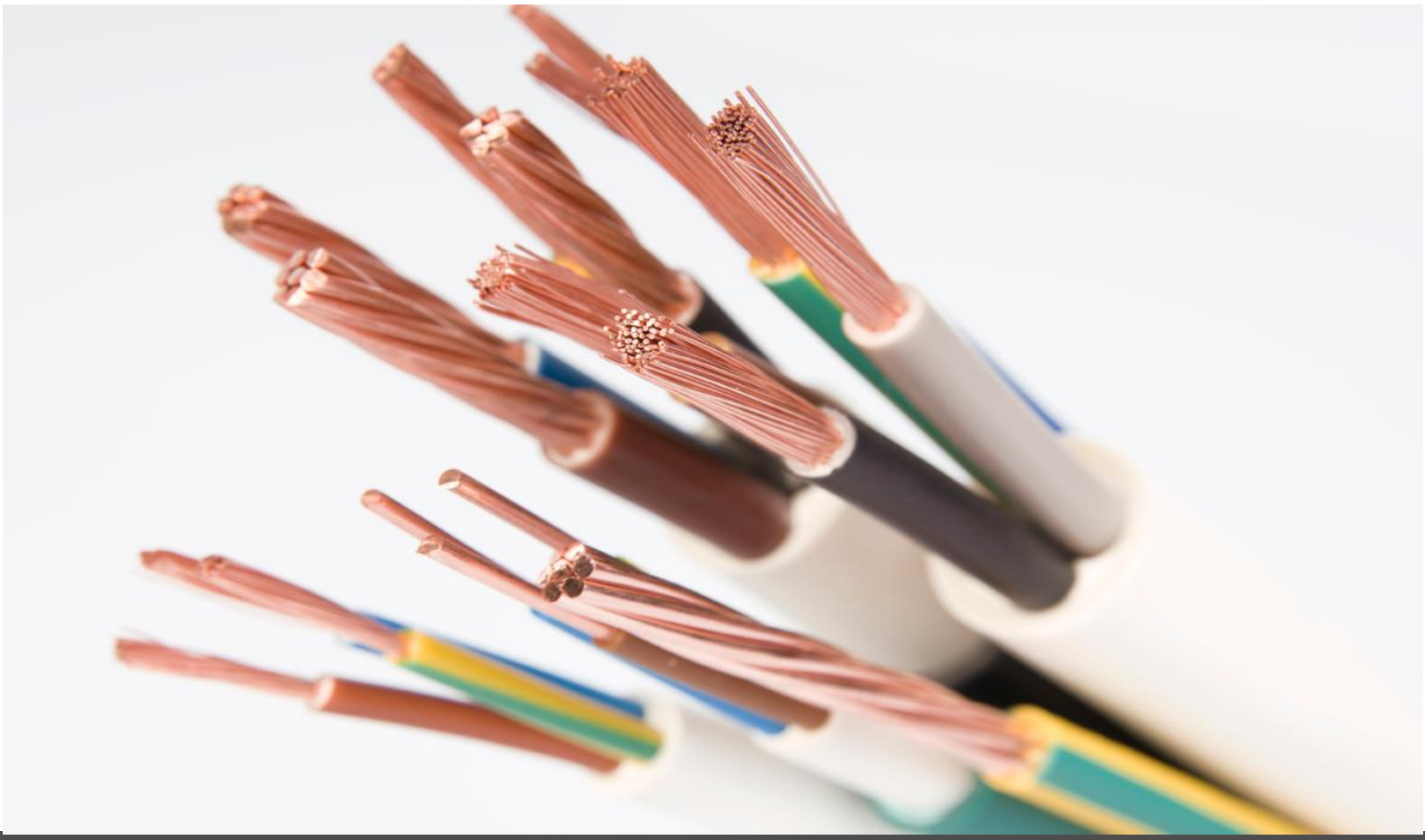

Final report

An investigation into the environmental effects of upsizing of copper cables in commercial applications

On behalf of: European Copper Institute

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ACRONYMS

ADP	Abiotic Depletion Potential
AP	Acidification Potential
CML	Centre of Environmental Science at Leiden
ELCD	European Life Cycle Database
EoL	End-of-Life
EP	Eutrophication Potential
GWP	Global Warming Potential
ILCD	International Cycle Data System
ISO	International Organization for Standardization
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
ODP	Ozone Depletion Potential
PE	PE INTERNATIONAL
POCP	Photochemical Ozone Creation Potential

GLOSSARY (ISO 14040/44:2006)

ISO 14040:2006, Environmental management - Life cycle assessment - Principles and framework, International Organization for Standardization (ISO), Geneva.

Allocation

Partitioning the input or output flows of a process or a product system between the product system under study and one or more other product systems

Functional Unit

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

Cradle to grave

Addresses the environmental aspects and potential environmental impacts (e.g. use of resources and environmental consequences of releases) throughout a product's life cycle from raw material acquisition until the end of life.

Cradle to gate

Addresses the environmental aspects and potential environmental impacts (e.g. use of resources and environmental consequences of releases) throughout a product's life cycle from raw material acquisition until the end of the production process ("gate of the factory").

Life cycle

A unit operations view of consecutive and interlinked stages of a product system, from raw material acquisition or generation from natural resources to final disposal. This includes all materials and energy input as well as waste generated to air, land and water.

Life Cycle Assessment - LCA

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

Life Cycle Inventory - LCI

Phase of Life Cycle Assessment involving the compilation and quantification of inputs and outputs for a product throughout its life cycle.

Life Cycle Impact assessment - LCIA

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

Life Cycle Interpretation

Phase of life cycle assessment in which the findings of either the inventory analysis or the impact assessment, or both, are evaluated in relation to the defined goal and scope in order to reach conclusions and recommendations.

EXECUTIVE SUMMARY

This study was commissioned to examine the environmental effects of the use of copper cables of larger sizes in offices and industrial applications. Common opinion cites that the environmental impact of production of additional copper makes the use of larger cable sizes environmentally disadvantageous. In order to investigate this claim to a greater degree of detail and include the use-phase implications of upsized cables, PE INTERNATIONAL conducted a comparative life cycle assessment of standard cables against upsized cables. The study follows ISO14040/44 requirements in its structure, quality on data, scope, and impact categories and it is ready for external review, which would be necessary to reflect full conformity.

For the purposes of this study, three application locations have been considered: small offices, large offices, and industrial areas. The definition of each of these application domains is available in the report 'Modified Cable Sizing Strategies' by Egemin Automation /EGEMIN/, which this study builds upon.

For the small and large offices, low voltage copper cables have been taken into consideration whereas for industrial areas, where power demand is higher, medium voltage copper cables have been considered. The amount of cable required for each of the three application cases is based upon the copper demand specified in the Egemin Automation /EGEMIN/ report. This data is enhanced by including the various layers of a cable (insulation, sheathing etc.). Using PE INTERNATIONAL's extensive and quality approved GaBi Databases and system modelling, the environmental impacts associated with the cable production (including production of all inputs, up each branch of the supply chain) have been quantified. The relative difference in power losses between standard cables and upsized cables has been considered. The difference arises from the fact that cables with larger cross-sectional area are subject to lower transmission losses. Lastly, at the end-of-life of the cables the collection and recycling has been accounted for. The recycled metal and plastic components are used in downstream material uses or energy generation through incineration. This downstream value takes the form of an environmental credit in the system under consideration. The credit represent the avoided burden of material or energy generation facilitated by the recycling of the product (cable).

Our study finds that in the production of the cable 60-90% of impacts result from the production of the copper required for the cable with the rest coming from the production of the plastic components. The exceptions to this range is the summer smog (photochemical oxidant creation potential, POCP) impact category. 44% of POCP impact stems from copper production because plastic production releases significant nitrogenous emissions that impact this category. It must, however, be noted here that toxicity indicators have been deliberately excluded from analysis. These indicators are in a nascent stage of development and yield contested results which are actively being debated in European forums. It is generally recommended to avoid the use of toxicity indicators for environmental decision-making without an in-depth discussion on inventory analysis and applied method approval. This discussion is out of scope of this study and therefore toxicity results have not been analysed in this report.

Extending the scope beyond production to include the entire life cycle (production, use, and end-of-life), it becomes clear that within a few years of use the impact from the production of the cables is overshadowed by the impacts due to energy losses. These impacts are represented by the emissions associated with the production of the same quantity of energy in the European power grid mix.

The cables with smaller cross sections (Baseline scenario) have a lower starting (production) impact but a greater annual energy loss rate. The upsized cables (Economic scenario), delivering equivalent electrical function, have a higher starting (production) impact but a lower annual energy loss rate.

Therefore the cumulative impacts for different impact categories (acidification, global warming etc.) intersect at a certain point before which the baseline scenario is advantageous and after which the economic scenario is environmentally advantageous. A reference chart for the Global Warming Potential in large offices is presented below.

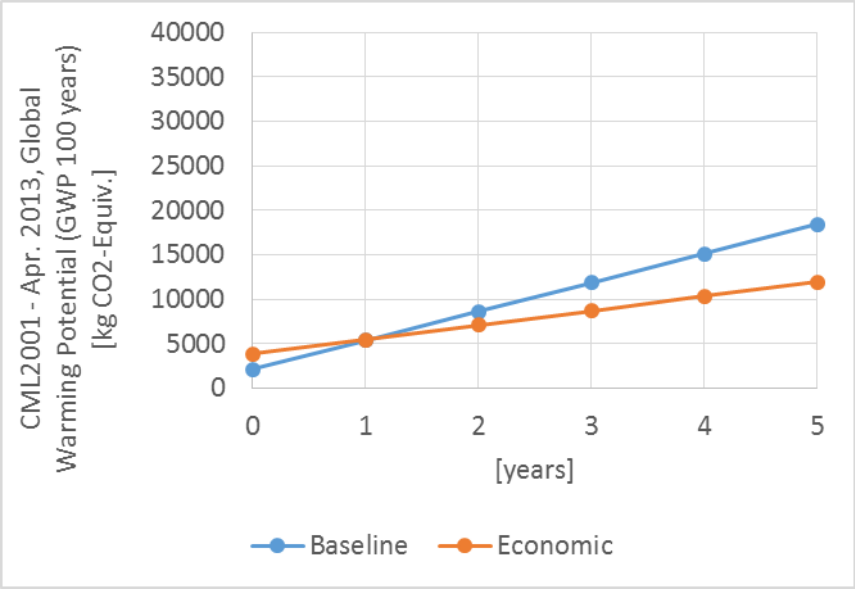

Figure 1: Global Warming Potential of Baseline vs. Economic scenario cables in large offices

For the impact categories considered (acidification, eutrophication, global warming, summer smog/ozone creation), this inflexion point lies before 1 year for all three application cases.

Overall, the environmental advantages of the upsized copper cables are apparent in our analysis. The mitigation of increased production impact by use-phase savings is visible in the early inflexion point (within 1 year compared to average cable lifetimes of about 30 years).

1 GOAL OF THE STUDY

The European Copper Institute (ECI) commissioned PE INTERNATIONAL to conduct an investigation into the environmental implications of upsizing copper cables used in commercial applications in Europe.

The commonly held view is that greater copper content is environmentally disadvantageous due to the environmental impact of copper production. However, cables of larger sizes contribute to reduced electricity losses. The goal of this study is to evaluate the reduced losses against the larger copper production impact to investigate viability of copper upsizing from an environmental perspective.

This study builds on the findings of the EGEMIN study, 'Modified Cable Sizing Strategies' (2011). The EGEMIN study specifies the copper cable content in the three commercial applications (small office, large office and industrial plants) investigated in this study. Furthermore, the EGEMIN study also quantifies the losses under the different cable sizes. These findings were to be used as a basis for the environmental evaluation by PE INTERNATIONAL.

This study will be used by the ECI to present the case for copper upsizing to the internal (copper and cable industry) stakeholders.

According ISO standards, in order to communicate the results externally (customers, LCA practitioners, public in general, etc.) a critical review is mandated. At this stage, the results are not intended to be used for communication disclosed to the public.

A critical review has not been conducted for this study.

2 SCOPE OF THE STUDY

The following section describes the general scope of the project to achieve the stated goals. This includes, amongst others, the identification of specific product systems to be assessed, the functional unit and reference flows, the system boundary, allocation procedures, and cut-off criteria of the study.

2.1 PRODUCT SYSTEM(S) TO BE STUDIED

The product system under consideration in this study is 'Total copper cables used in the specified commercial application'. The three commercial application cases considered are:

- Small offices
- Large offices
- Industrial plants

Low voltage copper cables have been used for the first two applications and medium voltage copper cables for the industrial plants application case.

The quantity of cables used in each of these individual cases was specified in terms of the copper used (EGEMIN study). This information was used by PE INTERNATIONAL together with bills of materials provided by DNV-GL on behalf of ECI for the different cable types.

The cable consists of a core copper conductor, plastic isolation and additional layers such as swelling tape and wire sheathing. All these materials have been accounted for in the model for this study.

The functional unit for this assessment is '**Mass of copper cables required to provide electrical demand of specific application case**'.

2.2 System Boundaries

Table 2-1: System Boundaries

Included	Excluded
✓ Raw materials	× Capital equipment and maintenance
✓ Waste treatment	× Overhead (heating, lighting) of manufacturing facilities when easily differentiated
✓ Recycling impacts	× Installation of cables
✓ Environmental credits	× Human labour
✓ Use phase losses	× Transports between all stages

2.2.1 Time Coverage

Foreground data is provided by DNV-GL, citing industry datasheets published in 2014 for low-voltage cables and 2011 of the other products as well as through the results of the EGEMIN study. All secondary data come from the Ga-Bi 2013 databases and are representative of the years 2009-2013. As the study intended to compare the product systems for the reference year 2014, temporal representativeness is warranted.

2.2.2 Technology Coverage

The technology mixes used are up-to-date for 2013 production of the respective materials. Further details on the technological process mixes for the various materials is available in the GaBi documentation online.

2.2.3 Geographical Coverage

The geographical scope of this project is the EU-27 region. Wherever available, European production data has been used for the manufacturing of the raw materials. Where no relevant European data is available, a suitable substitute has been used.

2.3 Cut-Off Criteria

No cut-off criteria are defined for this study. All available energy and material flow data have been included in the model.

