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Estimate of energy consumption and CO_2 emission associated with the production, use and final disposal of PVC, XLPE and PE cables.

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1. Summary

Cables are a fundamental tool in a large number of applications: distribution of electricity, the automotive industry, telecommunications, etc.

This study focuses on electricity distribution cables used domestically. Specifically, on single-pole cables with copper conductor and insulant made of just one material.

The methodology used is based on a procedure for environmental accounting of energy consumption and CO_2 emission figures, in which these indicators have been estimated in each of the stages in the cable's life cycle (extraction and supply of materials, production of the cable, transport for installation, use and final disposal). The end results signify the sum of the energy consumption and CO_2 emission figures equivalent to each of these stages.

The standard case for the study to be carried out was a single-pole cable with copper conductor and PVC insulation, with a rated section of 35 mm^2. The elements for comparison purposes selected were cables with insulant made of XLPE cross-linked polyethylene and PE with mineral charge, with a rated section of 25 mm^2, in such as way that the three types of cables compared allow a maximum admissible intensity as close as possible, taking Low-voltage Electrotechnical Regulations into consideration.

The XLPE cable additionally has a PVC coating since, although the choice of insulants with mixed materials has been avoided throughout, it has been noted that, for the specific case of cross-linked polyethylene, it is not usual to find single-pole cables without a coating of a different composition.

The unit of assessment selected was a section 1 m in length of each of the cables listed above. To calculate the energy losses in the usage stage, the cable's mean lifetime, considered as 50 years for all the materials, was contemplated, assuming a usage time of 8 hours per day.

In the case of the PVC and the PE with mineral charge, the option of introducing 25% recycled materials into the cable composition was contemplated, although at present, the use of recycled raw materials is not common. Cross-linked polyethylene is not usually subjected to recycling processes because of its structure, and this option has therefore not been considered.

The cable presenting the best results from the viewpoint of the environmental indicators considered is PVC with 25% recycled materials in its composition, with an energy consumption throughout the life cycle of 144 kWh m^{-1} and the associated CO_2 emission of 65 kg.

Not including recycled material in the cable signifies a 0.1% increase in energy consumption and in CO_2 emissions. The new PVC cable considered, throughout the life cycle, consumes 145 kWh m^{-1}, and signifies emission of 65 kg of CO_2.

There follow the polyethylene cables with mineral charge (with and without recycled material), which signify consumption of 198 kWh m^{-1} and emission of 88 kg of CO_2.

The cable signifying the largest energy consumption is the cross-linked polyethylene, 199 kWh m^{-1}, and emission of 88 kg of CO_2 m^{-1}.

The PE cables with mineral charge, either with or without recycled materials, and the cross-linked polyethylene, signify very similar energy consumption figures, with a difference of less than 1%.

Including 25% recycled materials in the composition of the PVC cable signifies an energy saving in the region of just 0.1%.

2. Background

Nowadays, cables are an essential tool in a large number of applications. They are widely used in construction, telecommunications (fibre-optics, etc.), in the automotive, railway and aerospace industries, in electricity distribution and in the field of electronics.

In this document, cables intended for domestic electrical installations are considered, specifically those specified in the Low-voltage Electrotechnical Regulations (Royal Decree 842/2002 of the 2nd August 2002).

Low-voltage distribution grids start out from high/low-voltage transformation stations and distribute electricity along main thoroughfares or streets, to provide the corresponding power supplies to buildings.

The most commonly used conductors in electricity distribution are aluminium and copper.

Furthermore, cables can be divided into two major groups: single-pole and multi-pole. The first consist of one single conductor wire, normally insulated by one or more dielectric materials, whilst the second comprise bundles of a certain number of conductors independently insulated and coated with a common dielectric.

All these factors and different possible layouts affect the characteristics of the insulant the conductor must be protected with.

For the study, the simplest kind of cables available on the market have been selected: single-pole cables used in domestic electrical installations with no outer coating; i.e. those solely comprising the conductor and the insulant produced from one single material.

2.1. Objective and calculation bases

This document presents an estimate of energy consumption and carbon dioxide (CO_2) emission attributable to the manufacture, use, recycling and final waste disposal of cables used domestically, solely comprising the copper conductor and the insulant, with no outer coating, and installed under embedded tube, with insulant made of PVC, XLPE and PE with mineral charge.

This focus is based on the consideration of all the stages of a study of the Life Cycle Assessment (LCA), although the scope focuses solely on the two aspects indicated above. An LCA cannot be used to compare products with each other, but rather services and/or product quantities carrying out the same function.

In order to make it possible to produce an analysis enabling comparative results to be obtained, the unit of assessment (the functional unit in an LCA study) used was 1 m of single-pole cable with copper conductor for low-voltage domestic electricity distribution.

Cables are classified according to the rated section of the conductor, which indicates the maximum resistance of the cable at 20°C (UNE-EN 60228). The maximum admissible intensity the cable may conduct will depend on the rated section, on its insulation type and on the type of installation. For multi-pole cables, the layout and number of single-pole cables it comprises will also have an influence (Low-voltage Electrotechnical Regulations; Royal Decree 842/2002 of the 2nd August 2002).

2.2. Contents of the document

A description is given of the stages comprising the life cycle of the cable, as well as the calculation hypotheses and scenarios for the comparative analysis. The magnitudes of the significant electrical consumption values are indicated, as well as the energy sources defining the CO_2 emission factors.

The results obtained are set out in detail and summary form. The estimates obtained are analysed, identifying the alternatives with the lowest energy consumption and CO_2 emission values, in ascending order.

3. The life cycle of a cable

Figure 3.1 shows the typical life cycle of a cable, focusing on energy use and the corresponding atmospheric emissions.

The first stage corresponds to extraction of the raw materials and supply of materials for production of the cable.

The second stage consists of actual production of the cable, which will depend on both the type of cable and on the materials used in its composition.

Next, the stages of installation and use of the cable are considered. It is estimated that all the cables have a mean lifetime of 50 years.

Once the cable's usage period has ended, it is dismantled and transported to a recycling centre. The non-recyclable portion is sent to a final waste-disposal management centre.

