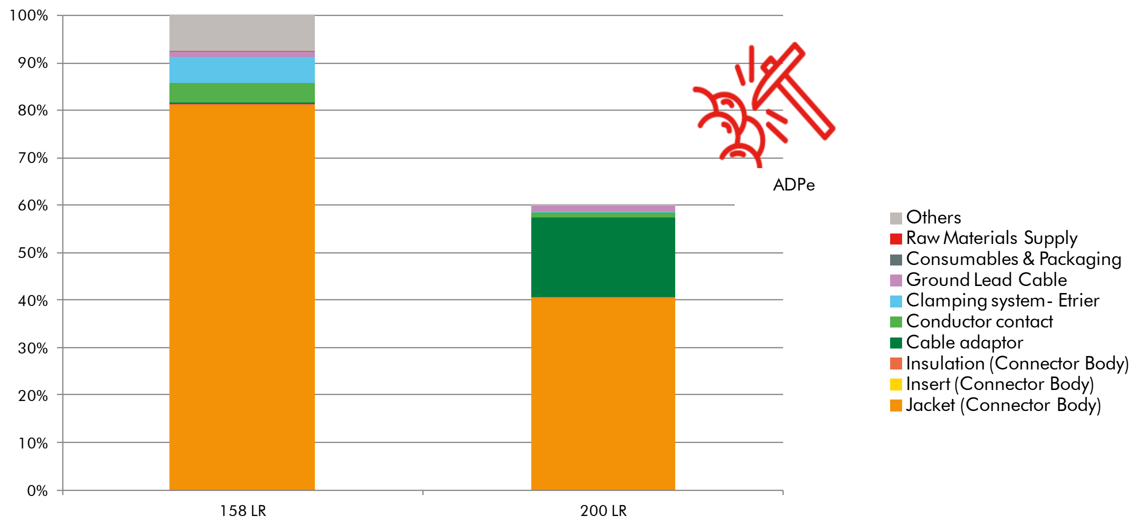


Figure 27: Comparison of the contributors to the abiotic depletion of resources potential of the manufacturing of 158 LR and 200LR

To summarize this section, the significant improvements of the manufacturing phase environmental impacts can be traced back to the following modifications of the design of the conductor:

- A reduction of the global weight of the product, and especially:
    - The reduction of the weight of elastomeric compound use;
    - The reduction of the length of conductor in the connector;
- The reduction of the stainless steel used in the clamping system.
- An investment in new equipment for manufacturing and
- Improvements of the process-ability thanks to the product shape.

VII. Sensitivity analysis

Sensitivity analysis is aimed at identifying how the modeling choice done affects the general and specific conclusions of the study. In the context of this report, the main objective of the sensitivity analyses below is to identify if the modeling choices are affecting the conclusion that the 200 LR product life cycle is an improvement on the 158LR, from an environmental assessment point of view.

Two main aspects are considered sensitive in this study: the modelling choices made for the complex chemicals used for the manufacturing of the rubber parts of the product and the energy mix used to model the power losses in use.

VII.1 Manufacturing: sensitivity of the model to the modeling of complex chemicals

To sustain the harsh conditions of the electric network, the rubbers used in the junction have technical properties delivered by the addition of different chemicals to the formula.
Some of these chemicals do not have readily available life cycle inventory in commercial and public generic database and so the life cycle inventory chosen is a proxy to model their impact. Most notably sulfur based organic compounds were modeled as sulfur from crude oil because they are obtained from this process.
The previous LCA report on the junction 158LR used the Finechem tool to assess if there was a difference in the carbon footprint of the manufacturing phase. This tool provides a carbon footprint based on the molecular structure of the product. The conclusion was that, using Finechem tool, the results of the study were not affected by the change.

In this report, the sensitivity analysis is based on the use of generic life cycle inventory for chemicals instead of specific ones:

- All the organic chemicals where a proxy was used were modeled using CODDE-0348 (Unspecified organic chemicals; average production; production mix, at plant; RER)
- All the inorganic chemicals where a proxy was used were modeled using CODDE-0347 (Unspecified inorganic chemicals; average production; production mix, at plant; RER).

For the detail on the substitution of modules, a colour code was added in Appendix 2 and Appendix 3 to identify which materials where modelled using unspecified organic chemicals and which ones where substituted by unspecified inorganic chemicals.

When comparing the impact of the manufacturing of the two products, using the 158LR initial model as the basis, the conclusion of the study is not affected: the manufacturing phase of the 200LR has less impact on all indicators.
The environmental impacts increase for both products on: acidification-A, eutrophication-E, Water pollution-WP.
The environmental impact decrease for both products on air pollution – AP.