2.4 Selection of LCIA Methodology and Types of Impacts

A set of impact assessment categories and other metrics considered to be of high relevance to the goals of the project are shown in Table 2-2 and Table 2-3. The CML impact assessment methodology framework was selected for this assessment. The CML characterization factors are applicable to the European context and are widely used and respected within the LCA community.

Table 2-2: Impact Assessment Category Descriptions

Impact Category	Description	Unit	Reference
Global Warming Potential (GWP)	A measure of greenhouse gas emissions, such as CO2 and methane. These emissions are causing an increase in the absorption of radiation emitted by the earth, increasing the natural greenhouse effect. This may in turn have adverse impacts on ecosystem health, human health and material welfare.	kg CO_2 equivalent	[Guinée 2001]
Eutrophication Potential	Eutrophication covers all potential impacts of excessively high levels of macronutrients, the most important of which nitrogen (N) and phosphorus (P). Nutrient enrichment may cause an undesirable shift in species composition and elevated biomass production in both aquatic and terrestrial ecosystems. In aquatic ecosystems increased biomass production may lead to depressed oxygen levels, because of the additional consumption of oxygen in biomass decomposition.	kg Phosphate equivalent	[Guinée 2001]
Acidification Potential	A measure of emissions that cause acidifying effects to the environment. The acidification potential is a measure of a molecule's capacity to increase the hydrogen ion (H+) concentration in the presence of water, thus decreasing the pH value. Potential effects include fish mortality, forest decline and the deterioration of building materials.	kg SO_2 equivalent	[Guinée 2001]
Photochemical Ozone Creation Potential (POCP)	A measure of emissions of precursors that contribute to ground level smog formation (mainly ozone, O_3), produced by the reaction of VOC and carbon monoxide in the presence of nitrogen oxides under the influence of UV light. Ground level ozone may be injurious to human health and ecosystems and may also damage crops.	kg ethene equivalent	[Guinée 2001]

Table 2-3: Other Environmental Indicators

Indicator	Description	Unit	Reference
Primary Energy Demand (PED)	A measure of the total amount of primary energy extracted from the earth. PED is expressed in energy demand from non-renewable resources (e.g. petroleum, natural gas, etc.) and energy demand from renewable resources (e.g. hydropower, wind energy, solar, etc.). Efficiencies in energy conversion (e.g. power, heat, steam, etc.) are taken into account.	MJ (net calorific value)	[GUINÉE 2001]

It shall be noted that the above impact categories represent impact *potentials*, i.e., they are approximations of environmental impacts that could occur if the emitted molecules would (a) actually follow the underlying impact pathway and (b) meet certain conditions in the receiving environment while doing so. In addition, the inventory only captures that fraction of the total environmental load that corresponds to the chosen functional unit (relative approach).

LCIA results are therefore relative expressions only and do not predict actual impacts, the exceeding of thresholds, safety margins, or risks.

2.5 ASSUMPTIONS AND LIMITATIONS

The limitations and assumptions associated with this LCA are listed below:

- The energy for the assembly of cables using the individual component materials has been excluded from the analysis. This energy consumption represents a relatively small fraction of net environmental impact and is not expected to skew the representativeness of the overall results.
- The transport of the raw materials to the production site and the transport of the finished product to the site of installation has not been accounted for. This impact is also relatively small in relation to the net impact per functional unit.
- The packaging of the products has not been included in the scope of the manufacturing phase of the products
- The effort of installation of cables is outside the scope of this study.
- An in-depth discussion or investigation of the applicability of available toxicity calculation methods for facilitating comparability of the toxicity aspects from metals, plastics and grid mixes lies outside the scope of this study.

2.6 SOFTWARE AND DATABASE

The LCA model was created using the GaBi 6 Software system for life cycle engineering, developed by PE INTERNATIONAL AG. The GaBi 2013 LCI database /GaBi/ (documented at http://www.gabi-

software.com/support/gabi/gabi-database-2013-lci-documentation/) provides the life cycle inventory data for several of the raw and process materials obtained from the background system.

2.7 Critical Review

No critical review has been conducted for this assessment. However the study follows the ISO14040/44 requirements and is therefore ready for external review.

3 Life Cycle Inventory (LCI) Analysis

3.1 Data Collection

The data for the manufacturing phase of the cables was sourced from the DNV-GL report, 'Typical cables for input LCA'. This report specifies the bills of material for different types of copper cables – high voltage, low voltage, medium voltage etc.

For the small and large office applications, low voltage cables have been taken into consideration. For the industrial plant application, medium voltage cables have been considered. The data for the quantities of cables required for the various applications has been sourced from the EGEMIN study 'Modified Cable Sizing Strategies, 2011'.

The data on the end of life collection rates for the cable industry have been based off the findings of the ECI market research consultant, Mr. Volker Schneider. Mr. Schneider interviews 8 cable recyclers and scrap dealers in Europe to determine expert estimates on the recovery of cables after their service lives. Furthermore, his findings provide a basis to determine the optimal recycling process through which the recovered copper re-enters the production loops.

3.1.1 Fuels and Energy – Background Data

National and regional averages for fuel inputs and electricity grid mixes were obtained from the GaBi 6 database 2013. Table 3-2 shows the most relevant LCI datasets used in modelling the product systems.

Table 3-1: Key energy datasets used in inventory analysis

Dataset name	Geography	Comment*
Electricity grid mix	EU-27	
Thermal energy from natural gas	EU-27	

* data were developed on-demand by PE for this specific project

3.1.2 Raw Materials and Processes – Background Data

Data for up- and downstream raw materials and unit processes were obtained from the GaBi 6 database 2012. Table 3-2 shows the most relevant LCI datasets used in modelling the product systems. Documentation for all non-project-specific datasets can be found at www.gabi-software.com/support/gabi/gabi-6-lci-documentation. /GaBi/

Table 3-2: Key material datasets used in inventory analysis

Basic material	LCI incl. national identification	Comment
Copper Wire Mix DKI/ECI	EU-27	As conductor
Aluminium extrusion profile	EU-27	As conductor
Polyvinyl Chloride Foil (PVC) (without additives)	EU-27	As outer sheath and core covering
Polyethylene Cross-Linked (PEXa)	DE	As insulation
Polyester Resin unsaturated (UP)	DE	As swelling tape
Polyethylene high density granulate (HDPE/PE-HD)	EU-27	As outer sheath and bedding
Compressed air 7 bar (medium power consumption)	GLO	For plastic extrusion
Electricity grid mix	EU-27	For plastic extrusion
Lubricant (aqueous emulsion of fatty substances)	GLO	For plastic extrusion
Thermal energy from natural gas	EU-27	For plastic extrusion
Plastic extrusion profile (unspecific)	GLO	For polyester and polyethylene extrusion
Lead primary and secondary mix ILA	EU-27	As sheath
Steel strip	DE	As steel wire
Polypropylene (PP) – fabric	EU-27	As yarn

3.2 PRODUCT SYSTEM

3.2.1 Overview of Life Cycle

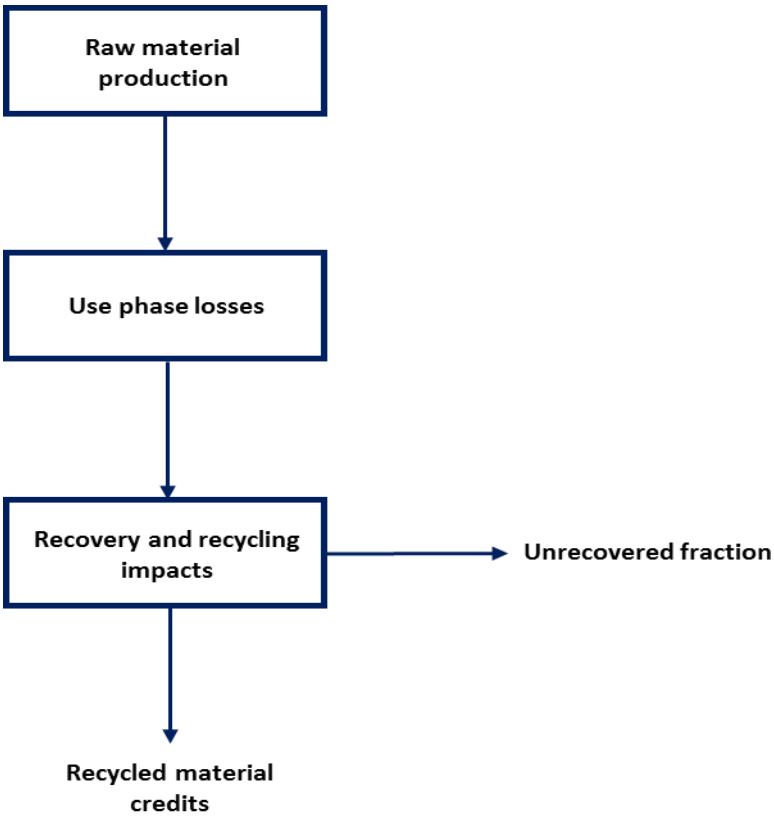

Figure 2: Life cycle flowchart of the product system

The life cycle of the product system considered in this study include the manufacturing of the cable subcomponents. This entails quantifying all the impacts and emissions associated with the production of the various cable parts such as the conductors, isolation sheathing etc.

For the use phase of the cables, this LCA includes the losses incurred per year of use of the cables in each respective application case.

At the end of their serviceable lives, the cables are recovered and recycled. The rate of recovery and efforts associated with the recycling of these products has been assessed in this study to estimate the environmental credits to be accorded for the return of secondary material to the market (and subsequent substitution of primary production.)

3.2.2 Description of Process Flow

3.2.2.1 Manufacturing

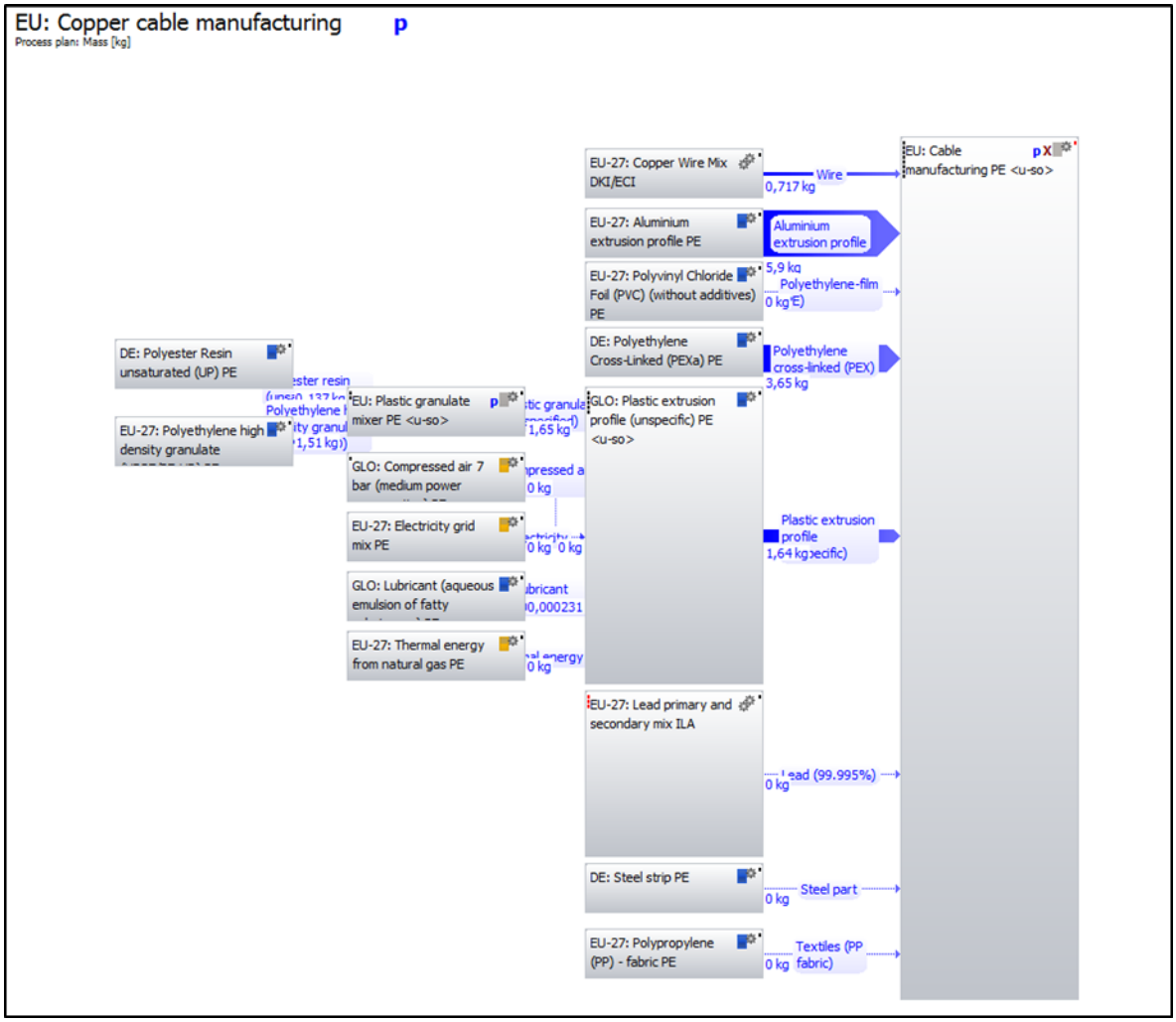

Figure 3: Example GaBi plan for manufacturing of cables

As seen in the figure above, the GaBi model for the manufacturing of the cables used in the respective application cases quantifies the inputs and outputs of the production of the various cable subcomponents. This study does not account for the energy required for the assembly of these individual components into the final cable but this energy impact is considered to be small in relation to the overall impact of the production of all the materials.

Table 3-3: Composition of the cables used in the scenarios small office, large office and large industrial plant

Composition [kg per m]	Small office (low voltage cable)	Large office (low voltage cable)	Large industrial plant (medium voltage cable)
Copper	0.851	0.851	2.912
PE	0.000	0.000	0.505
Polyester	0.000	0.000	0.059
PVC	0.755	0.755	0.000
XLPE	0.052	0.052	0.569

3.2.2.2 Transport

No transport has been considered in the foreground system this life cycle assessment.