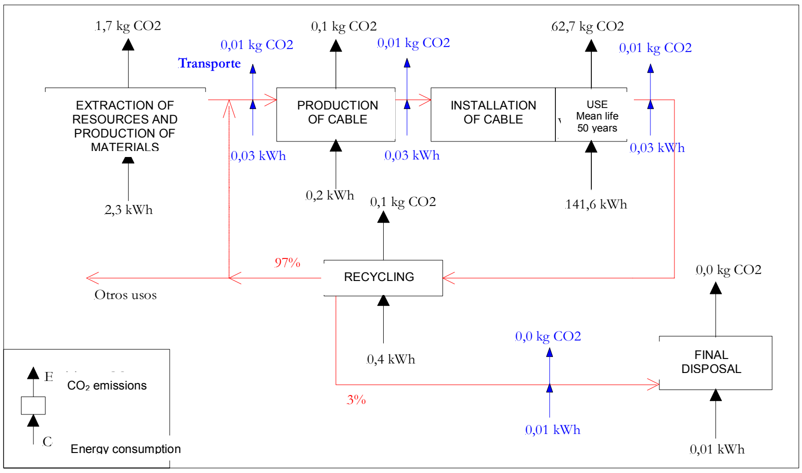

Figure 3.1. Flowchart of the life cycle of a cable

4. Estimate of energy consumption and CO_2 emission attributable to 1 m of cable for electricity distribution.

4.1. Calculation base

4.1.1. Dimensions

In order to produce comparable results, 1 m of single-pole cable was selected, with copper conductor and insulant made of different materials.

4.1.2. Materials

The analysis focuses on the estimate of energy consumption and the corresponding emissions of CO_2 per metre of cable insulated with:

- PVC
- XLPE (cross-linked polyethylene)
- PE with mineral charge

PVC cable | *XLPE cable with PVC coating* | *MDPE cable*

Figure 4.1. Commercial single-pole cables with insulant made of different materials

These materials were chosen because they are the most widely used as insulants.

Specifically, the calculation base used was a copper cable 1 m in length, with PVC insulation with a rated section of 35 mm^2, which signifies that it can admit a maximum intensity of 86 A (for the type of installation considered: embedded under tube).

Cables insulated with XLPE or PE with mineral charge allow a temperature of 90ºC to be developed in the conductor, versus the 70ºC of PVC-insulated cables. The maximum admissible intensities will increase in both types of cable compared with the PVC. The comparative elements determined were standardized cables presenting a maximum admissible intensity as close as possible to that of the cable with PVC insulation taken as the reference standard. In other words, XLPE cables and PE cables with mineral charge with a rated section of 25 mm^2, which will admit intensities of up to 96 A, 11% higher than in the case of PVC (Martín, F, 2003).

Cables comprising solely the conductor and the insulating layer are considered, in order to simplify the comparative study, to avoid mixtures of materials, which are common in more complex cables. However, in practice, cables made of XLPE insulant are not usually available without coating, not even for use in domestic electrical installations. In order to achieve as representative a result as possible of actual circumstances, it was decided to include a PVC coating in the XLPE cable.

4.1.3. Scenarios analysed

The following cases are analysed:

1) Cable with PVC insulant, no recycled PVC.

2) Cable with PVC insulant, with 25% recycled material.

3) Cable with XLPE (cross-linked) insulant, and PVC coating.

4) Cable with PE insulant with mineral charge, no recycled material.

5) Cable with PE insulant with mineral charge, with 25% recycled material.

All with copper conductor.

To size these cables, the reference taken was commercially available single-pole cables with a rated section of 35 mm^2 in the case of PVC, and a rated section of 25 mm^2 in the case of XLPE and PE with mineral charge.

Their basic characteristics are listed in Table 4.1.

Table 4.2 shows the electrical characteristics of the cable (maximum resistance at 20 °C and maximum admissible intensity) taken for reference purpose to make the comparison and to select the different standard cables for each material.

The weight calculated per metre of cable differs slightly from the commercial weight specified by the sources consulted; to calculate this, the volumes determined from the commercial dimensions were used, along with a standard composition for each insulant, which is indicated in Table 4.3. It was considered advisable to establish the specific weight of each cable this way, and not the weight supplied in the commercial specifications, to give the study greater generality and to prevent it being limited to the cable produced by any one specific manufacturer.

Table 4.1. Characteristics of the cables selected.

Insulant	RS (mm^2)	Outer coating	Outer ∅ (mm)	Insulant thicknes s (mm)	Coating thickness (mm)	Tabulated weight ($kg\ m^{-1}$)	Calculated weight ($kg\ m^{-1}$)			
							Copper conductor	insulant	coating	TOTAL
PVC	35	no	13.5	2.6		0.45	0.31	0.15	--	0.46
XLPE	25	PVC	11.2	0.9	1.4	0.32	0.22	0.03	0.06	0.31
PE with mineral charge	25	no	9.0	1.2		0.27	0.22	0.06	--	0.28

Sources selected for sizing of the cables:
PVC cable. Sintenax valio.
XLPE cable. Retenax valio.
PE cable with mineral charge. Afumex 750.
Prysmian.
(http://www.ar.prysmian.com/es_AR/cables_systems/energy/catalog_prices/catalog/catal_cat_ar.jhtml, November 2005)

Table 4.2. Characteristics of the cables considered: maximum resistance at 20 °C and maximum admissible intensity.

Insulant	RS (mm^2)	Maximum resistance at 20 °C (Ohm/km) Une EN 60228	Maximum admissible intensity (A)
PVC	35	0.524	86
XLPE	25	0.727	96
PE with mineral charge	25	0.727	96

Table 4.3. Mean composition of the insulants of the standard cables considered

INSULANT	Rated section (mm^2)	Outer section (mm^2)	Composition (1)	(% in weight)	Material density ($kg\ m^{-3}$)		Insulant weight ($kg\ m^{-1}$)
PVC	35	143.1	PVC resin	45	1400	1400	0.15
			Ca carbonate	25	2700		
			Plasticizer (DIDP)	25	967		
			Lubricant, stabilizer and others	5	1400		
XLPE	25	98.5	LDPE	97	915	950	0.03
			Cross-linking agent (silane)	3	--		
PE with mineral charge	25	63.6	LDPE	40	915	1450	0.06
			Aluminium hydroxide	36	2420		
			Magnesium hydroxide	24	2360		

(1). The mean composition of the different insulants was provided by *Benvic*.
(2). Excluding the PVC coating.
(3). Due to the difficulty of establishing the density of the silane compound used as the cross-linking agent, the density of the commercial XLPE was considered; the following compound was used as the standard case: LUTENE SP3450NT LG CHEM.

(http://www.chemwide.co.kr/product3/0matter/matter_type.jsp?prodSeq=26&locale=en&prodSelect=98,93,99,91, November, 2005)
The use of recycled plastics for cable production is not a common situation at present.

In the case of XLPE, recycling is not possible. With regard to PVC and PE with mineral charge, they are usually separated out and recycled for other uses. However, cases including 25% recycled material in the cable composition have been included, as considerable efforts are being made in this direction, and it is believed that use of them in the future could become commonplace.