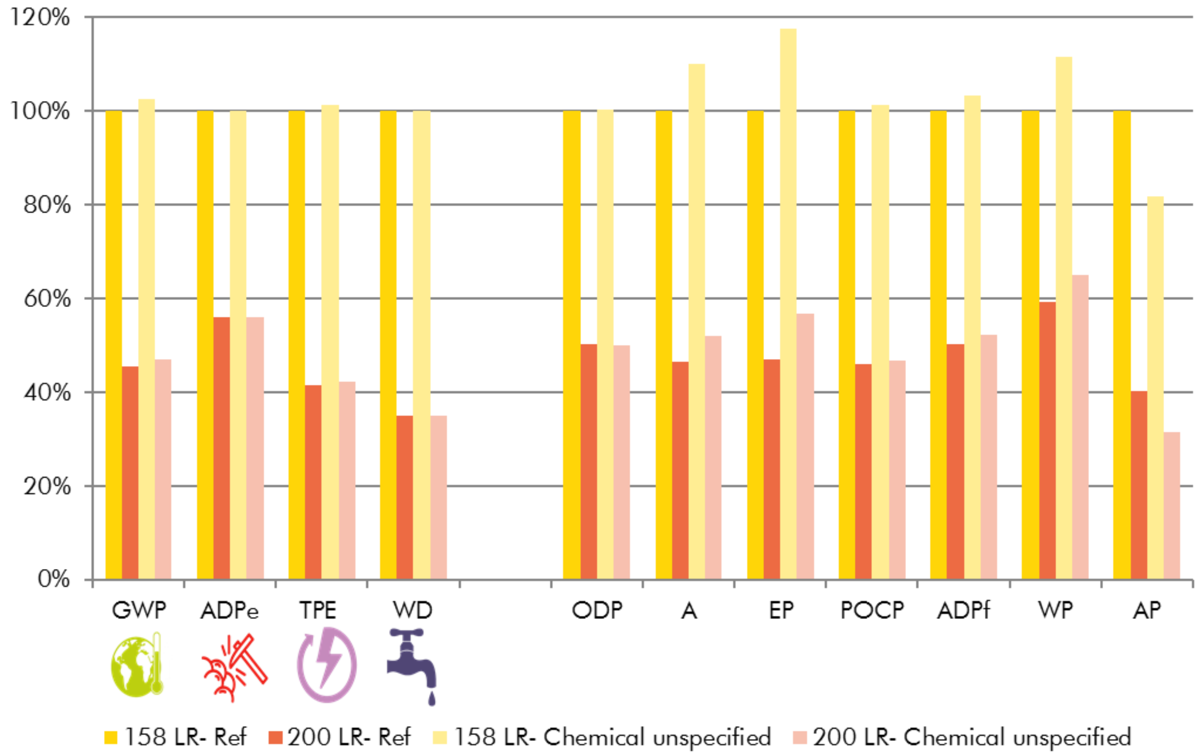


Figure 28: Environmental impacts of the manufacturing phase using different proxy for chemicals modelling

The table below shows the results of the comparison of the 200LR with the 158LR using the two modelling approach, the second column shows the comparison for the initial scenario and the third on shows the results of the comparison of 200LR using chemical unspecified and 158LR using chemical unspecified as well.
If the products are compared using the same hypothesis for chemical modelling the difference of impact is of similar scale.

Table 16: Comparison of the manufacturing phase relative environmental improvements in the initial scenario and in the sensitivity chemical unspecified

	Initial Scenario	Chemical unspecified
GWP	45%	46%
ADPe	56%	56%
TPE	42%	42%
WD	35%	35%
ODP	50%	50%
A	46%	47%
EP	47%	48%
POCP	46%	46%
ADPf	50%	51%
WP	59%	58%
AP	40%	38%

It can be concluded that as long as the modelling rules for complex chemicals are applied on both products consistently, the conclusion remains intact: the 200LR manufacturing phase is lower than the one of the 158LR, with improvements ranging from 40% to 65%.

VII.1.1 Focus on TDEC

One of the chemicals that has been modeled using proxy is the TDEC, Tellurium diethyldithiocarbamate (molecular structure below). In this specific case, in the initial scenario, it has been modeled has an unspecified organic substance, with the addition of an elementary flow of Tellurium.

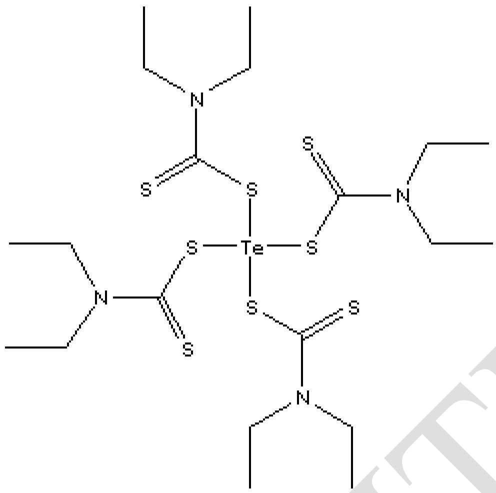


Figure 29: Molecular structure of TDEC (image from Caslab.com)

The tellurium flow has been added because Tellurium is a scarce resource which contributes to the indicator abiotic depletion of elements-ADPe (characterisation factor of 40.7 kg eq Sb in the PEPecopassport ® indicator set). The weight of the flow is equivalent to the molecular mass contribution of the tellurium atom to the TDEC molecular mass (16%) by the quantity of TDEC.
This flow is one of the main contributor to the impact of the rubber elements of the product on abiotic depletion of resources.

In this sensitivity analysis, the focus is on the influence of the addition or not of this flow on the conclusion of the study on the indicator ADPe.
The table below show that the Tellurium significantly impact the results of the environmental assessment of the manufacturing phase of the product: the manufacturing phase of the 158LR is 91% less impacting if the tellurium flow is not taken into consideration.
Yet the conclusion of the study remains intact: the 200LR has less impact on the environment than the 158LR. The reduction is more significant if the Tellurium flow is not taken into consideration.