3.2.2.3 Use

The use phase losses associated with each cable system for each application case has been sourced from the EGEMIN study. These losses have been simulated as an additional consumption of power from the EU-27 Electricity Grid Mix.

3.2.2.4 End-of-Life

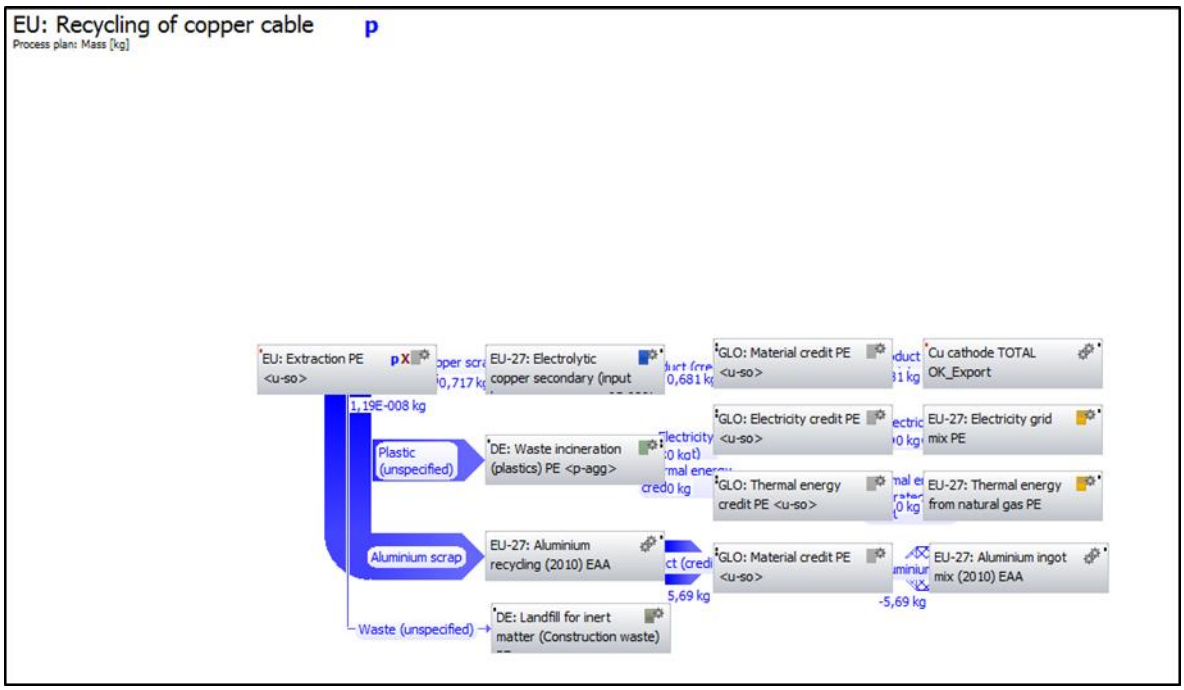

Figure 4: Example GaBi plan for end-of-life of cables

The figure above shows the GaBi plan for the end-of-life stage of the life cycle of a power cable. This part of the model quantifies the collection rates (fraction of cables recovered from the ground after cessation of service), the impacts from the recycling processes and associated material losses, and the incineration and energy recovery during the recycling of the plastic fractions. Furthermore, the

recovered material and energy is granted an environmental credit to acknowledge the fact that these recycled quantities substitute primary production on the market and thereby offset impacts that would have otherwise occurred.

4 LIFE CYCLE IMPACT ASSESSMENT (LCIA)

The software model described above enables the calculation of various environmental impact categories. The impact categories describe potential effects of the life cycle stages on the environment. As different resources and emissions are summed up per impact category the impacts are normalised to a specific emission and reported in "equivalents", e.g. Greenhouse gas emissions are reported in kg CO2 equivalents.

Environmental impact categories are calculated from "elementary" material and energy flows. Elementary flows describe the origin of resources from the environment as basis for the manufacturing of the pre-products and generating energy, as well as emissions into the environment, which are caused by a product system.

A set of impact assessment categories considered to be of high relevance to the goals of the project has been chosen. The CML (Center voor Milieukunde at Leiden, NL) impact assessment methodology framework was selected for this assessment. The CML characterization factors are applicable to the European context and are widely used and respected within the LCA community. The most recently published list of characterisation factors "CML 2001 – Apr. 2013" has been applied.

Global warming potential and primary energy were chosen because of their relevance to climate change and to energy and resource efficiency, which are strongly interlinked, of high public and institutional interest, and deemed to be some of the most pressing environmental issues of our times.

Eutrophication, acidification, and photochemical ozone creation potentials were chosen because they are closely connected to air, soil, and water quality and capture the environmental burden associated with commonly regulated emissions such as NOx, SO2, VOC, and others.

Toxicity impact categories have been excluded from this study for the following reasons:

- The application of general toxicity criteria within the life cycle impact assessment (LCIA) of metals, i.e. related to emissions of metal and metal compounds, currently poses significant methodological and scientific problems as stated in the specific ILCD handbook. For metals, the USEtox method does not consider some metal specificities (e.g. essentiality) or is highly uncertain regarding the model parameters related to the long term behaviour, i.e. ageing, due to their permanent character. Therefore, the USEtox characterization factors for metals are rated as interim in the USEtox website and should then only be used with caution and not for product comparison purposes.
- LCIA results for toxicity indicators are strongly impacted by the degree of development of the LCI dataset since several thousands of substances are contributing to this impact category. Therefore, the toxicity indicators are highly sensitive to the degree of completeness of the LCI datasets not only for the foreground processes but also for all the background processes. Hence, even if the quality of the LCIA methodologies is improving, the level of completeness of the various LCI datasets is not sufficiently homogeneous to secure robust and non-discriminatory results.

- For toxicity indicators, the PEF normalisation factors based on domestic European production is largely underestimated compared to normalisation factors based on the European consumption. Such underestimation is particularly significant for the indicators related to toxicity and resource depletion. Hence, the contribution of USEtox indicators is largely overestimated due to this inadequate choice of PEF normalisation factors.

It shall be noted that the above impact categories represent impact potentials, i.e., they are approximations of environmental impacts that could occur if the emitted molecules would (a) actually follow the underlying impact pathway and (b) meet certain conditions in the receiving environment while doing so.

LCIA results are therefore relative expressions only and do not predict actual impacts, the exceeding of thresholds, safety margins, or risks.

In fact, the results from the impact assessment are only relative statements, which give no information about the endpoint of the impact categories, exceeding of threshold values, safety margins or risk.

The following information on environmental impacts is expressed with the impact category parameters of LCIA using characterisation factors. Used method is CML 2001 (latest updated in 2013) and USEtox.

4.1.1 Acidification Potential (AP)

Table 4-1: Acidification Potential for the manufacturing and EoL of copper cables in a small office, large office and large industrial plant

AP [kg SO_2-equiv.]	Small office		Large office		Large industrial plant	
	Baseline	Economic	Baseline	Economic	Baseline	Economic
Total	1.85	2.51	5.01	8.04	61.62	131.29
Manufacturing	2.39	4.40	10.58	19.79	171.04	388.59
EoL	-0.54	-1.89	-5.57	-11.76	-109.42	-257.30

4.1.1.1 Small office

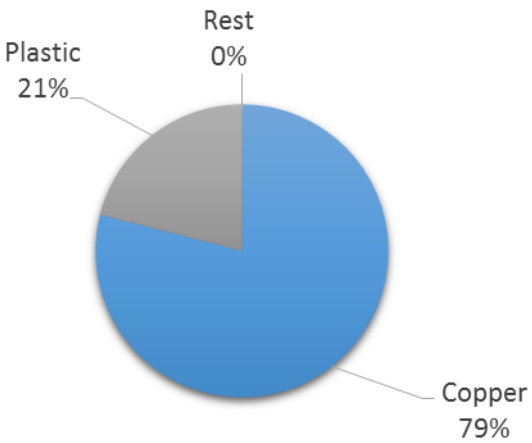

Figure 4-1: Contributions to the Acidification Potential of the manufacturing of the copper cable used in small offices

In the Acidification Potential Category, 79% of the impacts from the manufacturing of raw materials is associated with the production of the copper for the conductor. This stems mainly from the sulphur dioxide emissions during the smelting and converting processes in the production of primary copper cathode from ore. The plastic components of the cable (isolation, tape) contribute the remainder for the AP impacts in manufacturing.

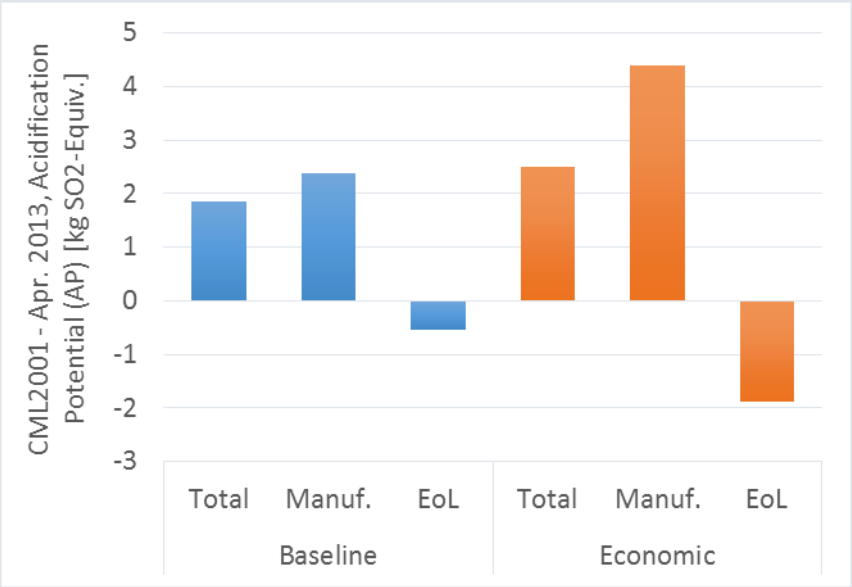

Figure 4-2: Acidification Potential for the manufacturing and EoL of copper cables in a small office

When looking at the manufacturing and end-of-life impacts together, it is seen that a significant proportion of impacts are offset at EoL through credits. This is due to the fraction of copper that is recovered and recycled and thereby 'avoids the burden' of production of primary copper when it re-enters the market. To a smaller extent, these credits also account for the energy recovered from the incineration of the plastic components from the recovered cables.

In the 'Economic case', with upsized copper cables, we see and larger impact from the production of copper and a larger credit. The net value for the Economic Case is is higher than the Baseline when we assess only the manufacturing and EoL stages. The chart below shows the life cycle impacts when we take the effects of the use-phase losses into account as well.

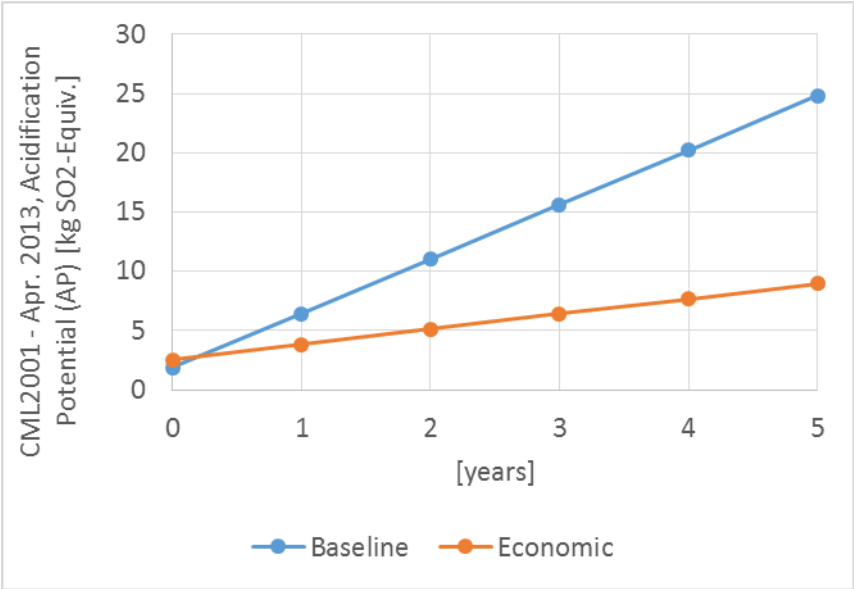

Figure 4-3: Acidification Potential for the life cycle including the use phase of copper cables in a small office

In the chart above, the time-scale is plotted on the X-axis while the AP impacts are on the Y-axis. At the start of its life, each cable system is represented only by the net (manufacturing+EoL) impacts from the previous chart. As the cable systems are used, the losses from the Baseline scenario contribute quickly to higher cumulative losses than the Economic scenario, where upsized cables lead to lower loss rates.

The high AP impact from the use-phase losses makes the manufacturing and EoL impacts almost negligible. The greater net manufacturing impact of upsized cables in the Economic scenario is offset in under 1 year of use, seen in the intersection of the orange and blue lines.

4.1.1.2 Large office

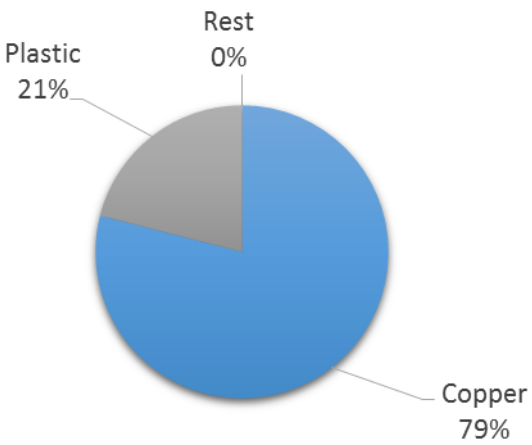

Figure 4-4: Contributions to the Acidification Potential of the manufacturing of the copper cable used in large offices

Since both small and large offices use low voltage cables, albeit in different quantities, the relative contribution from the different components remains the same as in the previous application case – 79% from the production of the copper conductor and 21% from the plastic components of the cable.