4.2. Extraction and production of materials

Extraction and production of materials includes the energy required for extraction of natural resources, transport to the factory and production of the materials used in the cable, chiefly: PVC, XLPE, PE, charges such as basic calcium carbonate or magnesium and aluminium hydroxides, plasticizers such as DIDP, lubricants, flame-retardants and others, as well as the copper conductor.

For the PVC, the energy consumption and CO_2 emission presented in the document "*Estimate of the energy consumption and CO_2 emission associated with unit production of PVC*" (Baldasano and Parra, 2005) have been used. The values of the calculation criterion that considers the joint obtention of PVC and caustic soda are used. The energy consumption for the manufacture of PVC is 7.2 kWh kg^{-1}; and the associated CO_2 emission factor is 0.3 kg CO_2 kWh^{-1}.

The cross-linked polyethylene and the polyethylene with mineral charge include low-density polyethylene (LDPE) in their composition, for the estimate of energy consumption associated with the production and the corresponding CO_2 emission, the values established in the ECO PROFILES of the European Plastics Industry (APME, 2003) are used. These give a result of an energy consumption of 7.3 kWh kg^{-1} and a CO_2 emission of 0.2 kg CO_2 kWh^{-1}.

Cross-linked polyethylene, in addition to LDPE, usually includes around 3% silane in weight, which assists the cross-linking process. In some cases, this additive can be added during the polyethylene synthesis process, or subsequently, once polymerization has taken place. In this case, given that the percentage of silane added per kg of polyethylene is very insignificant, it has not been considered in respect of the total, and the energy consumption for production of the cross-linked polyethylene is similar to that for LDPE.

In the case of the mineral charge for the PVC, calcium carbonate, energy consumption of 0.03 kWh kg^{-1} is estimated based on the data available in the "Reference Document on BAT in the cement and lime manufacturing industries" (IPPC, 2001). It is considered that the energy used is based on diesel, and the emission is established at 0.3 kg CO_2 kWh^{-1}.

The energy consumption figures required to produce the magnesium and aluminium hydroxides used as mineral charge for the PE were similar to those required for production of the corresponding oxides, resulting in the requirement of 3.9 kWh kg^{-1} for the alumina and 2.6 kWh kg^{-1} for the MgO. The associated CO_2 emissions in both these cases are 0.2 kg CO_2 kWh^{-1} (Chemlink, 2005; US Department of Energy, 2003).

For the plasticizer DIDP, the energy consumption and CO_2 emissions associated with a standard phthalate ester were chosen, with the result of 7.1 kwh kg^{-1} and 0.3 kg CO_2 kWh^{-1} (ECPI, 2001).

The energy consumption and CO_2 emissions associated with the extraction and supply of the remaining materials: lubricants, flame-retardants, etc., were similar to the base of the insulant in each case (PVC, LDPE). It is considered that the margin of error introduced by this approximation is not excessively large, given that the contribution of these components in terms of weight is between 3% and 5% of the total for the cable.

The extraction and supply of copper signifies an energy consumption of 4.7 kWh kg^{-1} (EPA, 2001) and associated CO_2 emissions of 0.3 kg CO_2 kWh^{-1}, considering fuel-oil, natural gas and electricity as the energy sources.

The energy consumption figures for the materials are summarized in Table 4.4.

Table 4.4 Energy consumption figures for extraction of natural resources and production of materials.

Material	Energy consumption ($kWh\ kg^{-1}$)	Source
PVC	7.19	(Baldasano and Parra, 2005)
XLPE	7.29	Eco-profile Polyolefins (APME, 2004). Eco-profile Conversion processes for polyolefins (APME, 2004)
Al Hydroxide	3.92	US Department of Energy, 2001. http://www.secat.net/docs/resources/ US_Energy_Requirements_for_Aluminum_Production.pdf September, 2005
Mg Hydroxide	2.63	Chemlink Consultants (http://www.chemlink.com.au/mag&oxide.htm, September 2005)
Ca Carbonate	0.06	Reference document on BAT in the cement and lime manufacturing industries (IPPC, 2001)
DIDP	7.10	ECO PROFILE of high volume commodity phthalate esters (ECPI; 2001)
Copper	4.73	BREF non ferrous metal industry (EPA, 2001)

4.3. Production of the cable.

The process of manufacturing the cable, although it depends on the particular type required, can be outlined in a stage of drawing, threading and stranding the conductor, and the subsequent extrusion of the insulant around it.

The mean energy consumption of the production process was estimated in line with the data obtained for a particular production company (Ascable (2002)), giving the result of consumption of 0.36 kWh per kg of cable produced.

To estimate the CO_2 emissions associated with this process, it was considered that the energy sources used were electricity and diesel.

4.4. Installation and dismantling of the cable.

The process of installing cables in homes can be done in various ways; specifically (as stipulated in ITC-BT-26 of the Low-voltage Electrotechnical Regulation passed by ROYAL DECREE 842/2002 of the 2nd August; Spanish State Gazette No. 224, Wednesday, 18th September) there are the following systems:

Embedded installations:

- Cables insulated under flexible tube
- Cables insulated under bendable tube

Surface installations:

- Cables insulated under bendable tube
- Cables insulated under rigid tube
- Cables insulated under enclosed protective duct
- Prefabricated ducting

The type of installation affects the maximum admissible intensity the cable may conduct; in this case, the installation was taken as embedded under tube.

In any case, it is considered that the process of installing and dismantling or removing the cable does not involve any major energy consumption. Moreover, these consumption figures are similar for the different cable types studied, and therefore negligible for a comparative analysis of results.

4.5. Use of the cable.

The energy consumption associated with the usage stage of the cable was estimated taking energy losses consequent to heat dissipation through Joule effect in the conductor into account. The resistance values for conductors tabulated in UNE EN 60228 standard were used, and the maximum admissible intensities were those indicated in the Low-voltage Electrotechnical Regulations (REBT) (Royal Decree 842/2002 of the 2nd August 2002).

To calculate the energy losses, the mean lifetime of the cable was taken into consideration, taken as 50 years for all the materials, assuming a usage time of 8 hours per day.

The circulating intensity considered was the same for the three types of cable, taking half the maximum admissible intensities for reference, in this case 86 A, corresponding to the cable with PVC insulation with rated section of 35 mm^2. This therefore signifies a circulating intensity of 43 A.

The heat losses through Joule effect are quantified according to equation Eq 1.

$$Q = I^2 \cdot R \cdot t \qquad \text{[Eq 1]}$$

where Q is the energy dissipated (J), I is the circulating intensity (A), R the resistance of the conductor (Ohm) and t the time considered (s).

