Copper or Aluminium cable conductors, broadly compared in a life cycle perspective

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Introduction

- The European Copper Institute (ECI) asked DNV KEMA (now DNV GL) and PE-international to investigate the following issues:

- ✓ The position of copper versus aluminium in power cables technically
- ✓ The decision model on which utilities decide to select copper or aluminium to be applied in their power cable conductors
- ✓ A life cycle assessment (LCA) of both conductor materials in power cables
- ✓ A life cycle cost analysis (LCCA) of both materials in power cables
- ✓ To bring these three studies together in a coherent paper and to present it at a prestigious conference.

Typical properties Cu / Al

- Copper has higher specific conductivity
- Copper has higher specific weight
- For equal conductance the cross sectional area of Al has to be increased by a factor of 1.6 (when considering radius it is a factor 1.3)
- For equal conductance the weight of Copper conductor is almost doubled
- Copper has a higher tensile strenght, higher E-mod, higher fatigue resistance and lower coëfficiënt of expansion
- Copper is far less sensitive for corrosion.

Major failure mechanisms

- **Aluminium**

- Chemical reaction between water and aluminum
- Oxide layer on aluminum by corrosion
- Thermal-mechanical failure due to mechanical properties

- **Copper**

- No clear threatening ageing mechanisms

Questionnaire for both LV and MV cables and accessories

- In a questionnaire, sent to utilities, they were asked to inform us via a scoring system (1-5) of the following criteria how the utilities decide to select copper or aluminum for their LV and MV cables:

  1. Price
  2. Radial size
  3. Weight
  4. Mechanical properties
  5. Easiness of accessory installation
  6. Easiness of repair
  7. Cost of corrective maintenance
  8. Company standard
  9. Compatibility with existing cable network
  10. Environmental concern
  11. Expected problems with connectors
  12. Any other factor

Decision makers summary

- The following decision makers for both LV and MV cables scored high:
  - “Mechanical”, “well functioning connector” and radial size” score high for copper,” as the decision makers “price” ,“company standard” and “compatibility with existing network” score high for aluminum

- The following decision makers scored low:
  - The technical decision makers “price” and “weight” score low for copper as the decision makers” repair” and “radial size” score low for aluminum

- The company standard seems to play a role for both Copper and Aluminum, which can be explained as in both situations the company strategy is decisive

- Surprisingly the environment does not seem to be a dominating issue

Opportunities and Challenges

- Because of material properties, copper is better than aluminium in almost every situation

- BICC Electric Cables Handbook:

✓ *Almost the only unsatisfactory feature of Copper is the way the price fluctuates*

✓ *Aluminum has become a replacement solely on the basis of cost*

- Nevertheless aluminium is becoming an inevitable competitor

- More work should be done to collect statistical information on the impact of conductor material on cable failure.

Life Cycle Assessment

- LCA is an analysis technique that allows us to examine the total environmental impact that a product has over the course of its entire lifetime i.e. production, use, recycling, disposal

- LCA helps to understand the impact on the environment as measured through different indicators (such as acidification, global warming, energy demand etc.)

- Through a holistic understanding of the environmental profile of products, better decisions in the sphere of sustainability are possible

- LCA aggregates powerful databases in order to account for both the direct emissions incurred through production and use of the product, as well as indirect emissions precipitated by the demand for the product

LCA system boundaries

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- System boundaries crucial to define in an LCA, in order to have meaningful interpretation

- System for this study includes:
  - Raw material manufacturing (cradle-to-gate)
  - Energy production
  - Cable manufacturing
  - End-of-life collection & Recycling
  - Credits for recovered material and energy

- As electrically equivalent copper and aluminium cables are compared, the use phase has been excluded, as it is identical for both materials.

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Bal, Remco; 11/05/2015

LCA scenarios

- Two scenarios have been assessed for each cable:
  - Use in ducts/tunnels
  - Installed buried in the soil

- Since the recovery of cables requires significant effort, recovery rates are a function of value and ease

- Copper has higher observed recovery rates than aluminium when effort is significant

- Recovery of cables for tunnels/ducts is higher than from directly buried due to difference in cost and effort

Data used

- GaBi Databases 2013 – Reference LCI databases representing the latest industry data
- Market survey of recyclers – conducted through European Copper Institute
- Specification of Materials for cables from DNV-GL
- Models are constructed in GaBi6 Software , a mathematical algorithm which covers all input/output flows for material and energy for the considered scenarios.