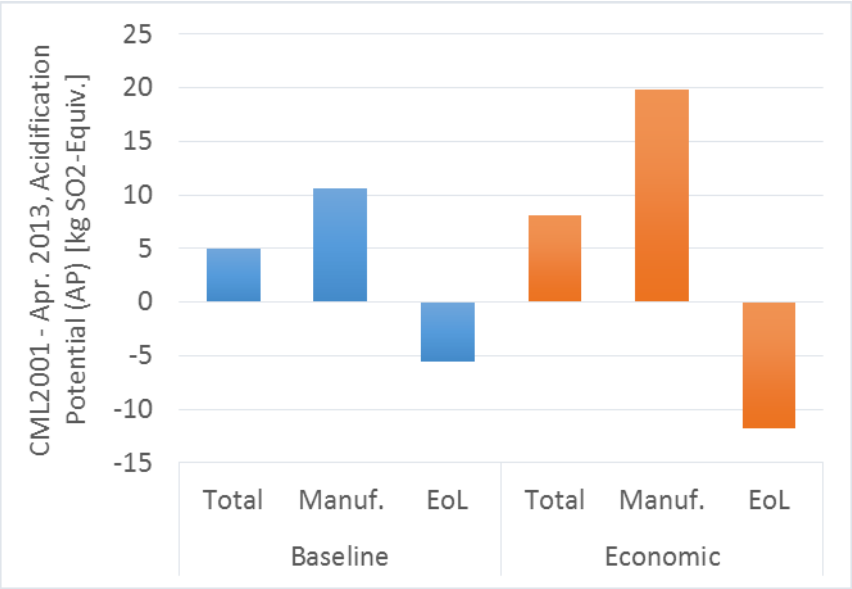

Figure 4-5: Acidification Potential for the manufacturing and EoL of copper cables in a large office

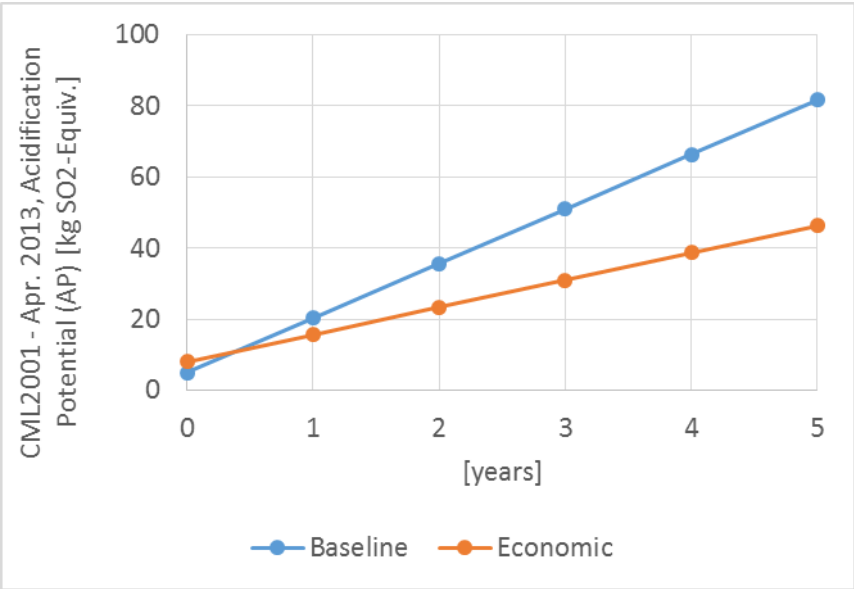

Figure 4-6: Acidification Potential for the life cycle including the use phase of copper cables in a large office

Similar to the application case for small offices, the net manufacturing impact (manufacturing+EoL) in negligible to the scale of impact associated with the use phase losses. When comparing the Baseline and Economic (upsized cables) scenario, the latter quickly offsets the greater production impact in under a year.

4.1.1.3 Large industrial plant

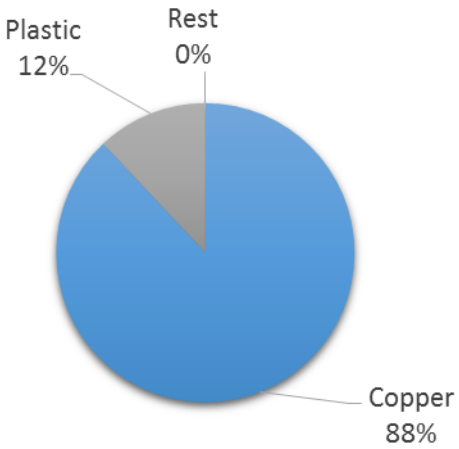

Figure 4-7: Contributions to the Acidification Potential of the manufacturing of the copper cable used in large industrial plants

For industrial plants, larger medium voltage cables have been taken into consideration in this LCA. With this bigger cables, the copper conductor has a higher share of the manufacturing stage impacts. 88% of total manufacturing impact comes from the conductor while 12% is from the plastic components.

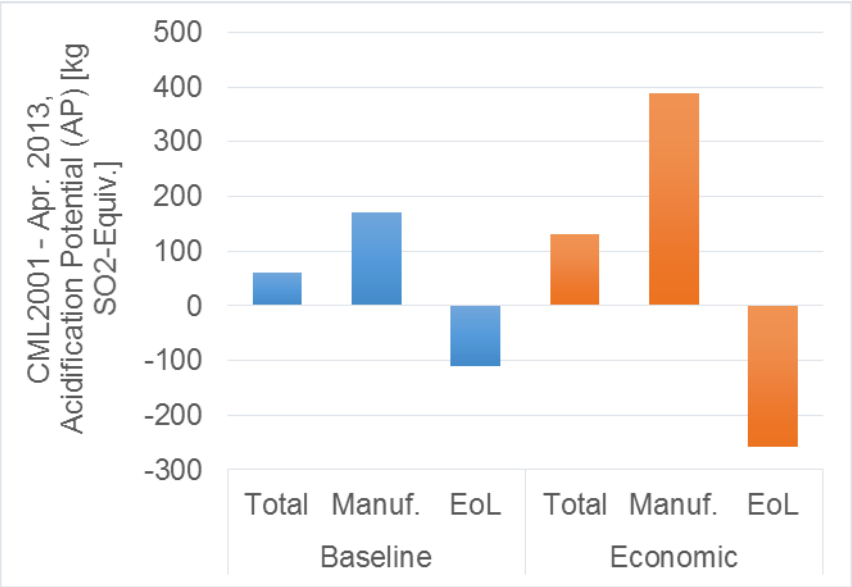

Figure 4-8: Acidification Potential for the manufacturing and EoL of copper cables in a large industrial plant

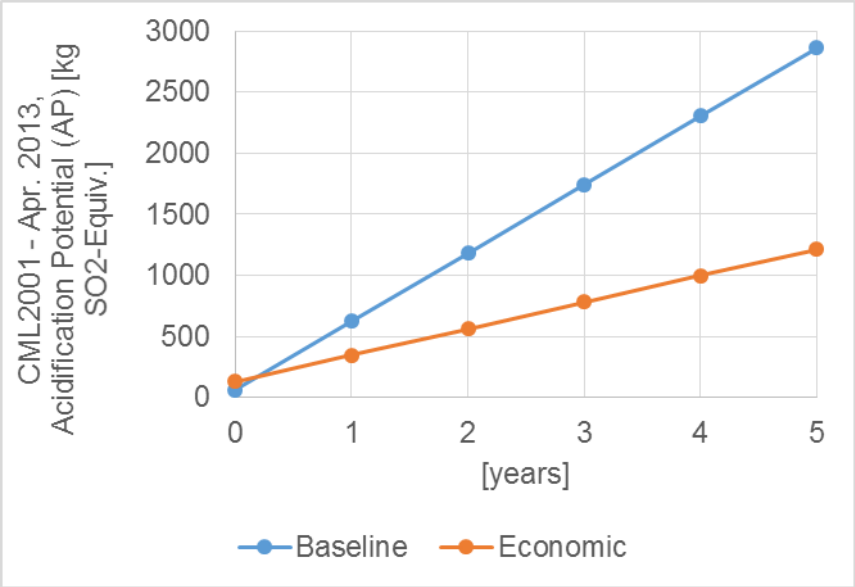

Figure 4-9: Acidification Potential for the life cycle including the use phase of copper cables in a large industrial plant

The large difference in loss rates between regular cables in the Baseline scenario and the upsized cables in the Economics scenario ensure that the larger manufacturing impact is offset in a couple of month and diverges greatly there on wards.

4.1.2 Eutrophication Potential (EP)

Table 4-2: Eutrophication Potential for the manufacturing and EoL of copper cables in a small office, large office and large industrial plant

EP [kg PO_4^{3-}-equiv.]	Small office		Large office		Large industrial plant	
	Baseline	Economic	Baseline	Economic	Baseline	Economic
Total	0.12	0.19	0.41	0.71	5.00	10.95
Manufacturing	0.17	0.35	0.88	1.71	14.50	33.29
EoL	-0.05	-0.16	-0.47	-1.00	-9.50	-22.34

4.1.2.1 Small office

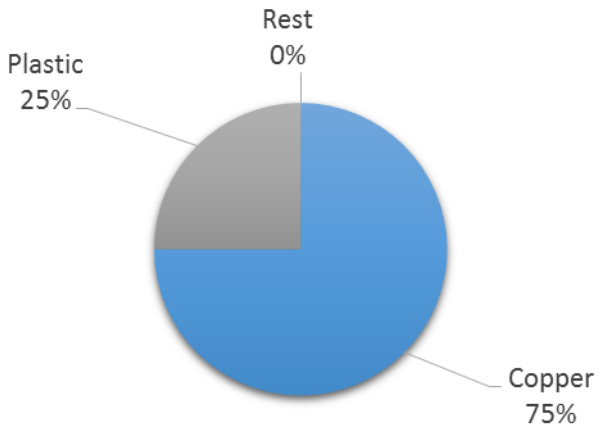

Figure 4-10: Contributions to the Eutrophication Potential of the manufacturing of the copper cable used in small offices

75% of the manufacturing phase EP impacts stem from the production of the copper conductor in the cable systems. The plastic components contribute 25%.

These impacts are mostly associated with nitrogenous emissions from the production of the copper conductor and the aluminium sheathing required for the low voltage cables.

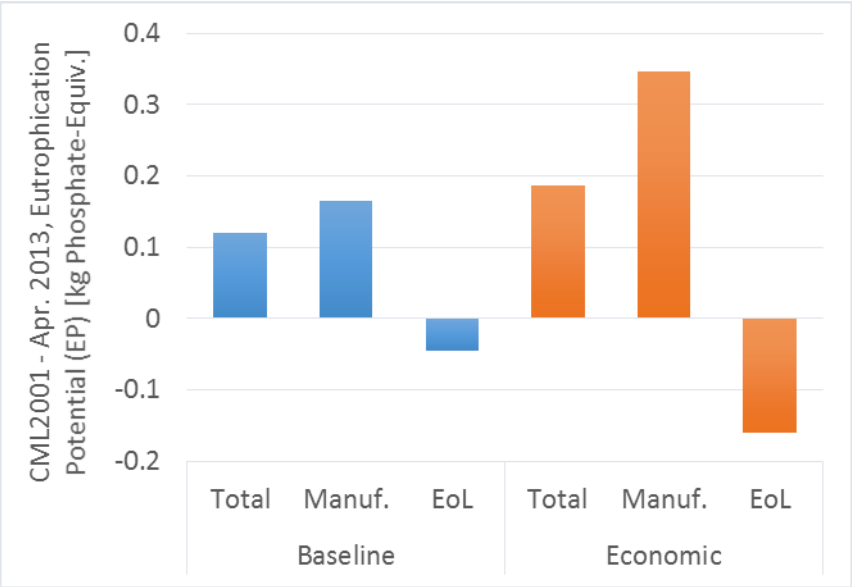

Figure 4-11: Eutrophication Potential for the manufacturing and EoL of copper cables in a small office

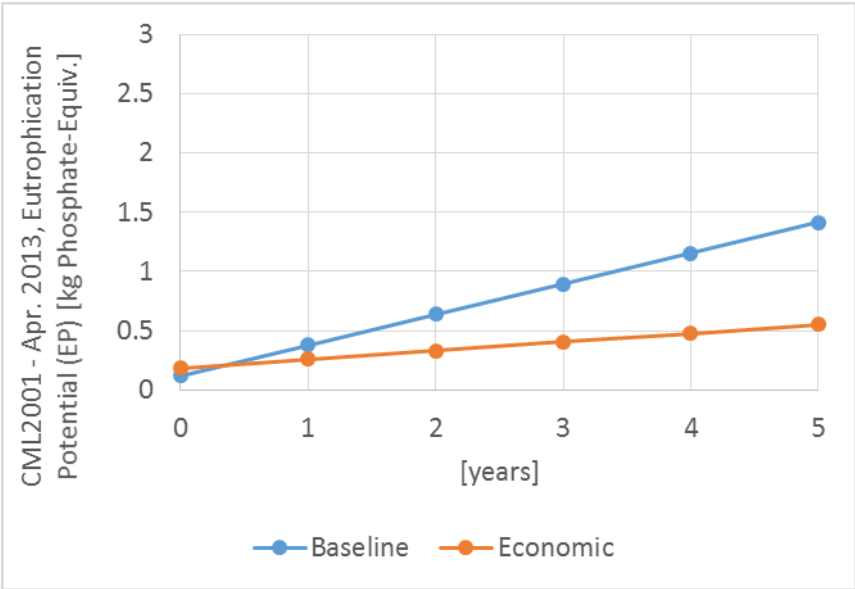

Figure 4-12: Eutrophication Potential for the life cycle including the use phase of copper cables in a small office

The net manufacturing impacts are offset in under 1 year for the upsized cables due to the large savings in use phase impacts.