The results obtained for energy consumption and CO_2 emissions corresponding to the usage stage of the cable are shown in Table 4.5. The relative importance of this stage is 96-99%, for both energy consumption and CO_2 emissions.

Table 4.5. Estimated energy consumption in the usage stage of the cable. Considering heat losses through Joule effect.

Material	**RS (mm^2)**	**Max. admissible I (A)**	**Circulating I (A)**	**Resistance (ohm km^{-1})**	**Heat losses through Joule effect (50 years) J m^{-1}**	**Heat losses through Joule effect (50 years) kWh m^{-1}**
PVC	35	86	43	0.524	5.09 10^8	141.6
XLPE	25	96	43	0.727	7.07 10^8	196.4
PE with mineral charge	25	96	43	0.727	7.07 10^8	196.4

4.6. Recycling

It is assumed that 97% of the materials contained in the cable insulation are recyclable, except in the case of the cross-linked polyethylene, which is assumed to be sent entirely for final disposal. The remaining 3% consists of waste materials which are deposited in a disposal site

Since the cables being considered are single-pole cables with just one material as the insulant, they can be recycled by a mechanical process. In more complex cables, which comprise different materials in the insulation, processes with selective solvents normally have to be used, such as the Vinyloop process for PVC.

To recycle the PVC and the polyethylene, an electricity consumption of 0.25 kWh kg^{-1} is used. The associated CO_2 emissions are estimated by applying the Spanish electrical mix, with a result of 0.4 kg CO_2 kWh^{-1}.

Cross-linked polyethylene is not recyclable, and it is therefore sent entirely for final disposal after use.

It is assumed that the recycling process for copper signifies an energy saving of 75% with regard to the original production process (Secretary of State's Office for Energy, industrial development and small and medium-sized enterprises, Ministry for the Economy, 2001), whereby this would signify consumption of 1.2 kWh kg^{-1}. Considering that the energy sources are coal and electricity, 50%/50%, the emissions associated with the recycling process are 0.4 kg CO_2 kg^{-1}.

4.7. Final disposal

Energy consumption of 0.16 kWh is assumed per kg of waste deposited in a disposal site (Choate and Ferland, 2004). It is considered that the energy is 100% diesel.

4.8. Transport

It is assumed that the transport connecting the different stages of the life cycle is performed with cargo trucks which run on diesel, and which have an energy demand of 0.00073 kWh km^{-1} kg^{-1} (WEC, 1998). This value is applicable to Western Europe.

A mean distance of 100 km was considered for transport in all cases: transport of materials to the production plant, transport of the cable to the installation site, transport for recycling and for final disposal.

4.9. Emission factors

Table 4.6 shows the base CO_2 emission factors used in each stage, according to the composition or type of energy supply already indicated for each case.

Table 4.6. CO_2 emission factors.

Energy source / fuel	Emission factor t C TJ^{-1} (IPCC, 1996)	t CO_2 TJ^{-1}	t CO_2 MWh^{-1}
Spanish electrical mix			0.443*
PVC production at Hispavic - Vinilis (Martorell)			0.284*
XLPE production		1.7	0.233
PE production		1.7	0.270
DIDP production		1.8	0.257
Aluminium hydroxide production			0.225
Diesel / fuel-oil	20.2	74.1	0.267
Natural gas	15.3	56.1	0.202
Coal	26.2	96.1	0.346

* Deduced in the document: "Estimate of the energy consumption and CO_2 emission associated with unit production of PVC", JM Baldasano and R. Parra. January 2005".
¶ Corresponds to the calculation criterion that considers the objective of joint obtention of PVC and caustic soda.

5. Results and comparative analysis

The energy consumption and CO_2 emission figures for each of the cases studied are set out in tables 5.1 to 5.5, and in diagram form in figures 5.1 to 5.5.

Tables 5.6 and 5.7 show a summary of the results obtained for each of the materials.

The stage of the life cycle which signifies the largest energy consumption and the highest CO_2 emissions into the atmosphere is use of the cable. A mean lifetime of 50 years has been considered for all the cables, with use of 8 hours per day, and the losses through Joule effect have been estimated, resulting in a contribution of between 97% and 99% to the energy consumption and to the CO_2 emissions for all the cases.

Extraction and supply of materials signifies 2% of the energy consumption and 3% of the CO_2 emissions for new PVC. This means that including recycled material in the cable composition barely has any effect on the overall calculation of energy requirements and CO_2 emitted.

For the cases of cables with PE insulation with mineral charge and XLPE, the importance of this stage is even less, not exceeding 1% of the total.

The cable presenting the best results from the viewpoint of the environmental indicators considered is PVC with 25% recycled materials in its composition, with energy consumption throughout the life cycle of 144 kWh m^{-1}, and the associated CO_2 emission of 65 kg.

The new PVC cable considered consumes 145 kWh m^{-1} throughout the life cycle, and signifies emissions of 65 kg of CO_2.

The polyethylene cables with mineral charge (with and without recycled material) and the cross-linked polyethylene cable signify consumption of 198 kWh m^{-1} and 199 kWh m^{-1} respectively, and emission of 88 kg of CO_2.

Table 5.1. Energy consumption and CO_2 emission estimates for the different life cycle stages of 1 m of RS 35 mm^2 single-pole cable with copper conductor and PVC insulant.

	Energy consumption ($kWh\ m^{-1}$)	**%**	**CO_2 emissions ($kg\ CO_2\ m^{-1}$)**	**%**
Extraction and supply of materials	2.29	1.59	1.70	2.63
Transport of materials to the production plant	0.03	0.02	0.01	0.01
Production of the cable	0.17	0.11	0.07	0.11
Transport of the cable for installation	0.03	0.02	0.01	0.01
Installation	0.00	0.00	0.00	0.00
Use	141.57	97.95	62.69	96.97
Dismantling	0.00	0.00	0.00	0.00
Transport to recycling	0.03	0.02	0.01	0.01
Recycling	0.37	0.26	0.15	0.23
Transport to final disposal	0.01	0.00	0.00	0.00
Final disposal	0.01	0.01	0.00	0.01
TOTAL	144.53	100.00	64.65	100.00

Table 5.2. Energy consumption and CO_2 emission estimates for the different life cycle stages of 1 m of RS 35 mm^2 single-pole cable with copper conductor and PVC insulant, with 25% recycled PVC in the insulant.