Table 17: Comparison of the results of the indicator ADPe of the manufacturing using or not a tellurium flow for TDEC modelling

	Initial Scenario		Without Tellurium flow	
	158LR	200LR	158LR	200LR
ADPe (ref 158LR initial scenario)	100%	56%	19 %	2 %
ADPe (ref 158LR without Tellurium flow)			100%	13%

VII.2 Manufacturing: sensitivity analysis to the life cycle inventory used to model the environmental impacts of EPDM production

The connector is mainly made of EPDM compound. EPDM stands for ethylene propylene diene monomer rubber. It is a terpolymer of ethylene, propylene and diene.
The LCI used in the reference scenario for EPDM is ECO-002-. This module is based on data collected in 1992 in the United States. Even though the process of manufacturing has not changed since then, the EPDM supplied by the Erembodegem plant is produced in Europe at the time of the study
In order to assess if the choice of LCI for EPDM has an influence on the conclusion on the study, a sensitivity analysis has been made where the impact for the production of EPDM has been evaluated using two different LCI sources:

1) The first alternative LCI represents the production of synthetic rubber, essentially EPDM, in 2003 in Europe and is from the LCI database ecoinvent v2. The information for the process of EPDM production comes from literature. The analyses done with this value are called Ecoinvent;
2) The second alternative is a low density polyethylene (LDPE). LCPE has been chosen because it is one of the three copolymers of the EPDM. The LCI used for LDPE is ELCD-0144, it represents the production of LDPE in Europe in 1999. The values are coming from on-site data collection of European manufacturers of plastics. The analyses done with this value are called LDPE.

The following graphic shows that the environmental impact of the manufacturing phase of the connector is influenced by the type of life cycle inventory chosen to represent the impact of EPDM production (in this case the 158-LR but conclusions are similar for the 200-LR).
The impact of manufacturing decreases on global warming potential - GWP (-16% with the ecoinvent value and -18% with LDPE) and on POCP and ADPf (for both value).
The impact also increases on eutrophication potential – EP when using the value from the ecoinvent database (+27%).

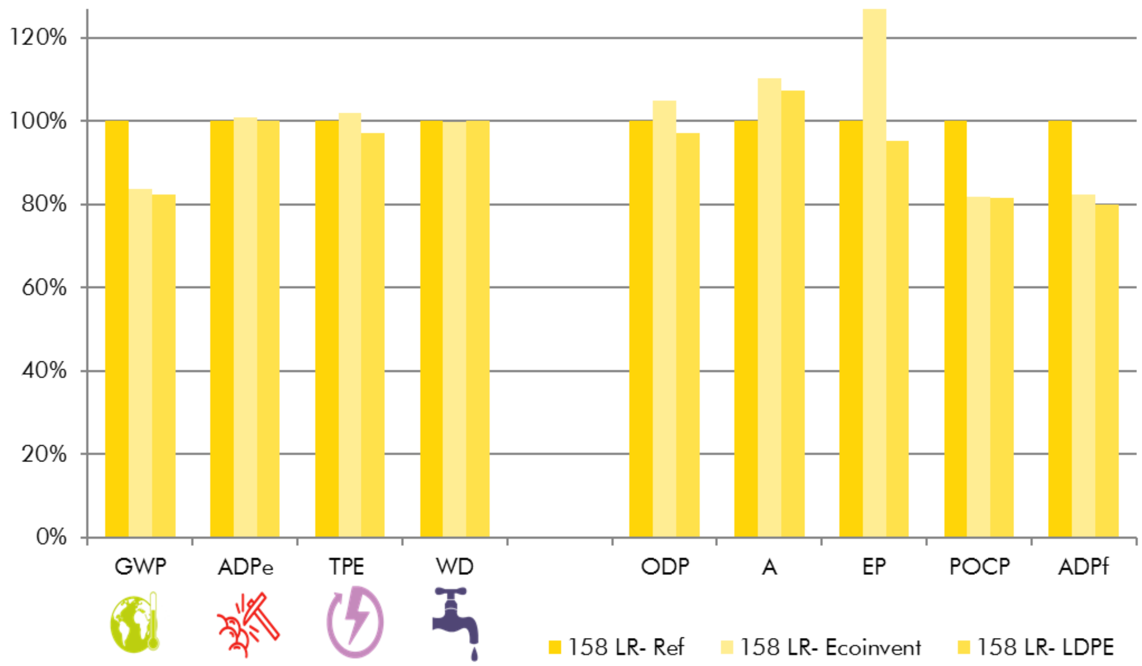


Figure 30: Sensitivity of the manufacturing phase of the 158-LR to the type of LCI used to represents EPDM environmental impacts

Since this study is a comparative assessment, it is of interest to see if the conclusions of section VI, that the 200 LR has a lower environmental impact than the 158 LR are still valid when the LCI used for EPDM is modified.

The following figure shows the impact of the 200 LR when compared to the version of the 158 LR product using the same LCI for modelling the environmental impact of the EPDM.
It can be seen that the scale of the modification of the environmental improvements is minor. For example, the improvements on the global warming potential for the 200 LR is of:

- 55% for the reference scenario and of;
- 58% for the Ecoinvent scenario and the LDPE scenario.