4.1.2.2 Large office

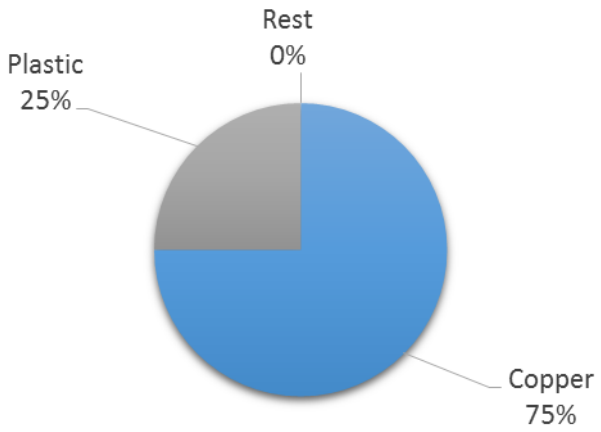

Figure 4-13: Contributions to the Eutrophication Potential of the manufacturing of the copper cable used in large offices

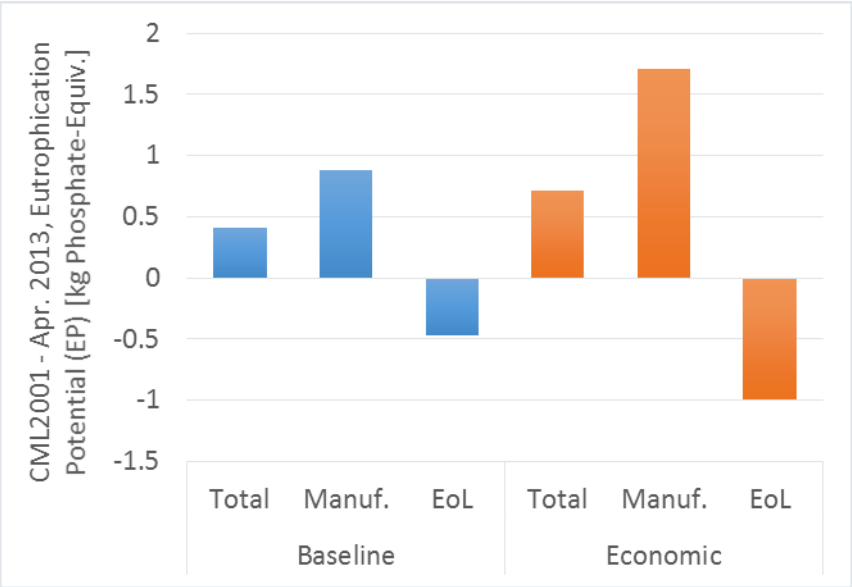

Figure 4-14: Eutrophication Potential for the manufacturing and EoL of copper cables in a large office

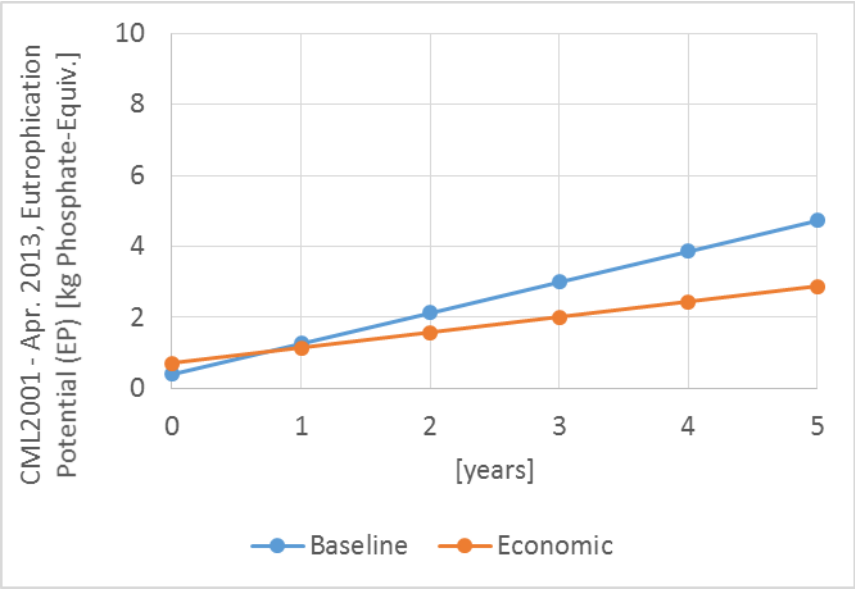

Figure 4-15: Eutrophication Potential for the life cycle including the use phase of copper cables in a large office

For large offices, the duration for the offset of manufacturing phase impacts is longer than that for small offices but still under 1 year. Beyond that threshold the Economic scenario upsized cables are advantageous in the EP category.

4.1.2.3 Large industrial plant

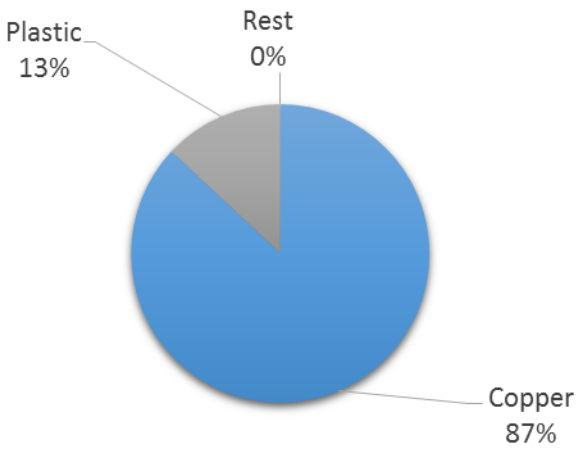

Figure 4-16: Contributions to the Eutrophication Potential of the manufacturing of the copper cable used in large industrial plants

For industrial plants, a greater share of the manufacturing stage impacts comes from the greater copper conductor required for medium voltage cables. In this application case, 87% of the EP

contribution stems from the production of the copper while 13% is associated with the production of plastics used in the cable construction.

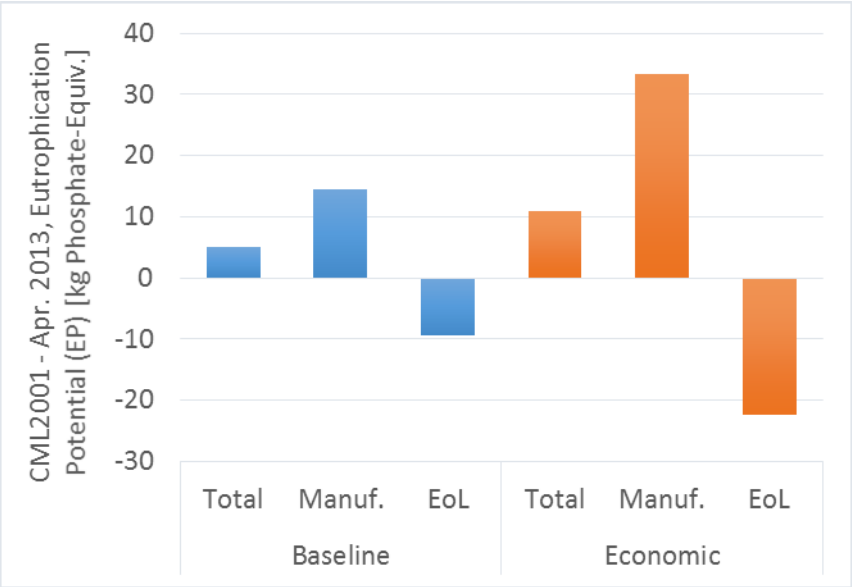

Figure 4-17: Eutrophication Potential for the manufacturing and EoL of copper cables in a large industrial plant

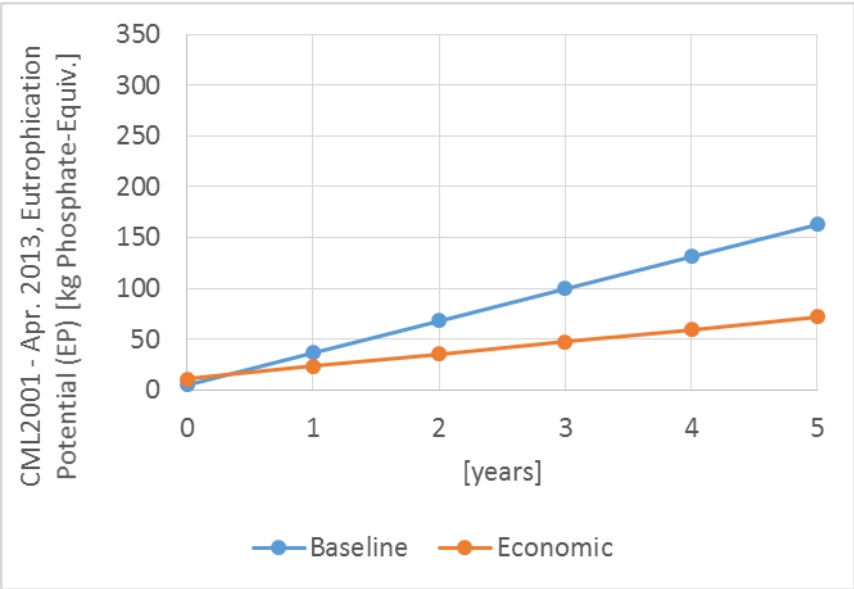

Figure 4-18: Eutrophication Potential for the life cycle including the use phase of copper cables in a large industrial plant

The payback of greater EP impacts for the upsized Economic case, through lower impacts for the use phase, is less than 1 year for the industrial plant application case.

4.1.3 Global Warming Potential (GWP)

Table 4-3: Global Warming Potential for the manufacturing and EoL of copper cables in a small office, large office and large industrial plant

GWP [kg CO_2-equiv.]	Small office		Large office		Large industrial plant	
	Baseline	Economic	Baseline	Economic	Baseline	Economic
Total	547	921	2113	3822	21313	46702
Manufacturing	600	1107	2662	4980	37203	84068
EoL	-53	-186	-549	-1159	-15890	-37366

4.1.3.1 Small office

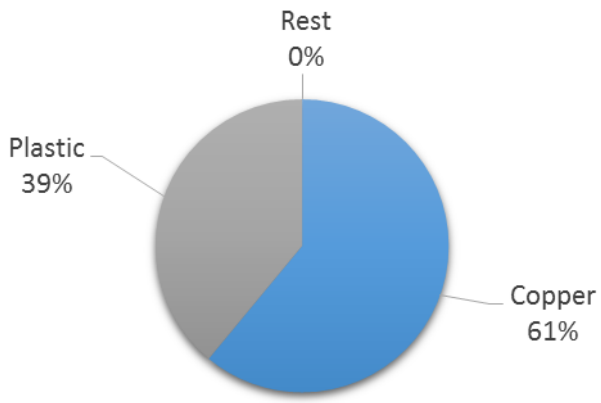

Figure 4-19: Contributions to the Global Warming Potential of the manufacturing of the copper cable used in small offices

In the GWP category, over 90% of the impacts for this category are associated with carbon dioxide emissions at various stages of the life cycle.

These carbon dioxide emissions for low voltage cables are mostly through the production of the copper conductor and through the production of the PVC isolation used.

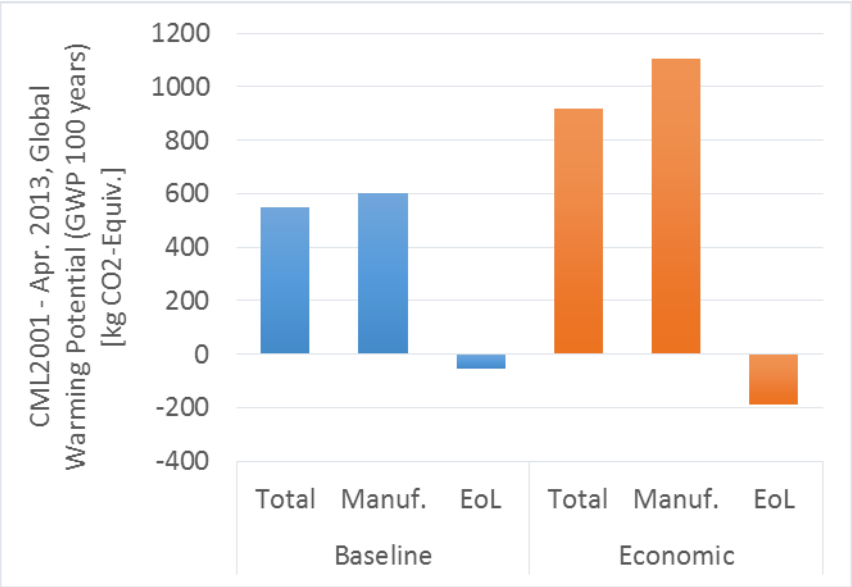

Figure 4-20: Global Warming Potential for the manufacturing and EoL of copper cables in a small office

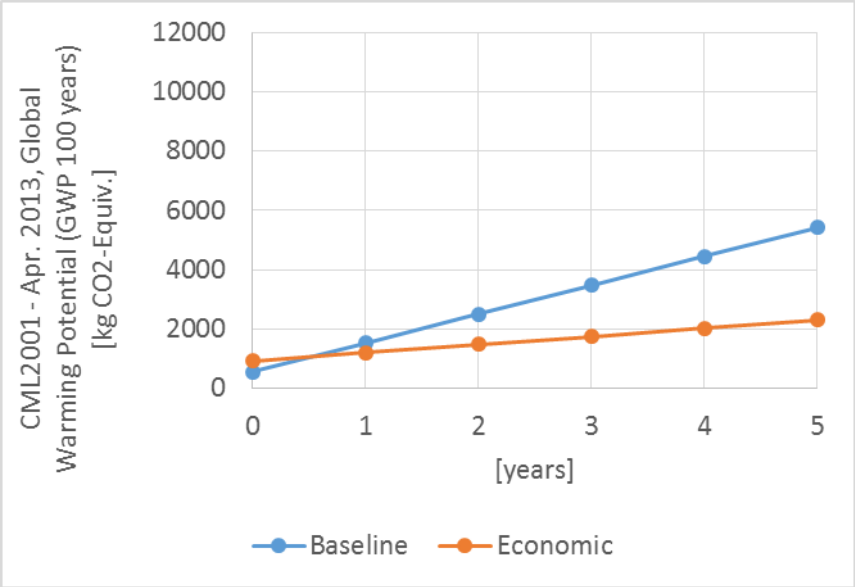

Figure 4-21: Global Warming Potential for the life cycle including the use phase of copper cables in a small office

The carbon dioxide emissions associate with the electricity losses are far higher than that associated with the manufacturing of the upsized cables. As a result, the greater manufacturing phase impacts due to upsizing the copper cables are offset in half a year. From that point onwards, all use of upsized cables leads to a lower GWP over the life cycle compared to the regular cables of the baseline scenario.