	Energy consumption ($kWh\ m^{-1}$)	**%**	**CO_2 emissions ($kg\ CO_2\ m^{-1}$)**	**%**
Extraction and supply of materials	2.17	1.50	1.67	2.58
Transport of materials to the production plant	0.03	0.02	0.01	0.01
Production of the cable	0.17	0.11	0.07	0.11
Transport of the cable for installation	0.03	0.02	0.01	0.01
Installation	0.00	0.00	0.00	0.00
Use	141.57	98.04	62.69	97.03
Dismantling	0.00	0.00	0.00	0.00
Transport to recycling	0.03	0.02	0.01	0.01
Recycling	0.37	0.26	0.15	0.23
Transport to final disposal	0.01	0.00	0.00	0.00
Final disposal	0.01	0.01	0.00	0.01
TOTAL	144.40	100.00	64.61	100.00

Table 5.3. Energy consumption and CO_2 emission estimates for the different life cycle stages of 1 m of RS 25 mm^2 single-pole cable with copper conductor and XLPE insulant, with PVC coating.

	Energy consumption (kWh m^{-1})	**%**	**CO_2 emissions (kg CO_2 m^{-1})**	**%**
Extraction and supply of materials	1.70	0.86	0.50	0.57
Transport of materials to the production plant	0.02	0.01	0.01	0.01
Production of the cable	0.11	0.06	0.05	0.06
Transport of the cable for installation	0.02	0.01	0.01	0.01
Installation	0.00	0.00	0.00	0.00
Use	196.41	98.91	86.98	99.23
Dismantling	0.00	0.00	0.00	0.00
Transport to recycling	0.02	0.01	0.01	0.01
Recycling	0.25	0.13	0.10	0.11
Transport to final disposal	0.01	0.00	0.00	0.00
Final disposal	0.01	0.01	0.00	0.00
TOTAL	198.57	100.00	87.66	100.00

Table 5.4. Energy consumption and CO_2 emission estimates for the different life cycle stages of 1 m of RS 25 mm^2 single-pole cable with copper conductor and PE insulant, with mineral charge.

	Energy consumption (kWh m^{-1})	**%**	**CO_2 emissions (kg CO_2 m^{-1})**	**%**
Extraction and supply of materials	1.33	0.67	0.39	0.45
Transport of materials to the production plant	0.02	0.01	0.01	0.01
Production of the cable	0.10	0.05	0.04	0.05
Transport of the cable for installation	0.02	0.01	0.01	0.01
Installation	0.00	0.00	0.00	0.00
Use	196.41	99.11	86.98	99.36
Dismantling	0.00	0.00	0.00	0.00
Transport to recycling	0.02	0.01	0.01	0.01
Recycling	0.26	0.13	0.10	0.12
Transport to final disposal	0.00	0.00	0.00	0.00
Final disposal	0.01	0.00	0.00	0.00
TOTAL	198.17	100.00	87.54	100.00

Table 5.5. Energy consumption and CO_2 emission estimates for the different life cycle stages of 1 m of RS 25 mm² single-pole cable with copper conductor and PE insulant with mineral charge, with 25% recycled PE.

	Energy consumption (kWh m⁻¹)	%	CO_2 emissions (kg CO_2 m⁻¹)	%
Extraction and supply of materials	1.29	0.65	0.38	0.44
Transport of materials to the production plant	0.02	0.01	0.01	0.01
Production of the cable	0.10	0.05	0.04	0.05
Transport of the cable for installation	0.02	0.01	0.01	0.01
Installation	0.00	0.00	0.00	0.00
Use	196.41	99.13	86.98	99.37
Dismantling	0.00	0.00	0.00	0.00
Transport to recycling	0.02	0.01	0.01	0.01
Recycling	0.26	0.13	0.10	0.12
Transport to final disposal	0.00	0.00	0.00	0.00
Final disposal	0.01	0.00	0.00	0.00
TOTAL	198.13	100.00	87.53	100.00

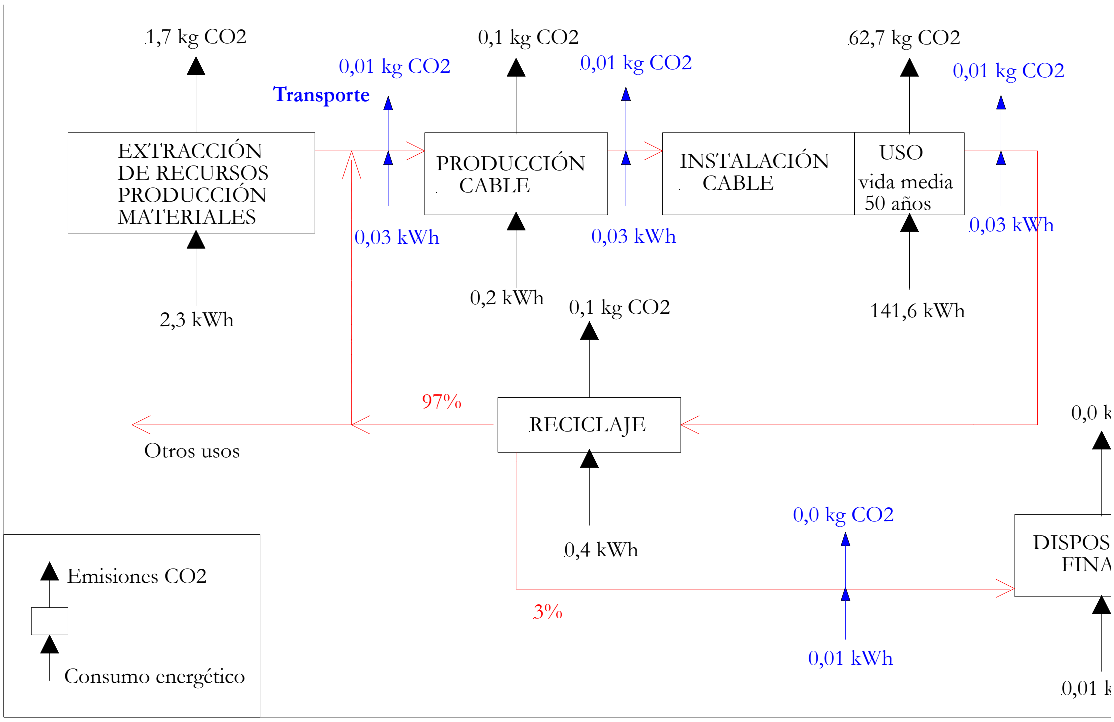

Figure 5.1. Estimate of energy consumption and CO_2 emissions associated with the life cycle of single-pole cables for electricity distribution with PVC insulant.