On the three other key indicators, there is almost no difference in the scale of improvements.

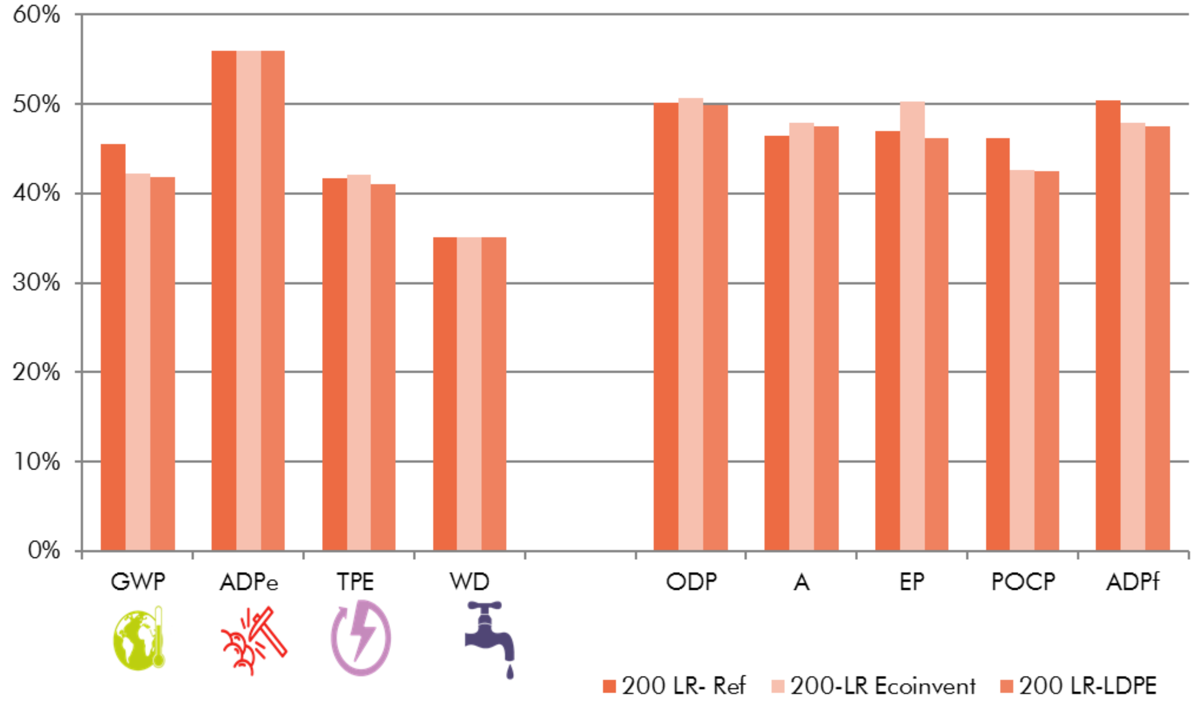


Figure 31: Sensitivity of the comparison of the manufacturing phase of 200-LR to the 158-LR depending on the type of LCI used to represents EPDM environmental impacts

It can be concluded that the choice of LCI inventory to model the EPDM used in the products does not affect the conclusion of the comparative study.
Yet, it should be kept in mind that it does have an influence on the environmental impact of the manufacturing when looking at the impact of the product alone.

VII.3 Use: sensitivity analysis of the model to a different energy mix in use

It has been considered that the product is being used in the German distribution network of medium voltage electricity. The life cycle inventory used in the environmental assessment to represents the power losses in the accessory over its lifetime is based on the electricity mix of Germany medium voltage network in 2008.
Since 2008, the electricity mix of Germany has been changing. For example, Germany decided to close all nuclear power plant following the Fukushima Daiichi power plant accident in 2011.

Additionally, the product can be used in any electricity network where it fulfills the local standards of the operators.

Since use phase is a key contributor to the environmental impact of the product and that the redesign of the product also affects positively the environmental performance of the use phase, this sensitivity analysis is aimed at testing if another electricity mix used to model the power losses in use is affecting the results of the study.
A mix that represents the production of electricity from wind turbine has been used (Electricity from wind power; AC; production mix, at power plant; <1kV; RER) to test if the conclusion of the study were affected by an electricity mix with less environmental impact in use.

The following figure shows that all the environmental indicators that have use phase as their main contributors have a reduced environmental impact if the electricity that is lost in the transmission process was produced using wind turbine (except total primary energy). On the key environmental indicator, the following differences are identified:

- Global warming potential-GWP: the environmental impact is reduced by 87%. As a reminder, the contribution of the use phase was 89% for the initial scenario.
- Abiotic depletion of resources-ADPe: the environmental impact is reduced by 2%. As a reminder, the contribution of the use phase was 0% for the initial scenario.
  This reduction is explained by the fact that in the life cycle inventory of the production of electricity from wind power, a negative value has been allocated to some resources (most notably silver, lead and zinc). This means that the use of wind turbine for electricity production is virtually saving the extraction of these rare elements.
- Total Primary Energy-TPE: the environmental indicator is reduced by 6%. As a reminder, the contribution of the use phase was 82% for the initial scenario.
  This small reduction is explained by the fact that the change of means of production of electricity does not significantly affect the total energy that is used by the life cycle of the product. The small reduction of impact means that the production of electricity from wind is slightly more energy efficient than the German medium voltage electricity mix.
- Water depletion-WD: the environmental indicator is reduced by 96%. As a reminder, the contribution of the use phase was 97% for the initial scenario.