4.1.3.2 Large office

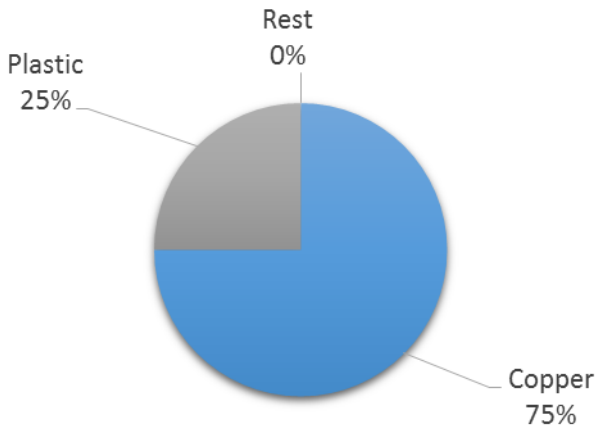

Figure 4-22: Contributions to the Global Warming Potential of the manufacturing of the copper cable used in large offices

The low voltage cables used for large offices have the same component contribution to GWP as in the small offices application case.

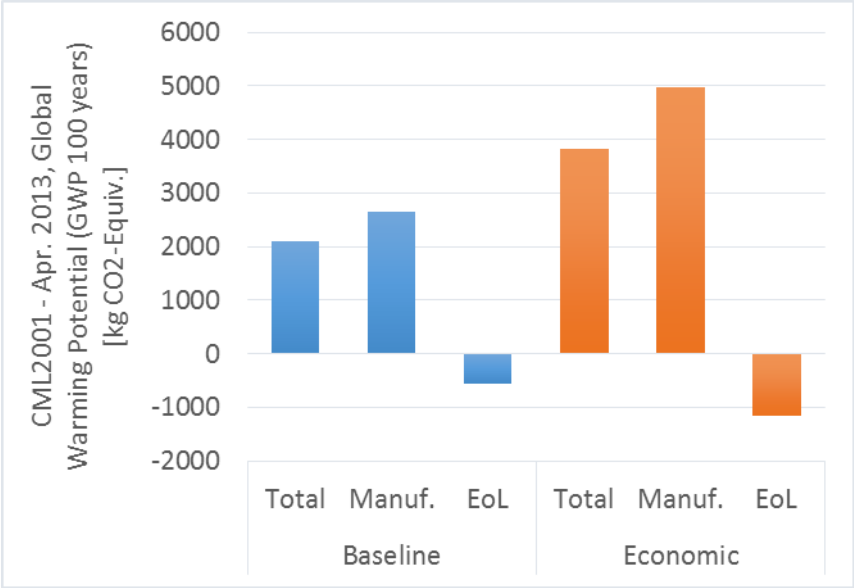

Figure 4-23: Global Warming Potential for the manufacturing and EoL of copper cables in a large office

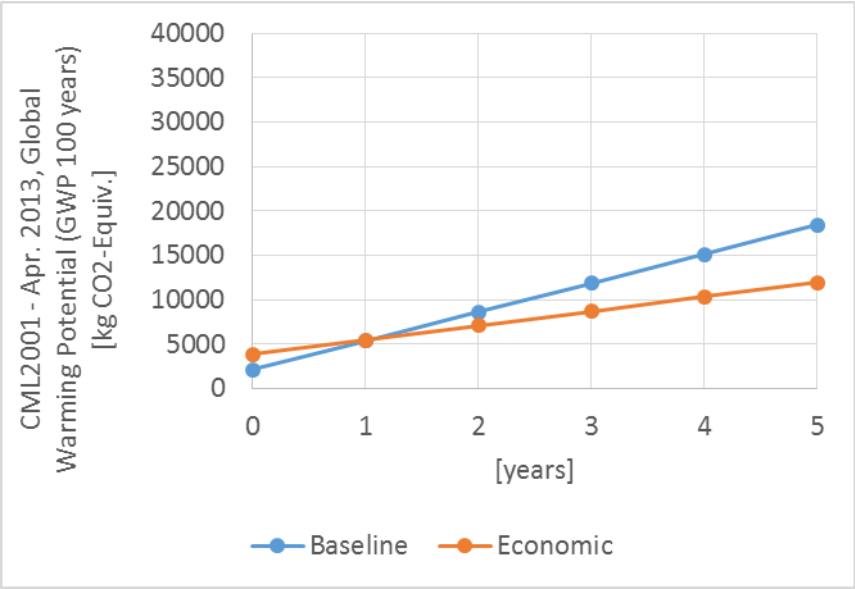

Figure 4-24: Global Warming Potential for the life cycle including the use phase of copper cables in a large office

The greater amount of cables required for large offices requires a longer payback period for GWP impacts than in the case for small offices. In 1 year, the greater manufacturing GWp impact of upsized low voltage cables in large offices is offset by use phase savings.

4.1.3.3 Large industrial plant

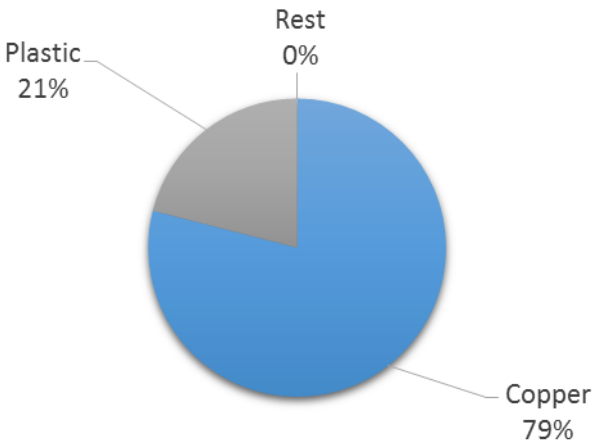

Figure 4-25: Contributions to the Global Warming Potential of the manufacturing of the copper cable used in large industrial plants

For the medium voltage cables used in aluminium plants, copper is the largest contributor to the GWP impacts during the manufacturing phase, through the carbon dioxide emissions, followed by the sheathing used.

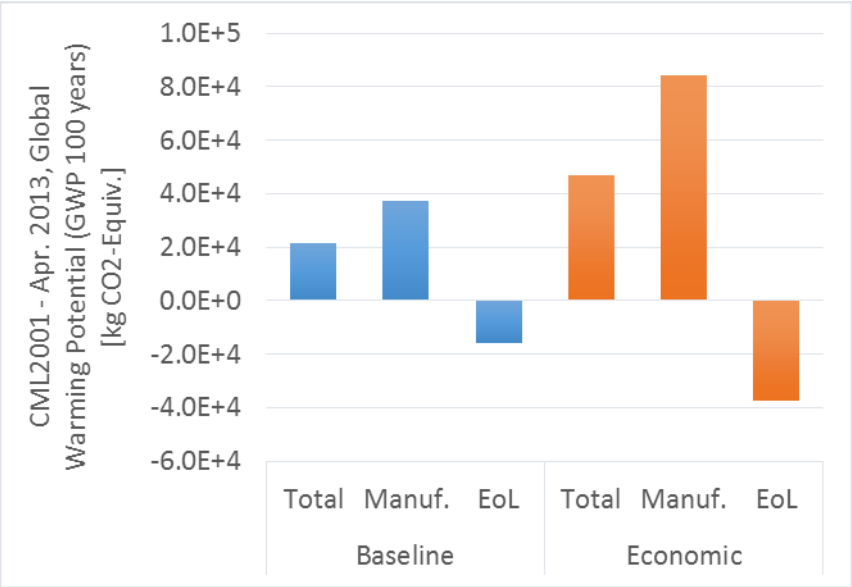

Figure 4-26: Global Warming Potential for the manufacturing and EoL of copper cables in a large industrial plant

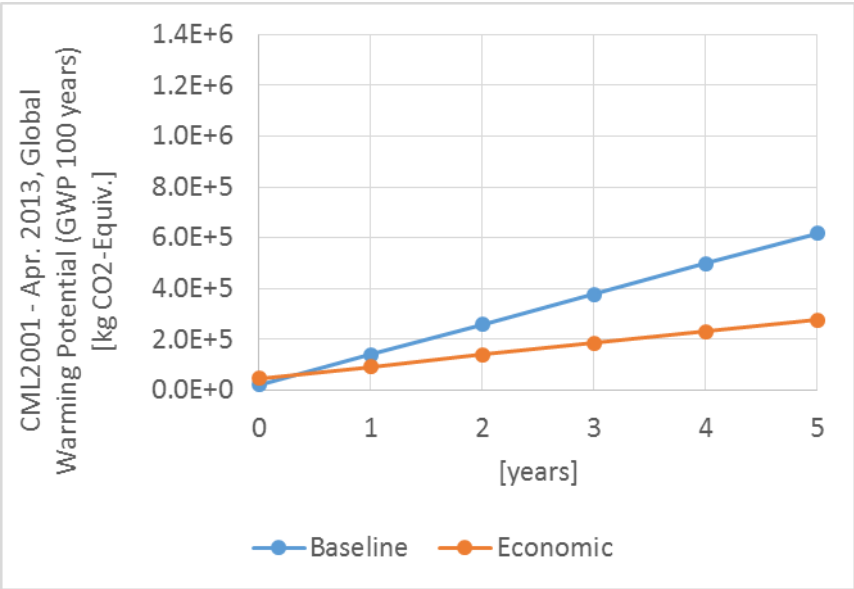

Figure 4-27: Global Warming Potential for the life cycle including the use phase of copper cables in a large industrial plant

The payback period for the larger GWP impacts for upsized cables in the Economic scenario is less than half a year.

4.1.4 Photochemical Ozone Creation Potential (POCP)

Table 4-4: Photochemical Ozone Creation Potential for the manufacturing and EoL of copper cables in a small office, large office and large industrial plant

POCP [kg Ethene-equiv.]	Small office		Large office		Large industrial plant	
	Baseline	Economic	Baseline	Economic	Baseline	Economic
Total	0.15	0.28	0.66	1.22	5.80	12.75
Manufacturing	0.18	0.39	0.99	1.92	12.02	27.39
EoL	-0.03	-0.11	-0.33	-0.70	-6.22	-14.63

4.1.4.1 Small office

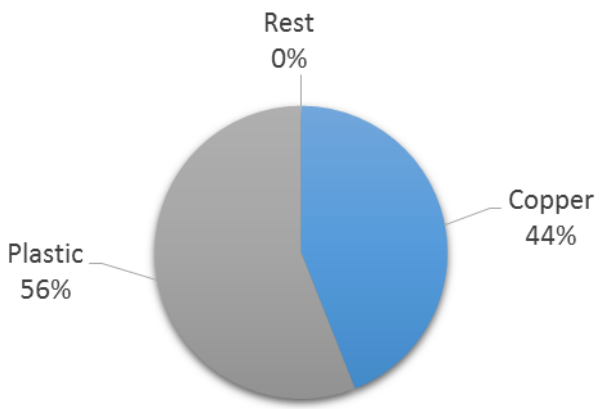

Figure 4-28: Contributions to the Photochemical Ozone Creation Potential of the manufacturing of the copper cable used in small offices

In terms of POCP impacts, it is not the copper but rather the PVC production that is the dominant source of impacts with 56% of total contribution. It is chiefly the sulphur dioxide and nitrogen oxides emission associated with the production processes that contribute to this category.

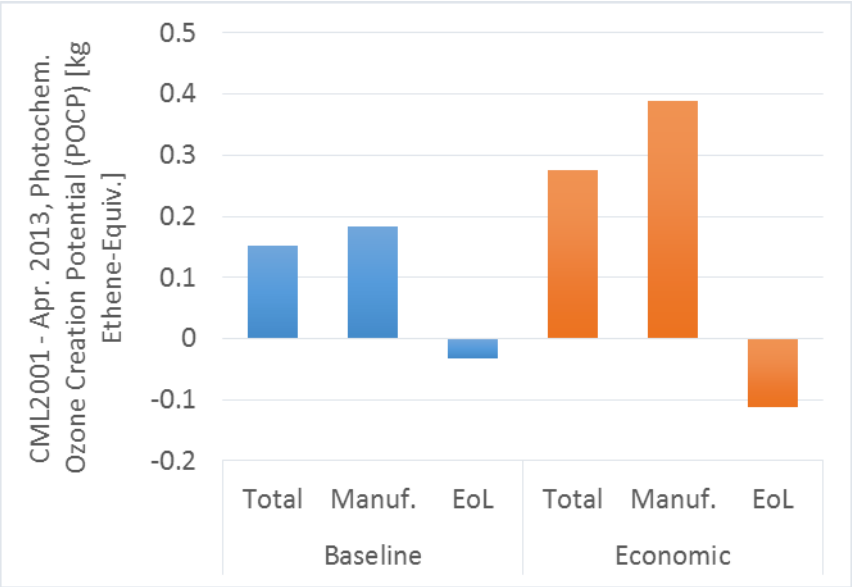

Figure 4-29: Photochemical Ozone Creation Potential Potential for the manufacturing and EoL of copper cables in a small office

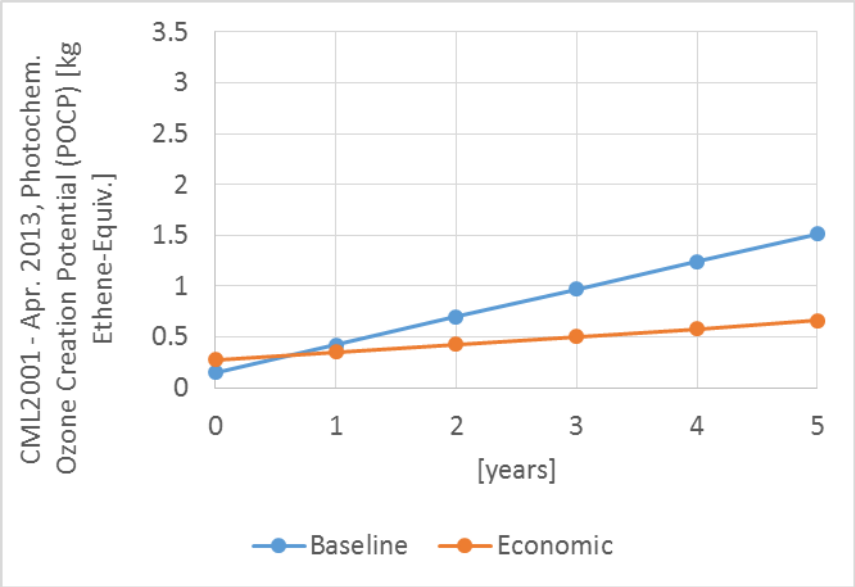

Figure 4-30: Photochemical Ozone Creation Potential Potential for the life cycle including the use phase of copper cables in a small office