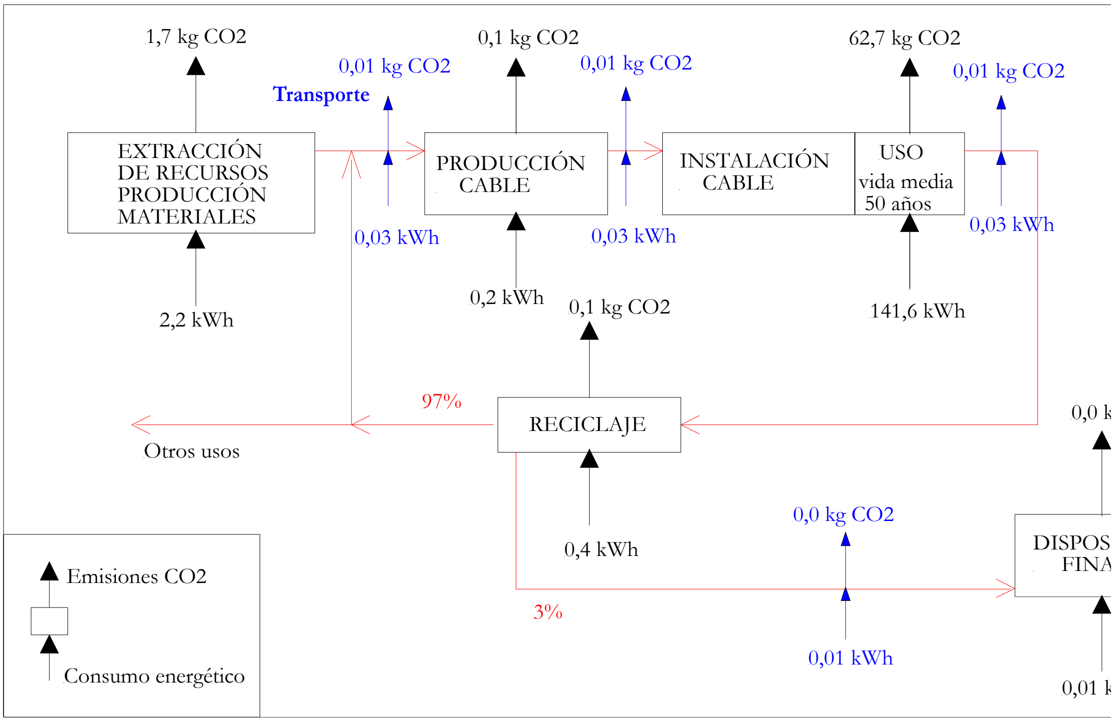

Figure 5.2. Estimate of energy consumption and CO_2 emissions associated with the life cycle of single-pole cables for electricity distribution with PVC insulant, with 25% recycled material in the composition.

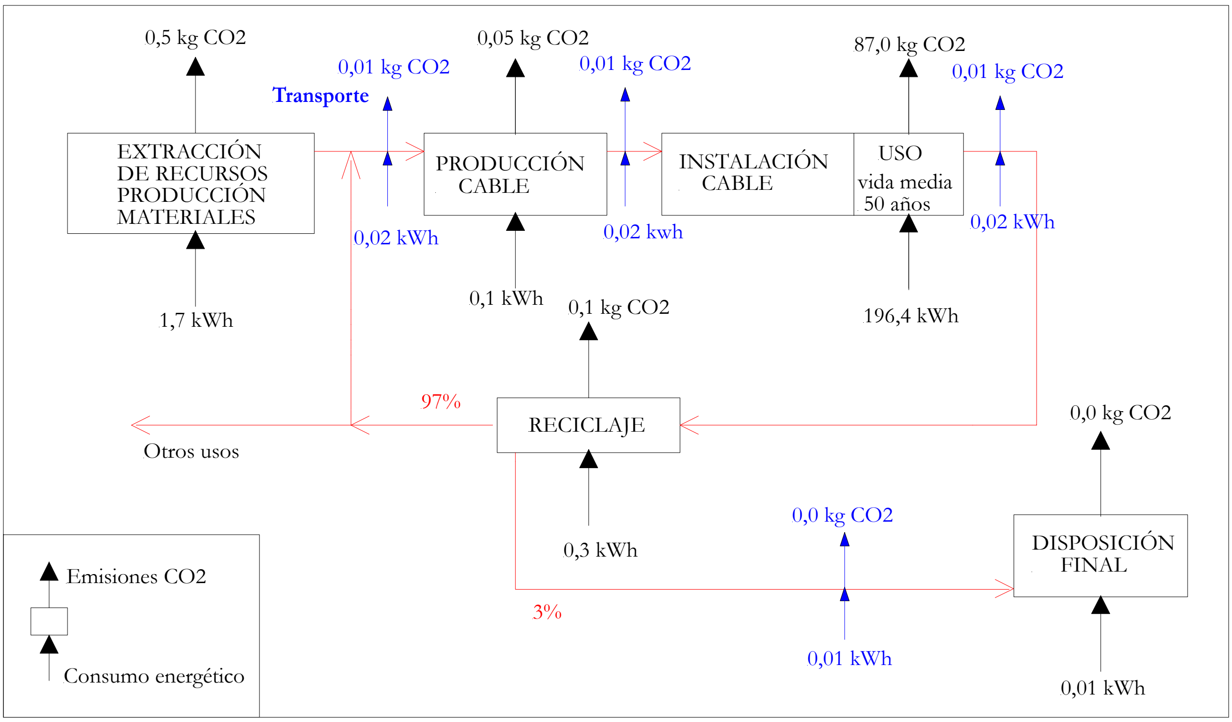

Figure 5.3 Estimate of energy consumption and CO_2 emissions associated with the life cycle of single-pole cables for electricity distribution with XLPE insulant