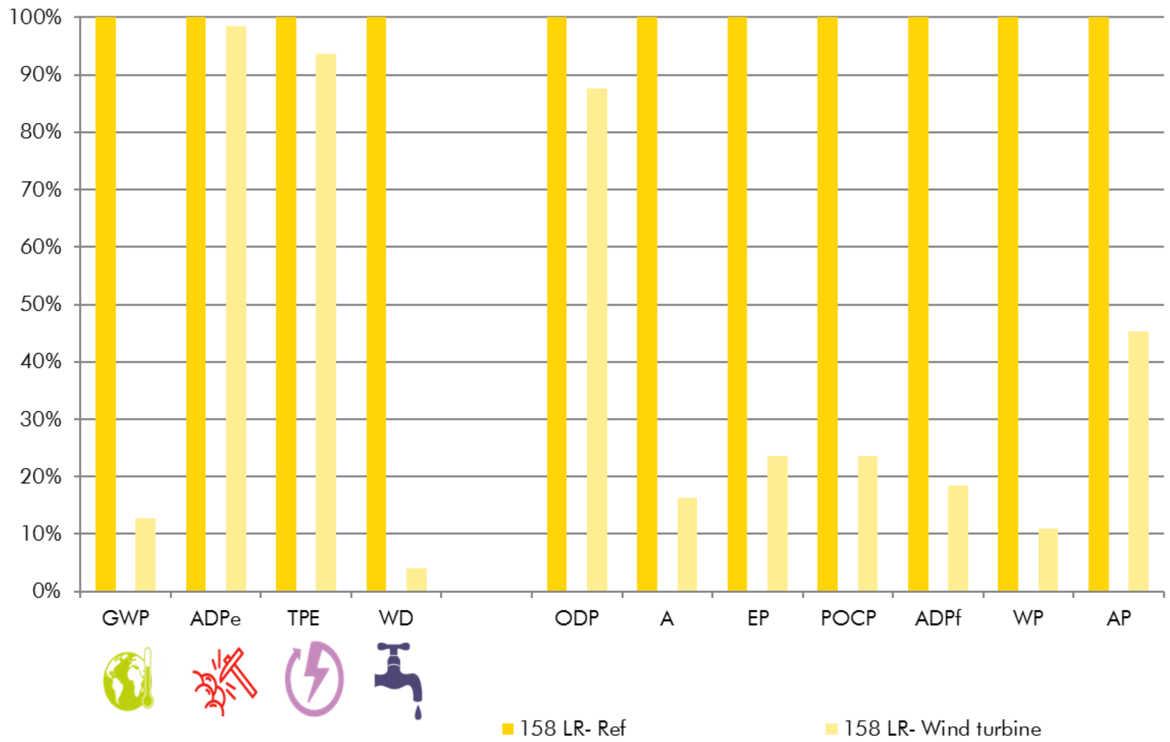


Figure 32: Comparison of the life cycle environmental impacts of the 158 LR when using electricity from wind to model power losses in use (basis for calculation: 158LR-initial scenario).

This means that a change on the electricity mix used for the use phase significantly affects the results of the life cycle assessment of the product. The recommendation here is that when communicating on the environmental profile of the individual products, the electricity mix is chosen carefully in order to represent the use conditions as realistically as possible.

The following figure compares the life cycle assessment results when the products are compared together using both the electricity from wind power to model the use phase. This is aimed at identifying if the conclusions of the comparative assessment can still be considered valid.

Based on the comparison of the 158LR and 200LR both using electricity from wind in use, the conclusion of the comparative assessments remains valid: the life cycle environmental impacts of the 200LR are **significantly lower** than the one of the 158LR.

The reduction of impacts is even higher on most indicators (except on water pollution where the initial assessment gives a reduction of 48% of the environmental impact and a reduction of 42% in the sensitivity analysis electricity from wind).