4.1.4.2 Large office

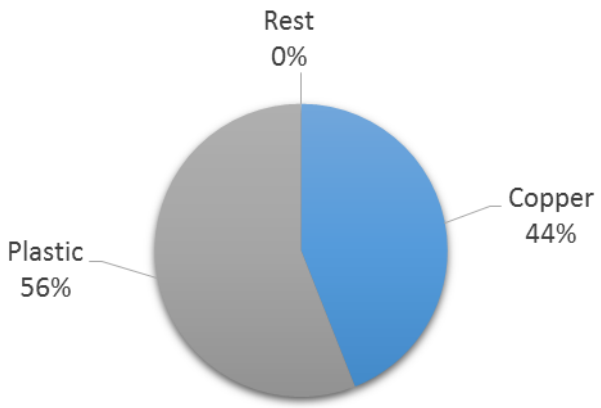

Figure 4-31: Contributions to the Photochemical Ozone Creation Potential of the manufacturing of the copper cable used in large offices

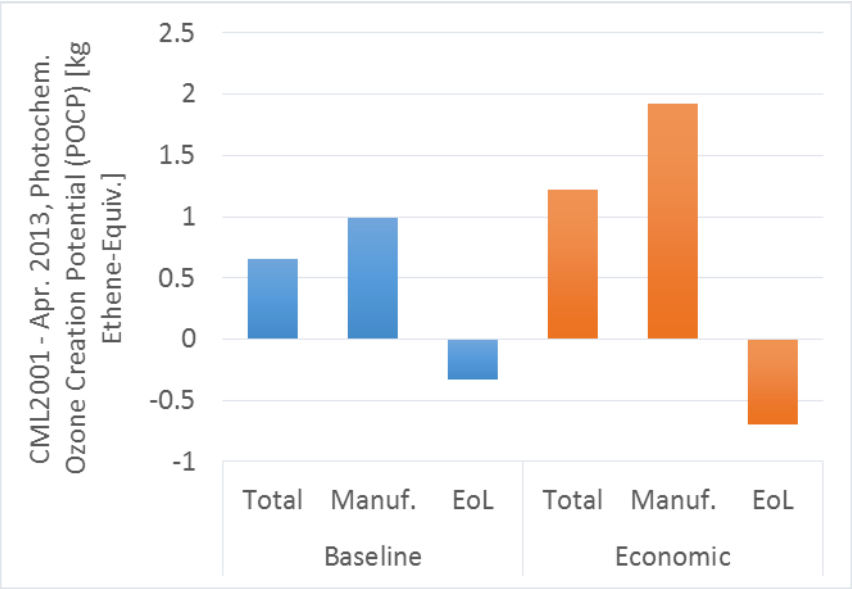

Figure 4-32: Photochemical Ozone Creation Potential Potential for the manufacturing and EoL of copper cables in a large office

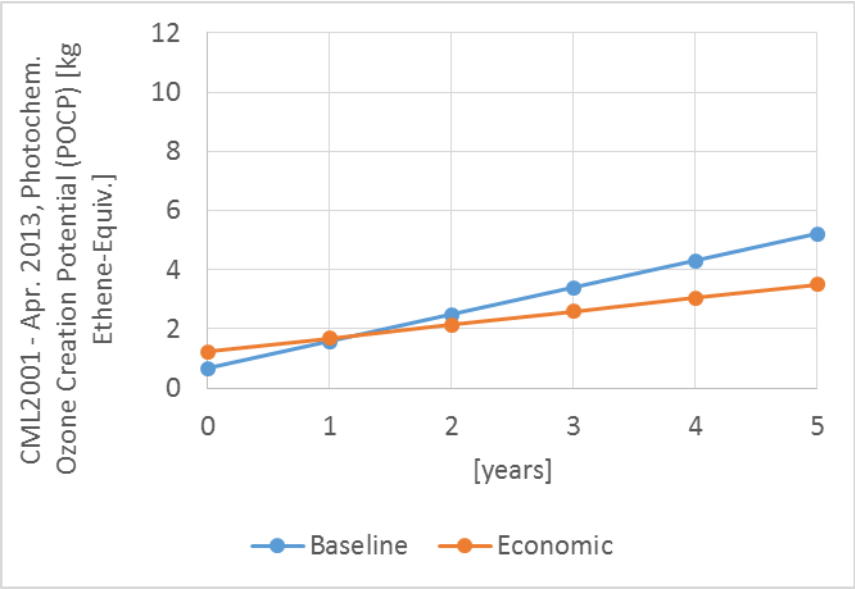

Figure 4-33: Photochemical Ozone Creation Potential Potential for the life cycle including the use phase of copper cables in a large office

As in the previous categories, the greater impact from upsized cables is offset within a year of their use. Beyond this time frame of use, the upsized cables have a lower life cycle impact to this impact category.

4.1.4.3 Large industrial plant

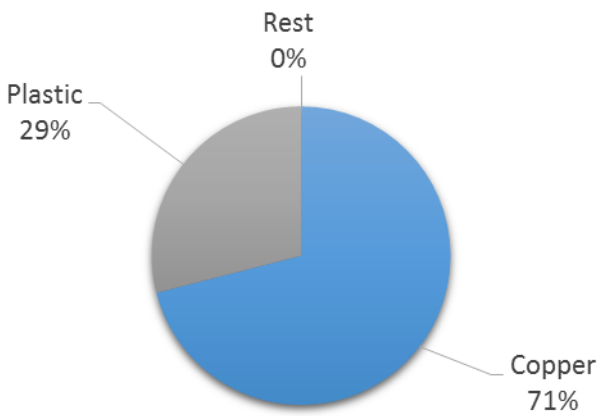

Figure 4-34: Contributions to the Photochemical Ozone Creation Potential of the manufacturing of the copper cable used in large industrial plant

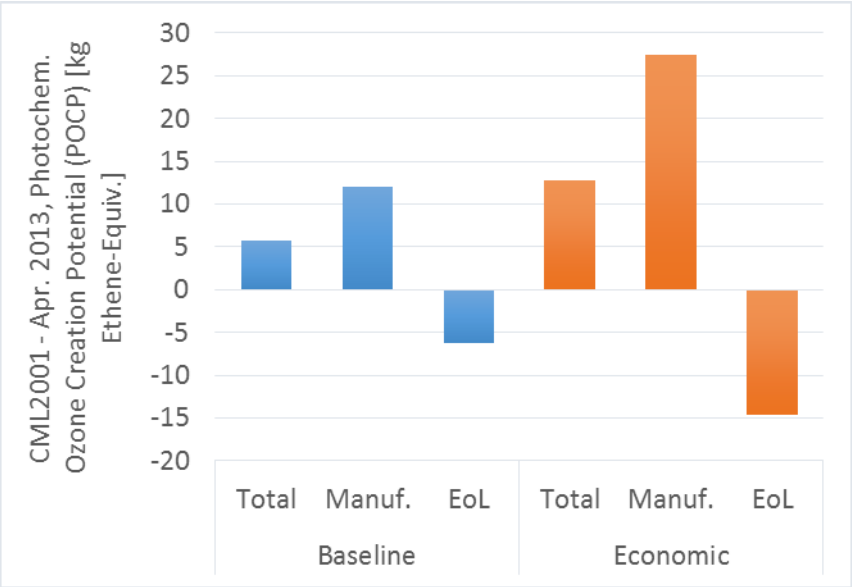

Figure 4-35: Photochemical Ozone Creation Potential Potential for the manufacturing and EoL of copper cables in a large industrial plant

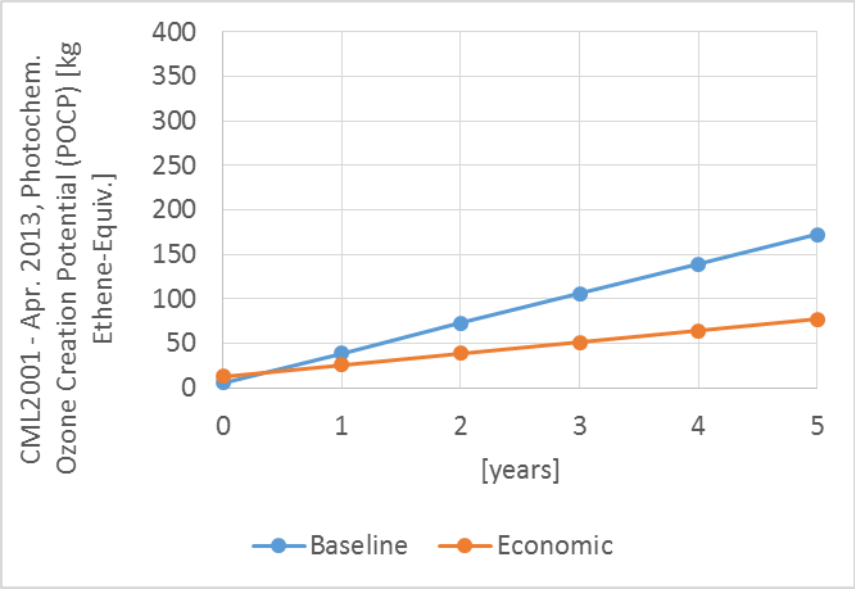

Figure 4-36: Photochemical Ozone Creation Potential Potential for the life cycle including the use phase of copper cables in a large industrial plant

4.1.5 Primary Energy Demand (renewable and non-renewable)

Table 4-5: Primary Energy Demand (renewable and non-renewable) for the manufacturing and EoL of copper cables in a small office, large office and large industrial plant

PED [MJ]	Small office		Large office		Large industrial plant	
	Baseline	Economic	Baseline	Economic	Baseline	Economic
Total	9870	14471	30546	51600	349553	753084

Manufacturing	11367	19722	46013	84248	593005	1325582
EoL	-1497	-5251	-15467	-32648	-243452	-572497

4.1.5.1 Small office

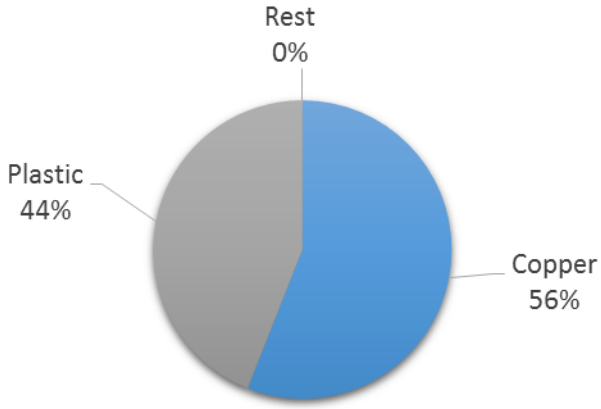

Figure 4-37: Contributions to the Primary Energy Demand of the manufacturing of the copper cable used in small offices

For the production of low voltage cables used in offices, the copper is the dominant consumer of primary energy in the manufacturing of the cable. The plastic isolation for these cables contributes about 44% of the total manufacturing impact.

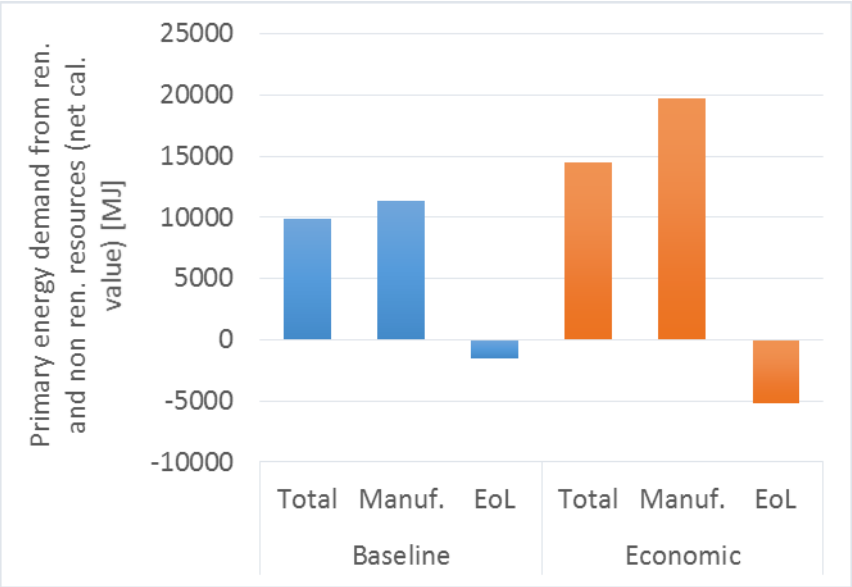

Figure 4-38: Primary Energy Demand (renewable and non-renewable) for the manufacturing and EoL of copper cables in a small office