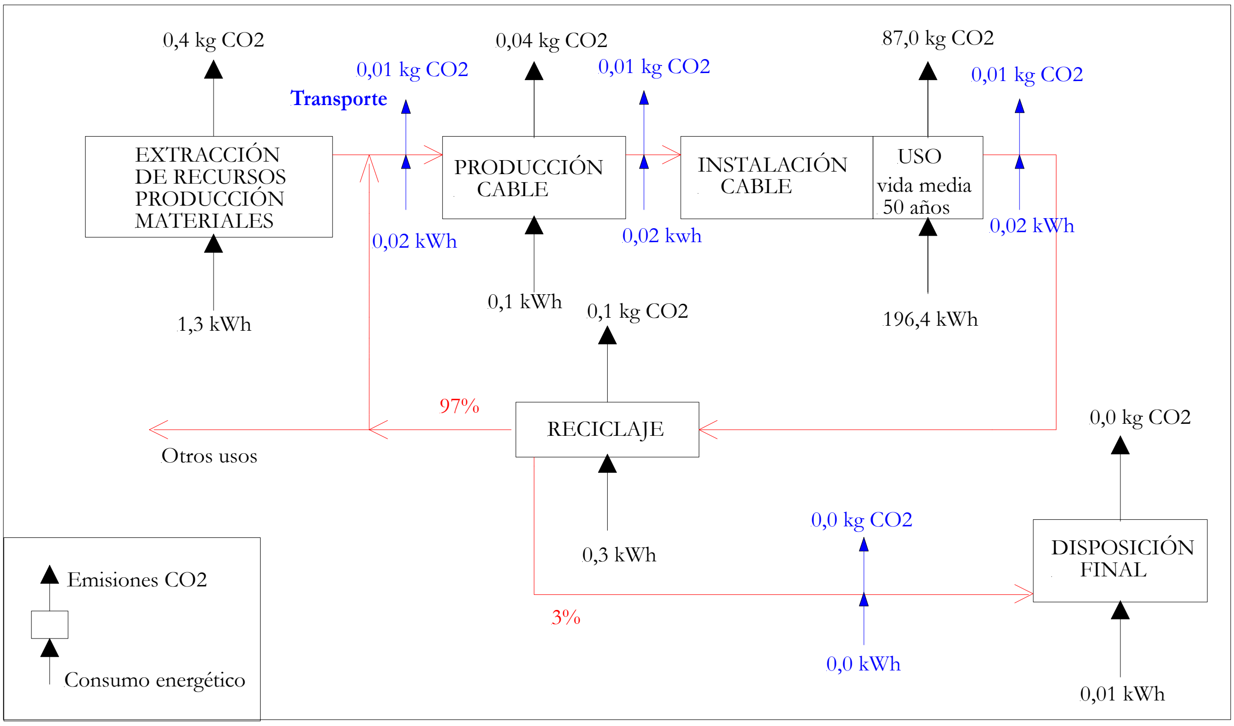

Figure 5.4. Estimate of energy consumption and CO_2 emissions associated with the life cycle of single-pole cables for electricity distribution with PE insulant with mineral charge

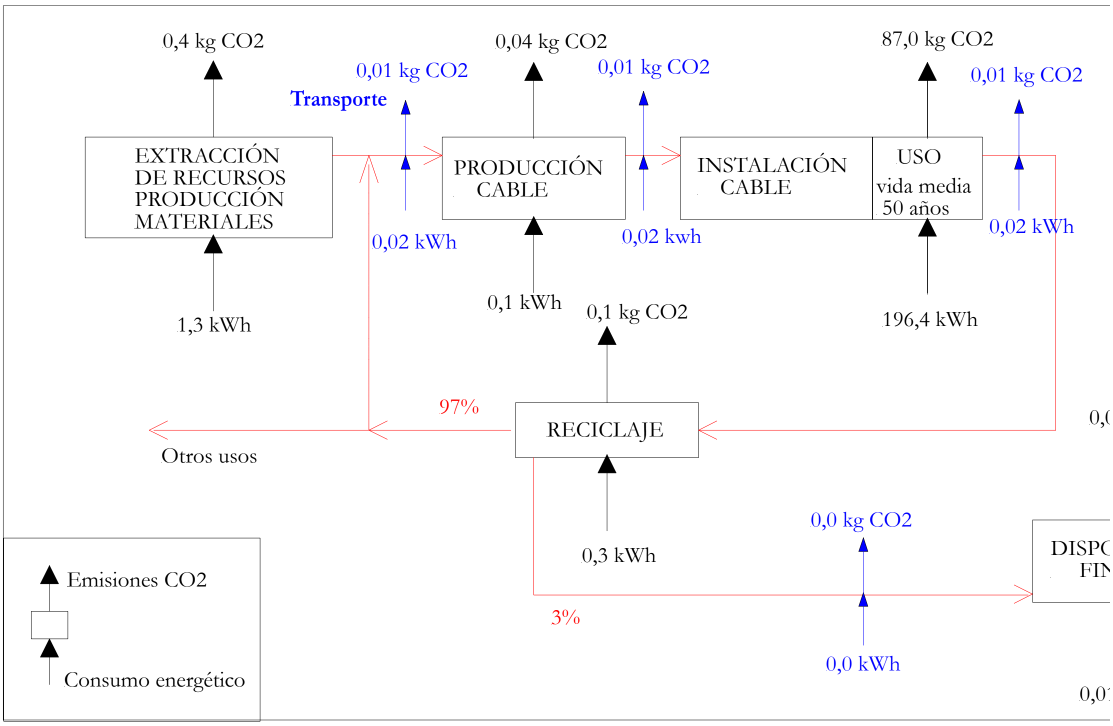

Figure 5.5 Estimate of energy consumption and CO_2 emissions associated with the life cycle of single-pole cables for electricity distribution with PE insulant with mineral charge, with 25% recycled material in the composition.

Table 5.6. Summary of energy consumption and CO_2 emissions associated with each of the life cycle stages of cables with insulants made of different materials.

Energy consumption (kWh m^{-1})	**New PVC RS35**	**PVC with 25% recycled material RS35**	**XLPE (with PVC coating) RS25**	**New PE with mineral charge RS25**	**PE with mineral charge RS25 25% recycled material**
Extraction and supply of materials	2.3	2.2	1.7	1.3	1.3
Transport of materials to the production plant	0.0	0.0	0.0	0.0	0.0
Production of the cable	0.2	0.2	0.1	0.1	0.1
Transport of the cable for installation	0.0	0.0	0.0	0.0	0.0
Use of the cable	141.6	141.6	196.4	196.4	196.4
Transport of used cable for recycling	0.0	0.0	0.0	0.0	0.0
Recycling	0.4	0.4	0.3	0.3	0.3
Transport for final disposal in waste disposal site	0.0	0.0	0.0	0.0	0.0
Final disposal in waste disposal site	0.0	0.0	0.0	0.0	0.0
TOTAL	144.5	144.4	198.6	198.2	198.1

CO_2 emissions (kg CO_2 m^{-1})	**New PVC RS35**	**PVC with 25% recycled material RS35**	**XLPE (with PVC coating) RS25**	**New PE with mineral charge RS25**	**PE with mineral charge RS25 25% recycled material**
Extraction and supply of materials	1.7	1.7	0.5	0.4	0.4
Transport of materials to the production plant	0.0	0.0	0.0	0.0	0.0
Production of the cable	0.1	0.1	0.0	0.0	0.0
Transport of the cable for installation	0.0	0.0	0.0	0.0	0.0
Use of the cable	62.7	62.7	87.0	87.0	87.0
Transport of used cable for recycling	0.0	0.0	0.0	0.0	0.0
Recycling	0.1	0.1	0.1	0.1	0.1
Transport for final disposal in waste disposal site	0.0	0.0	0.0	0.0	0.0
Final disposal in waste disposal site	0.0	0.0	0.0	0.0	0.0
TOTAL	64.6	64.6	87.7	87.5	87.5

Table 5.7. Energy consumption and CO2 emissions associated with the life cycle of single-pole cables with copper conductor and insulation made of different materials. Summary.