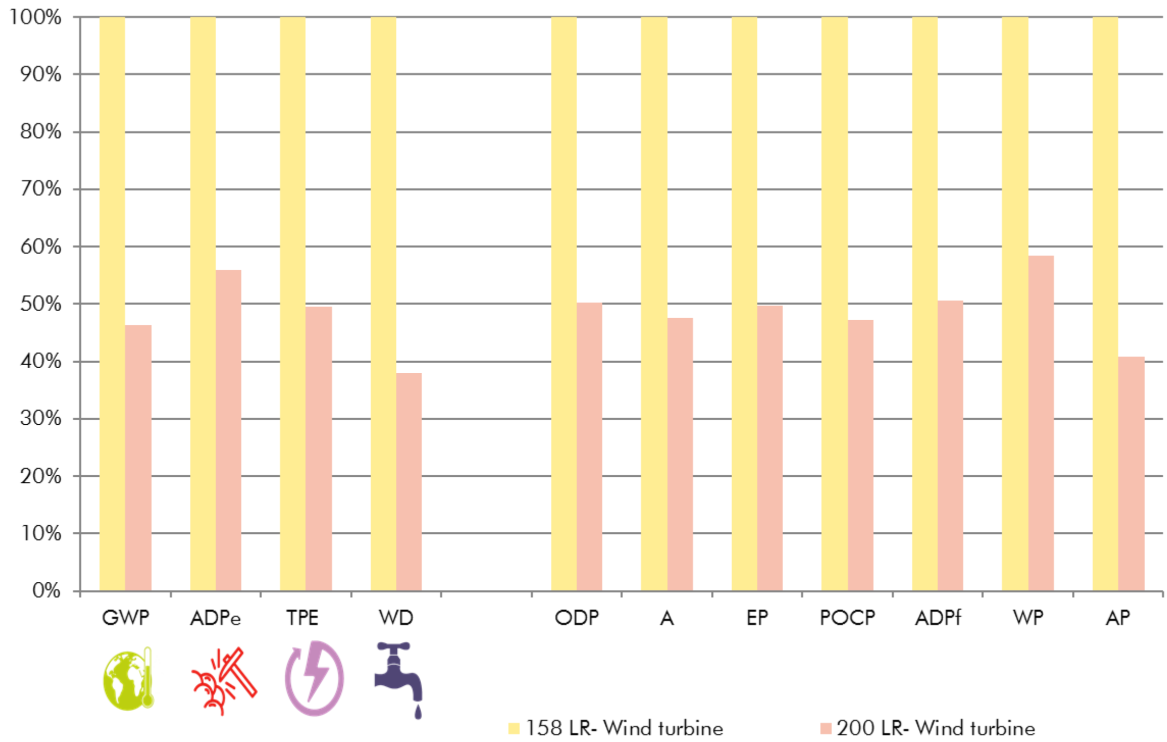


Table 18: Comparison of the life cycle assessment relative environmental impact in the initial scenario and in the electricity from wind scenario

	Initial Scenario	Electricity from wind	Difference
GWP	51%	46%	5 points
ADPe	56%	56%	0 point
TPE	50%	50%	0 point
WD	51%	38%	13 points
ODP	50%	50%	0 point
A	51%	48%	3 point
EP	51%	50%	1point
POCP	51%	47%	4 points
ADPf	51%	51%	0 point
WP	52%	58%	-6 points
AP	47%	41%	6 points

VIII. Conclusion

Based on the results of the comparative life cycle assessment, it can be concluded that the **ecodesign efforts** put on the redesign project of the elbow connector 158LR were **beneficial**. The new version of the product, 200LR, improves significantly the two first contributors to the environmental impact of an electric accessory for MV network life cycle:

- Use phase: thanks to a shorter length of conductor in the product, the energy losses have been cut by two.
- Manufacturing: thanks to a more compact design, with a better process-ability, less material use and energy efficiency improvements of the machinery, the impacts of manufacturing have been reduced.

Regarding manufacturing improvements, it is of interest to note that the **improvements, in term of environmental profile, are higher than the weight reduction**. The 200LR is 46% lighter than the 158LR but the impact reductions for the manufacturing phase are of at least 40% with the highest improvements on water depletion, with 65% less environmental impact.
No impact transfers were identified in this study; the environmental impacts of the distribution, installation and end-of-life have not been significantly modified.

It would be interesting to investigate is if the new design influence installation practices for this type of accessories.

LIMITATIONS:
The conclusions of this study are applicable for the life cycle inventory models described in this report and for these models only. Additionally, there are some identified limitations in the generalization of the conclusions:

- The modeling of the manufacturing phase of the 200LR is more detailed than the one of the 158LR. All elements of the 200LR have been modeled using life cycle inventory, whereas 0.1% of the 158LR weight have not been modeled. This means that the impact of the 158LR might be underestimated.
- Additionally, the modeling of the materials supplied to Nexans have been made based on the current materials that are supplied. When the 158LR was manufactured, different suppliers and different materials might have been used.
- The use of generic datasets to evaluate the impacts of the materials supply to Nexans means that the impact of their manufacturing process is not assess correctly. This is specifically true for all the materials that had no equivalent in the LCI database used by Nexans, mainly EPDM and complex chemicals such as TDEC and other vulcanization agents used in our processes. The model does not consider properly the evolution of energy mix in the upcoming years. This has been dealt with by doing a sensitivity analysis.
- The impacts of the installation processes are not assessed correctly. The contribution of this stage to the life cycle of the product is surely underestimated in this study.
- Finally, it is important to note that Life Cycle Assessment is not direct measurements of real impacts but it estimates relative potential impacts and that results and conclusions should be considered applicable only within the scope of the study.

IX. Recommendations for general public communication

For communication to the general public, it is advised to use the figure and values of the life cycle assessment report available in paragraph VI.3 that has been validated by the external reviewer, using a reminder of the main hypothesis for life cycle assessments:

"The environmental impacts of the 200LR connector have been improved significantly when compared to the previous version of the product:

- A reduction of the global warming potential of the product of 49%, equivalent to the saving of 45,46 kg eq CO_2 per connector.
- A reduction of the abiotic depletion potential of 44%, equivalent to the saving of 5.77g eq gold* per connector.