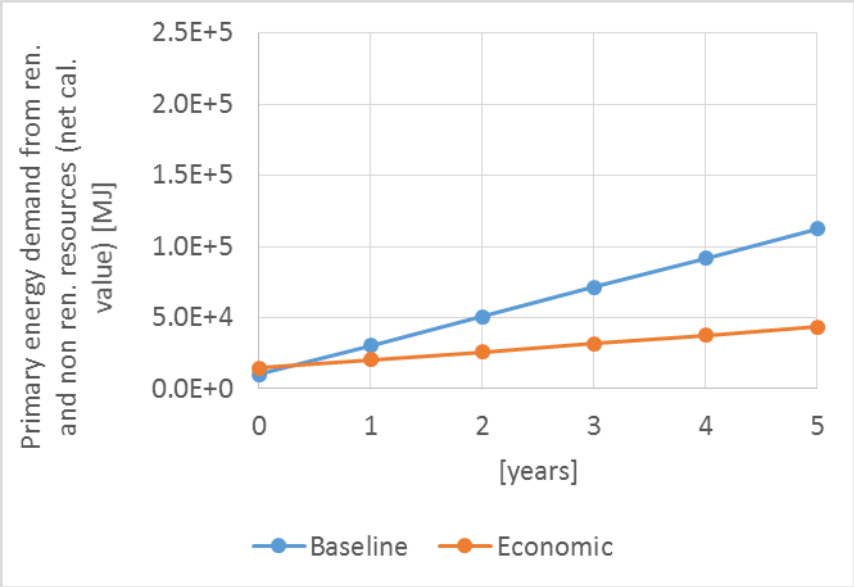

Figure 4-39: Primary Energy Demand (renewable and non-renewable) for the manufacturing and EoL of copper cables in a small office

4.1.5.2 Large office

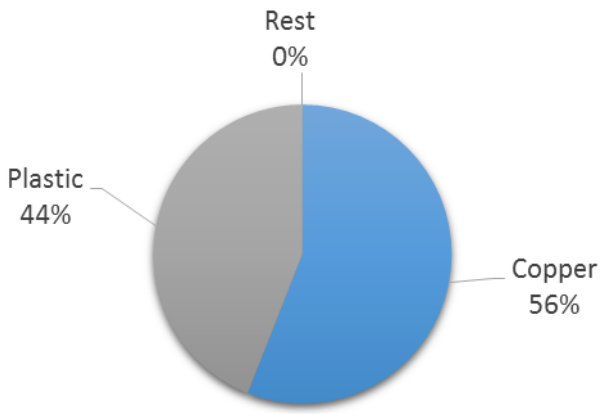

Figure 4-40: Contributions to the Primary Energy Demand of the manufacturing of the copper cable used in large offices

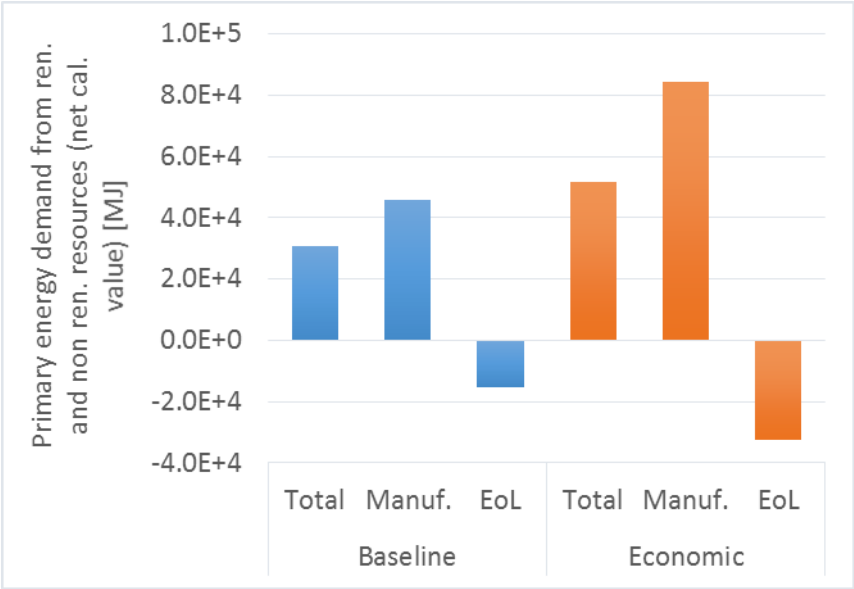

Figure 4-41: Primary Energy Demand (renewable and non-renewable) for the life cycle including the use phase of copper cables in a small office

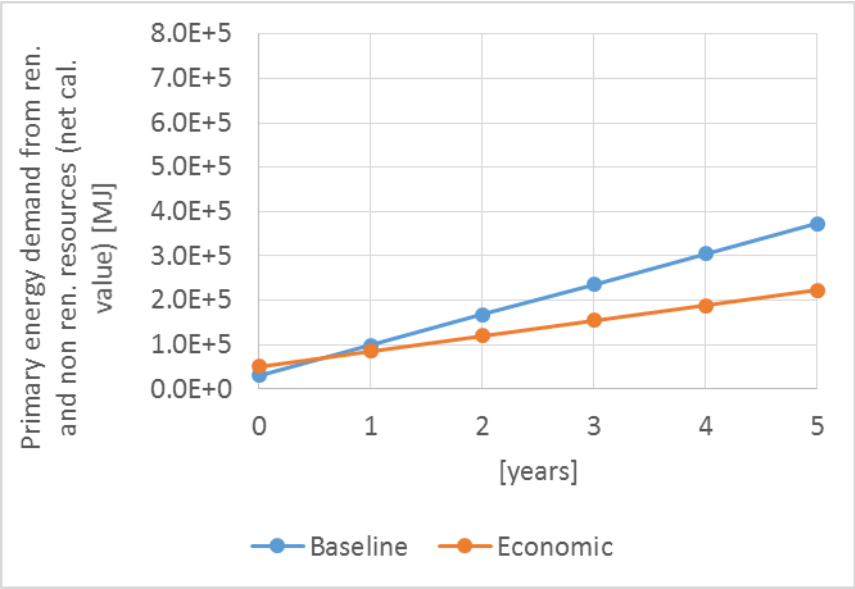

Figure 4-42: Primary Energy Demand (renewable and non-renewable) for the life cycle including the use phase of copper cables in a large office

4.1.5.3 Large industrial plants

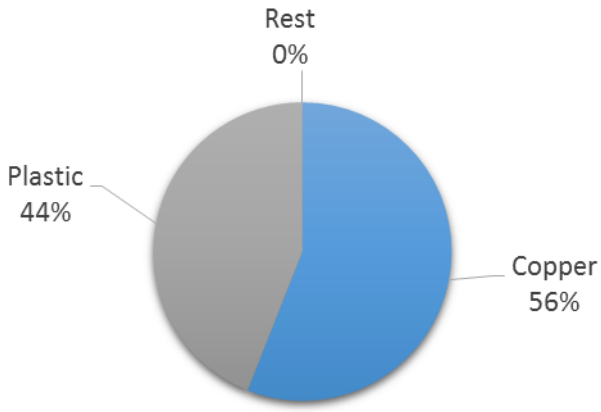

Figure 4-43: Contributions to the Primary Energy Demand of the manufacturing of the copper cable used in large industrial plants

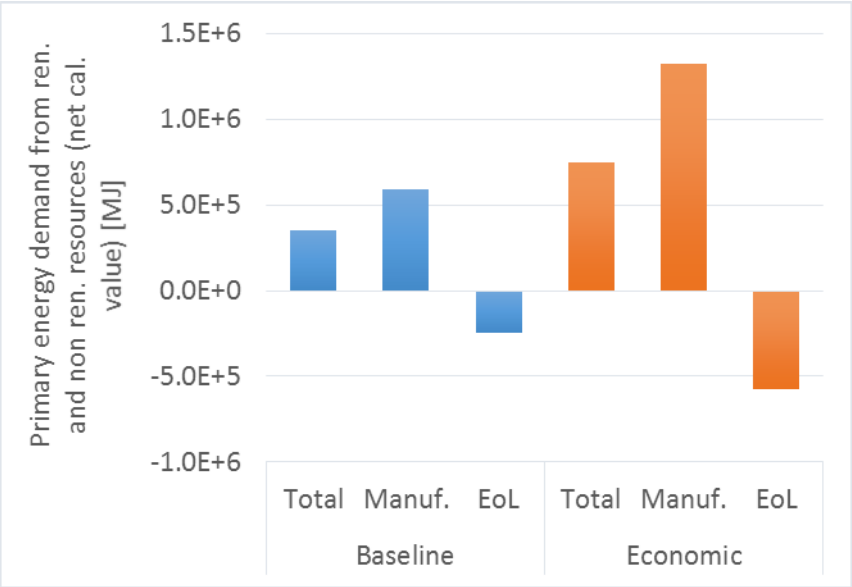

Figure 4-44: Primary Energy Demand (renewable and non-renewable) for the manufacturing and EoL of copper cables in a large industrial plant

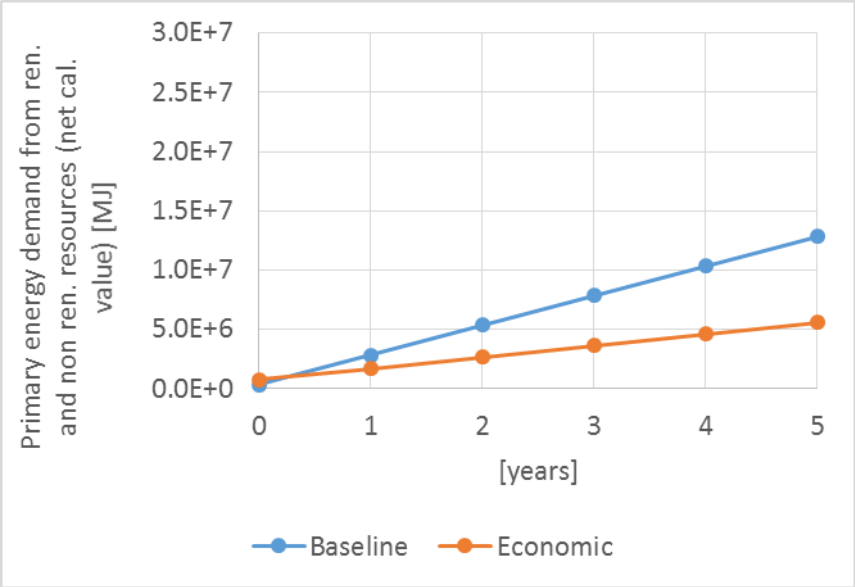

Figure 4-45: Primary Energy Demand (renewable and non-renewable) for the life cycle including the use phase of copper cables in a large industrial plant

For all three application cases studied above, under the Primary Energy Demand impact category, the payback of the greater net manufacturing impact from upsizing is offset within a year of use of the upsized cables.

5 INTERPRETATION

5.1 IDENTIFICATION OF RELEVANT FINDINGS

- Upsized cables have a higher impact during manufacturing stage but these impacts are offset by reductions in electricity losses
- For acidification, eutrophication, global warming, ozone creation and primary energy impact categories, upsized cables result in lower net life cycle impact after 1 year of their use
- Following the 1 year mark, the upsized cables result in lower net impact level for the aforementioned impact categories for each successive year of their use

5.2 DATA QUALITY ASSESSMENT

Inventory data quality is judged by its precision (measured, calculated or estimated), completeness (e.g., unreported emissions), consistency (degree of uniformity of the methodology applied on a study serving as a data source) and representativeness (geographical, temporal, and technological).

To cover these requirements and to ensure reliable results, first-hand industry data in combination with consistent background LCA information from the GaBi LCI database were used. The LCI data sets from the GaBi LCI database are widely distributed and used with the GaBi 6 Software. The datasets have been used in LCA models worldwide in industrial and scientific applications in internal as well as in many critically reviewed and published studies. In the process of providing these datasets they are cross-checked with other databases and values from industry and science.

5.2.1 Precision and completeness

- ✓ **Precision:** As the relevant foreground data are primary data or modelled based on primary information sources of the owner of the technology, no better precision is reachable within this project.

- ✓ **Completeness:** Each unit process was checked for mass balance and completeness of the emission inventory. See Section 2.5 for any omissions.

5.2.2 Consistency and reproducibility

- ✓ **Consistency:** All background data were sourced from the GaBi databases. Allocation and other methodological choices were made consistently throughout the model. The sources for the foreground data are the same for the Baseline and Economic scenarios studied here.

- ✓ **Reproducibility:** Reproducibility is warranted as much as possible through the disclosure of input-output data, dataset choices, and modelling approaches in this report. Based on this information, any third party should be able to approximate the results of this study using the same data and modelling approaches.

5.2.3 Representativeness

- ✓ **Temporal:** The primary data were based on DNV-GL bill of materials compiled in 2014, market research on recycling from 2014, and the EGEMIN study published in 2011. All secondary data come from the GaBi 6 2013 databases. As the study intended to compare the product systems for the reference year 2014, temporal representativeness is warranted.

- ✓ **Geographical:** As far as possible, primary and secondary data were collected specific to the EU-27 region under study. Geographical representativeness is considered to be high.
- ✓ **Technological:** All primary and secondary data were modelled to be specific to the technologies or technology mixes under study. Technological representativeness is considered to be good.

5.3 Completeness, Sensitivity, and Consistency

5.3.1 Completeness

All relevant process steps for each product system were considered and modelled to represent each specific situation. The process chain is considered sufficiently complete with regard to the goal and scope of this study.

5.3.2 Consistency

All assumption, methods, and data were found to be consistent with the study's goal and scope. Differences in background data quality were minimized by using LCI data from the GaBi 6 2013 databases. System boundaries, allocation rules, and impact assessment methods have been applied consistently throughout the study.

5.4 Conclusions, Limitations, and Recommendations

5.4.1 Conclusions

This study examines the environmental implications upsizing the copper cables used in three application cases: small offices, large offices, and industrial plants.

These environmental impacts have been measured according to selected indicators that are representative of environmental and health hazards.

This study finds that for the environmental impact categories of acidification, eutrophication, global warming, ozone creation, and primary energy demand, the upsizing of copper cables is environmentally advantageous. There is a greater impact associated with the production of these larger cables but these are offset through the reduction in electricity losses. Since electricity production based on the selected grid mix EU27 also contributes to the same impact categories, reduced losses translates to environmental benefits. The longer the use of cables with lower loss rates, the greater the environmental advantage in these impact categories tends to be. The difference in net manufacturing impact (manufacturing + end of life) between regular cables in the Baseline scenario and upsized cables in the Economic scenario is offset within 1 year of use for these impact categories.

Considering the widely accepted nature of the AP, EP, GWP, POCP and primary energy demand as well as the high margin for error and instability in the toxicity evaluation methodologies, this study concludes that, within the aforementioned scope of use and impact assessment, the upsized copper cables (represented in the economic scenario) afford significant environmental benefits over the life cycle of the cables.

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