Results

- Functional unit: 1m medium voltage underground power cable
- Indicators: Acidification Potential, Global Warming Potential, Primary Energy Demand
- Environmental impact category:manufacturing phase and End of life phase
- Applications: in duct/tunnels and normaly buried in the soil

AP [kg SO_2-eq.]	Tunnel		Urban area	
	Cu	Al	Cu	Al
Total	0,016	0,019	0,028	0,053
Manufacturing	0,064	0,088	0,064	0,088
EoL	-0,049	-0,070	-0,036	-0,035

GWP [kg CO_2-eq.]	Tunnel		Urban area	
	Cu	Al	Cu	Al
Total	6,8	8,1	8,6	13,2
Manufacturing	13,9	18,3	13,9	18,3
EoL	-7,1	-10,2	-5,3	-5,1

Manufacturing impacts constant across application scenarios

Primary Energy Demand [net]	Tunnel		Urban area	
	Cu	Al	Cu	Al
Total	108,5	122,5	135,6	240,3
Manufacturing	216,7	357,9	216,7	357,9
EoL	-108,1	-235,4	-81,1	-117,7

Greater environmental credits through higher recovery from tunnels

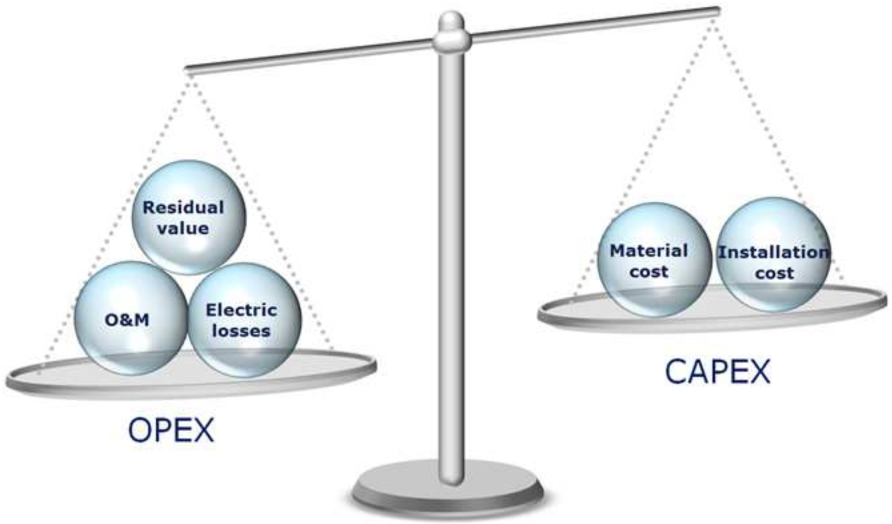
Life Cycle Cost Analysis (LCCA)

- Investment decisions are highly based on the initial investment only
- Lifetime costs provide a better understanding of all the costs of an underground cable
- Life Cycle Cost Analysis can be used to determine the optimum cost effective choice between technically equal components
- A computational model has been created which can compare cables based on their lifetime costs
- The values are discounted to the Net Present Value and added up resulting in the total lifetime cost of a cable

Chosen parameters	
Interest rate:	3%
Area:	Urban
Electricity price:	50 EUR/MWh
Lifetime:	50 year
Number of phases:	3
Length:	1 km

Capex and Opex

- Equipment cost
- Installation cost
- Operation & Maintenance cost
- Electrical losses
- Residual value
- Data used:
  - DNV GL cost database
    - Cost information from the industry
    - Constantly checked and updated
  - Failure data from a European network operator , however not giving significant differences copper/aluminium



Cables chosen for this analysis

- Commonly used cables are chosen
  - Three voltage levels
  - Three cross-sections per conductor