The results are given for 1 connector 200LR sold in a packaging of 3 connectors, for a lifespan of 40 years and an average use scenario when connecting aluminium cables with a section of 95mm² with a loading rate of 100A, 100% of the time and used in the medium voltage distribution network in Germany.

They were obtained using product life cycle assessment performed according to ISO 14040-44 standard. The following life cycle stages were considered: manufacturing, distribution, installation, use and end-of-life. For the other 11 environmental indicators, the reductions are similar to the one identified for global warming.
The life cycle assessment was conducted using the software EIME and the database Nexans-2017-06 and using the indicator sets of the Product Category Rules, edition 3 of the PEPecopassport ® environmental declaration program.

* The equivalence for gold abiotic depletion potential is based on the coefficient for this material in the ADPe indicator of the CML - IA Version 4.1, October 2012, Baseline "

Appendix

Appendix 1: Environmental indicators description

Global Warming Potential
This indicator assesses the contribution to the atmosphere global warming caused by the release of specific substances. Substances known to contribute to global warming are weighted based on an identified global warming potential expressed in kg of CO_2 equivalent.

Abiotic Depletion (resources):
This indicator is related to the extraction of minerals. It is determined for each minerals based on concentration reserves and rate of extraction. It is expressed in kg Sb equivalent.

Total Primary Energy:
The indicator relates to the total consumption/use of primary energy (raw material extraction, processing, etc). Primary energy is consumed from both non-renewable and renewable energy sources. It is expressed in MJ.

Water Depletion:
The Water Depletion indicator assesses the total consumption of water, from any sources. It is expressed in dm^3.

Ozone Depletion Potential:
This indicator represents the contribution to the depletion of stratospheric ozone layer by the emission of specific gases. The ozone layer aims to absorb most of solar short wave UV radiations which are dangerous for living organism. It is expressed in CFC-11 ozone depletion potential equivalent.

Air Acidification:
This indicator assesses the air acidification by gases released into the atmosphere. Indeed, some gases in the air, such as sulfur compounds (SO_x) or nitrogen compounds (NO_x) can be transformed into acids in wet conditions. Then, a wet deposition of these dissolved acids can occur through rainfalls, which is called acid rain. This reduces the pH of rivers, lakes and soils leading to soil degradation or plant species disappearance. This indicator is expressed in H^+ acidification potential equivalent.

Eutrophication:
Eutrophication is the degradation of aquatic environments, usually related to excessive inputs of nutrients (nitrogen from agricultural nitrates and phosphorus from wastewater phosphates). This increases the production of algae and deprives the bottom of light. It is expressed in PO_4^{3-} nitrification potential equivalent.

Photochemical Ozone Creation Potential:
Photochemical pollution is a complex mechanism which leads to ozone creation in lower atmosphere, also known as “smog”. Ozone is produced from interactions of volatile organic compounds, nitrogen oxides and solar UV radiations. It is expressed in C_2H_4 ozone creation potential equivalent.

Abiotic Depletion (fossil fuels):
This indicator is related to the Lower Heating Value expressed in MJ/kg of fossil fuel.

Air pollution

This indicator evaluates the air pollution by comparing the emission quantity of a substance emitted by a system with its limit admissible concentration in a working environment. This represents a volume of air polluted by hazardous substances and it is expressed in m^3.

Water Pollution

This indicator evaluates the water pollution by comparing the emission quantity of a substance emitted by a system with its tolerated admissible concentration into water. This represents a volume of water polluted by hazardous substances and it is expressed in m^3.

CONFIDENTIAL Appendix 2: Complete inventory data for 200LR connector life cycle

CONFIDENTIAL Appendix 3: Complete inventory data for 158LR connector life cycle

CONFIDENTIAL Appendix 4: Description of the life cycle inventory included in EIME by Nexans

CONFIDENTIAL Appendix 5: Data quality evaluation

Appendix 6 : Critical review Report

SYNTHESIS
FINAL CRITICAL REVIEW REPORT
OF THE STUDY
COMPARATIVE LIFE CYCLE ASSESSMENT OF TWO ELBOW CONNECTORS

FINAL REPORT OF THE STUDY

PRODUCED BY NEXANS

Reviewer – Julie ORGELET – LCA and Ecodesign Expert – DDemain

EXECUTIVE SUMMARY

A critical review was performed by Julie ORGELET at the end of comparative LCA elaboration process. The critical review aims at insuring the compliance with the ISO 14040/44 standards.

At the end of the critical review process, the reviewer concludes that the LCA report is fully compliant with the ISO14040/44 standards and with the goals of the study. The study results can be used by the marketing team in order to feed their BtoB communication.

The reviewer point out the fact that all of the comments were treated and that a special care has been given to challenge the data used in order to evaluate the environmental impacts of both solutions. As an example:

- The modeling hypothesis reflect a realistic use scenario
- Despite of a lack of data, a relevant proxy is used in order to model TDEC allowing to take into account the critical environmental impact potentially generated
- Sensitivity analysis are presented in order to reduce the limitation of the study : on used datasets, energy mix …
- A specific evaluation of data quality is presented in the report.