1 m of single-pole cable	RS (mm^2)	Weight (kg m^{-1})	Conductor diameter (mm)	Outer diameter (mm)	Insulant thicknes s (mm)	PVC coating (mm)	Maximum admissible intensity (A)	Conductor resistance at 20ºC (ohm km^{-1})	Energy consumpti on (kWh m^{-1})	CO_2 emissions (kg CO_2 m^{-1})	% variation energy consumed compared with PVC	% variation CO_2 emission compared with PVC
PVC with 25% recycled material	**35**	0.5	8.3	13.5	2.6	no	86	0.524	144.4	64.6	-0.1	-0.1
PVC	**35**	0.5	8.3	13.5	2.6	no	86	0.524	144.5	64.6	0.0	0.0
PE with mineral charge with 25% recycled material	**25**	0.3	6.6	9.0	1.2	no	96	0.727	198.1	87.5	37.1	35.4
PE with mineral charge	**25**	0.3	6.6	9.0	1.2	no	96	0.727	198.2	87.5	37.1	35.4
XLPE	**25**	0.3	6.6	11.2	0.9	2.8	96	0.727	198.6	87.7	37.4	35.6

6. Conclusions

Single-pole cables with copper conductor and insulant comprising just one material, normally used in domestic electrical installations, have been studied.

The standard case taken for the study was a cable with PVC insulant and rated section of 35 mm^2. The maximum admissible intensity this type of cable can withstand is 86 A.

The elements for comparison selected were cables with cross-linked XLPE and PE with mineral charge, as these are the materials most commonly used. Cables with dimensions allowing a maximum admissible voltage as close as possible to that for the PVC cable were considered, pursuant to the provisions of the Low-voltage Electrotechnical Regulations; in both cases, these are cables with a rated section of 25 mm^2, admitting a maximum intensity of 96 A, 11% higher than the standard case.

The energy consumption and CO_2 emission figures associated with each of the stages of the life cycle of these three types of cable were estimated, taking 1 m of cable as the unit of assessment.

In the case of the PVC and the PE with mineral charge, the option of including 25% recycled materials in the cable composition was contemplated, although at present the use of recycled raw materials is not habitual. Cross-linked polyethylene is not usually submitted to recycling processes because of its structure, and this option has therefore not been considered.

The cross-linked polyethylene cable considered has a PVC coating, as it was noted that single-pole XLPE cables without a coating in different materials are not commonly available on the market.

The determinant stage for the energy consumption and CO_2 emissions during the life cycle of the cable is the usage stage. The energy losses through Joule effect were estimated over a mean lifetime of 50 years, with 8 hours use per day, signifying between 97 and 99% of the total consumption and emissions.

The cable presenting the best results from the viewpoint of the environmental indicators considered is PVC with 25% recycled material in its composition. Including 25% recycled PVC and copper in the cable composition signifies a negligible energy saving: 0.1% compared with use of totally new materials. The CO_2 emissions are reduced by the same proportion.

Next come the cable insulated with PE with mineral charge, including 25% recycled materials in its composition, and the PE cable with mineral charge without recycled materials (with 37% more energy demand and 35% more CO_2 emissions into the atmosphere than the new PVC cable).

Last come the XLPE cables, with 37% higher energy consumption than the PVC cable taken as the standard case.

The results obtained for the PE cable with mineral charge and the XLPE cable are practically identical (differences in the region of 1% energy consumption per metre of cable).

It should be born in mind that using 25% recycled materials in production of the cable barely varies the results for either the PVC or the polyethylene with mineral charge.

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TABLA XIV - 4

INTENSIDADES MÁXIMAS ADMISIBLES EN AMPERIOS PARA CONDUCTORES DE **COBRE** AISLADOS

INSTALACIÓN **BAJO TUBO EMPOTRADO**	CONDUCTORES UNIPOLARES			CONDUCTORES MULTIPOLARES		
BIPOLAR – TIPO DE CONDUCTOR	2 UNIPOLARES			1 BIPOLAR		
TEMPERATURA AMBIENTE: 40 °C TEMPERATURA DE CONDUCTORES: (PVC) 70 °C (XLPE) Y (EPR) 90 °C FACTORES DE CORRECCIÓN: POR TEMPERATURA DIFERENTE: TABLA FC-1; POR AGRUPAMIENTO: TABLA FC-5 **SECCIÓN NOMINAL (mm^2)**						
1,5	12,5	17,5	17,5	12	17	17
2,5	17	24	24	16	23	23
4	22	32	32	22	30	30
6	29	41	41	28	38	38
10	40	56	56	37	52	52
16	53	74	74	50	69	69
25	69	96	96	65	90	90
35	86	119	119	80	110	110
50	103	144	144	96	132	132
70	131	182	182	121	167	167
95	158	219	219	145	200	200
120	183	253	253	167	230	230
150	209	317	317	190	264	264
185	237	329	329	216	299	299
240	278	386	386	253	351	351
300	319	442	442	290	402	402
TIPO DE AISLAMIENTO	CLORURO DE POLIVINILO	POLIETILENO RETICULADO	ETILENO PROPILENO	CLORURO DE POLIVINILO	POLIETILENO RETICULADO	ETILENO PROPILENO

(see translation of the table in the next page).

TABLE XIV – 4
MAXIMUM ADMISSIBLE INTENSITIES IN AMPERES FOR INSULATED COPPER CONDUCTORS

INSTALLATION **UNDER EMBEDDED TUBE**		SINGLE-POLE CONDUCTORS	MULTI-POLE CONDUCTORS
TWO-POLE	TYPE OF CONDUCTOR	2 SINGLE-POLE	1 TWO-POLE

AMBIENT TEMPERATURE: **40ºC** TEMPERATURE OF CONDUCTORS: (PVC) **70ºC** (XLPE) AND (EPR) **90ºC** CORRECTION FACTORS: BY DIFFERENT TEMPERATURE: **TABLE FC-1** BY GROUPING: **TABLE FC-5**	**RATED SECTION (mm^2)**							

TYPE OF INSULATION	POLYVINYL CHLORIDE	CROSS-LINKED POLYETHYLENE	ETHYLENE PROPYLENE	POLYVINYL CHLORIDE	CROSS-LINKED POLYETHYLENE	ETHYLENE PROPYLENE