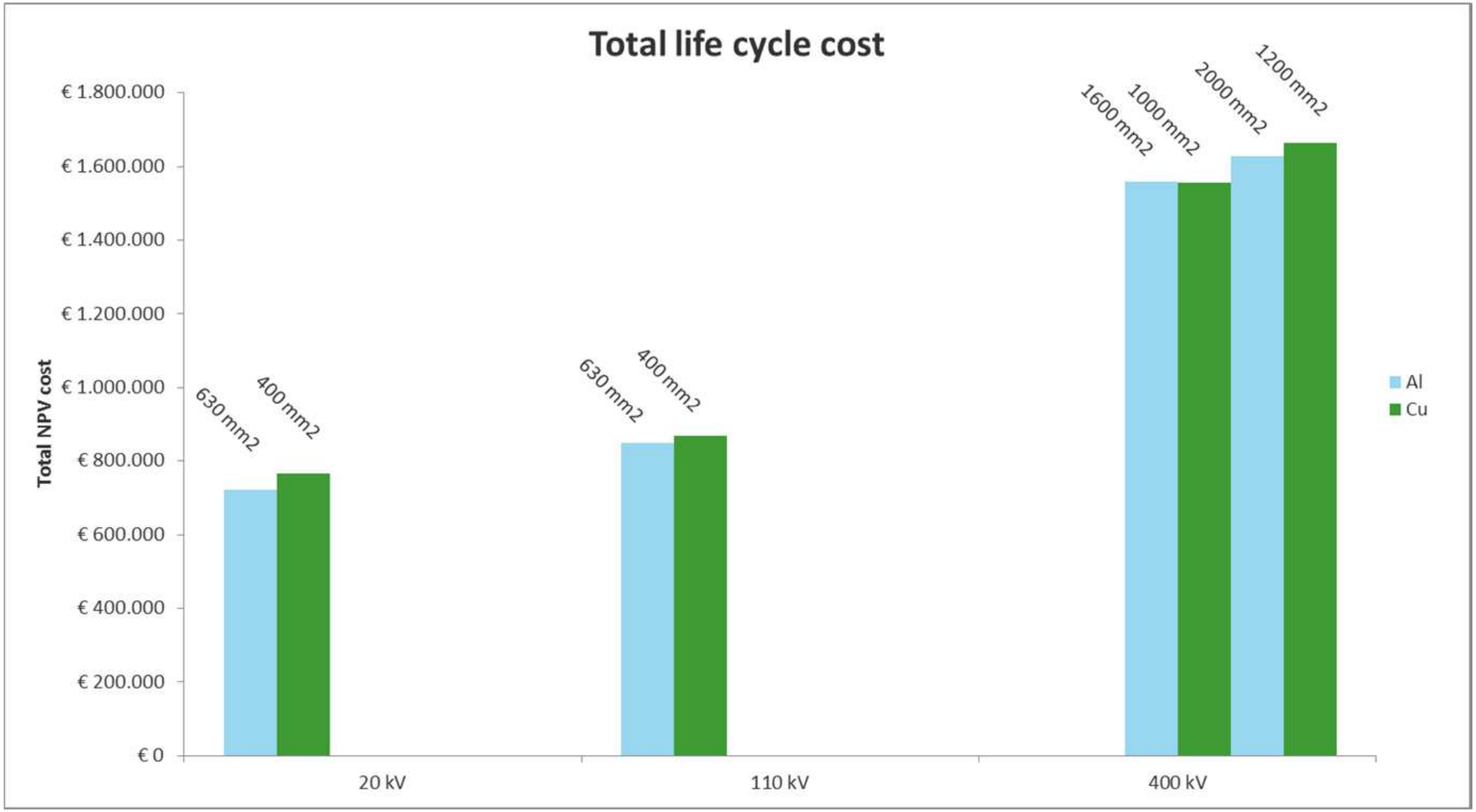
Voltage level (kV)	Cross-section	
	Copper (mm^2)	Aluminium (mm^2)
20	400	630
110	400	630
400	1.000	1.600
400	1.200	2.000

Results

- Total Life Cycle Cost per cable type
  - Differences in cost over the life are small
  - Larger cross-sections seem to decrease the cost difference
  - Average of 3% difference in cost

Conductor material	Cross-section (mm)	Voltage level		
		20 kV	110 kV	400 kV
Al	630	€722.000	€849.000	
Cu	400	€767.000	€867.000	
Al	1.600			€1.559.000
Cu	1.000			€1.556.000
Al	2.000			€1.627.000
Cu	1.200			€1.663.000

Results



Total life cycle cost
Total NPV cost
€ 1.800.000
€ 1.600.000
€ 1.400.000
€ 1.200.000
€ 1.000.000
€ 800.000
€ 600.000
€ 400.000
€ 200.000
€ 0
630 mm2
400 mm2
630 mm2
400 mm2
1600 mm2
1000 mm2
2000 mm2
1200 mm2
20 kV
110 kV
400 kV
Al
Cu

Conclusions

- Copper conductor cables have a higher technical preference because of lack of problems with connectors, easiness of installation, better mechanical properties, smaller radial size and better chemical properties
- Aluminum conductors are almost always selected for economical reasons, except for the additionally advantage of lower weight
- BICC Electric Cables Handbook:
  - ✓ *Almost the only unsatisfactory feature of Copper is the way the price fluctuates*
  - ✓ *Aluminum has become a replacement solely on the basis of cost*
- Copper cables have lower life cycle impacts than aluminium cables in the product and scenarios examined in this study, as measured by the three indicators cited earlier,
- At end-of-life, underground copper cables rather than aluminium cables are preferentially recovered due to the higher scrap price on the market
- The large initial investment cost difference between the copper/aluminium conductor cables has been reduced to 3% over its entire lifetime
- The difference in O&M costs needs further analysis and might reduce the cost difference over the lifetime of cables
- The initial cost issue seems to have a too dominating effect on the decision to choose a conductor material for cables
- Statistical information about impact of copper/aluminium on cable reliability is needed.

Thank you very much
for your attention,