1 ORGANIZATION AND MANAGEMENT OF THE CRITICAL REVIEW

The critical review was performed at the end of the project. The review process was organized throughout two web meetings. The exchanges are presented in the Excel file: Critical review_1806_LCA_MEM_038_ Accessories recodesign_final report_v1.

The planning of the review is presented in the following graph:

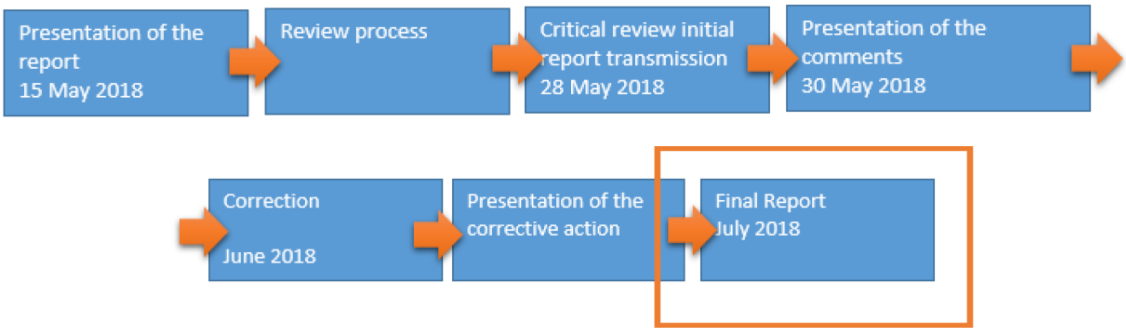


Figure 1 – Planning of the critical review

All the remarks were classified as follow:

- Non conformity
- Weakness point
- Improvement point
- Correction
- Strong point

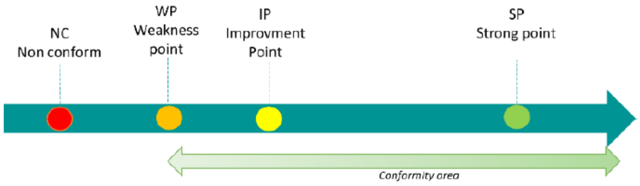


Figure 2 - Classification of the critical review comments

2 AIM OF THE REVIEW

The review process was based on the review of the final study report. The critical review aims at:

- Insuring that the methodology used by Nexans is:
  - Consistent with the requirements provided in the ISO 14040-44 standard series;
  - Valid from a technical and scientific perspective;
  - Relevant and reasonable regarding the study objective.
- Verifying that Nexans interpretation reflects the limitations identified and the study objective.
- Verifying that the detailed report is transparent and consistent.

This review statement is only valid for this specific report dated June 2018. The analysis of individual datasets and the review of the LCA software models used to calculate the results are outside the scope of this review.

3 COMPLIANCE WITH ISO 14040 AND 14044

The report in its final version is compliant with ISO 14 040 and 14 044. The report explores in depth key environmental aspects of the quantification of the environmental performances of 158LR & 200LR elbow connectors.

The team in charge of the study has provided interesting insights, resolving all the questions asked during the critical study.

The study has been made using the state-of-the-art methodologies of Life Cycle Assessment at the date of the beginning of the work. Results produced are interesting and conclusions are presented clearly without bias.

4 Coherence with the scope of the study

As stated in the report, the study aims at comparing "the environmental performance of 158LR & 200LR elbow connectors.

The final purposes are:

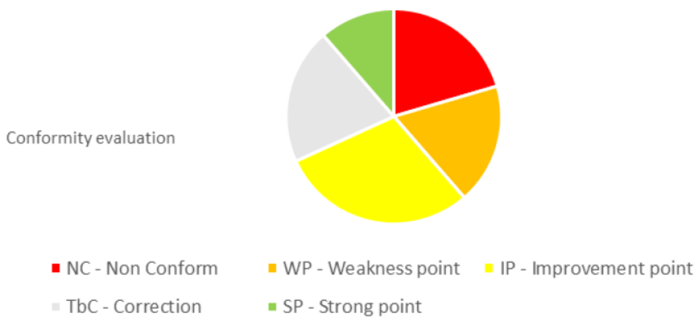
- Make an accurate environmental profile of the new connector;
- Evaluate potential improvements and/or deterioration of the 200LR life cycle compared to the 158LR;
- Support environmental claims for the marketing campaign of the new connector.

In order to ensure that the report satisfies the goal of the study, the reviewer ensures that any bias in favor of the new elbow connector is prevented.

5 Summary of the critical review feedbacks

At the end of the first step of the critical review, more than 39 comments were presented to the LCA provider. The comments were classified as followed:

Conformity evaluation	Quantity
NC - Non Conform	9
WP - Weakness point	8
IP - Improvement point	13
TbC - Correction	9
SP - Strong point	5



All the comments are presented in the excel files: Critical review_1806_LCA_MEM_038_ Accessories recodesign_final report_v1.

Following the correction period, all the comment were treated and approved by the verifier and 7 strong points have been identified:

- The modeling hypothesis have been adapted to realistic use scenarii,
- Despite of a lack of data, a relevant proxy is used in order to model TDEC allowing to take into account the critical environmental potentially generated,

- Sensitivity analysis have been performed in order to validate the results : EPDM, chemicals, TDCE, energy mix,
- A specific evaluation of data quality is presented in the report.

Julie ORGELET – DDemain