2022-05 - Copper’s contributions towards reducing greenhouse gas emissions

markres342 · 03-May-2022; 15:24
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Update May 18, 2022 (see notes)

ECI Publication Cu0279

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Increasing the cross section of wires and cables, overhead railway lines and motor and transformer windings can significantly increase electrical energy efficiency. Incorporating one extra kilogram of copper contributes to saving between 100 and 3,750 kilograms of greenhouse gas emissions (CO2e). At the same time, the energy savings achieved will, in a majority of cases, lead to lower life-cycle costs.

Every conductor in an electrical system has a built-in resistivity. This means that part of the electrical energy that it carries is dissipated as heat and is lost as useful energy. Although the electricity system is rapidly decarbonizing, generating this wasted electrical energy still produces carbon emissions and consequently contributes to global warming.

An important initial decision, in seeking to reduce these losses, is to use copper as the conductor. Differences in resistivity mean that a copper conductor has only 60% of the losses of the same diameter in aluminium.

Once the decision for copper has been made, energy losses can be reduced further by increasing the diameter of the conductor. While this cannot be increased endlessly, the environmental optimum for transformer and motor windings and electrical cables currently lies at a significantly higher conductor size than prescribed by standards..

This means that investing in additional copper conductor material makes sense from both an environmental and an economic point of view.

The following examples describe how increasing the copper conductor diameter can reduce carbon emissions:

A 15 kW induction motor [2-4]

A 15 kW low voltage induction motor pumps water, drives an air compressor or operates a ventilation system. Upgrading the motor, from 89.4% to 91.8% efficiency, requires an increase in the copper conductor content from 8.3 to 10.3 kg. Assuming that the motor has a lifetime of twenty years and an average loading of 50% over 6,000 hours per year, the improved efficiency leads to a lifetime emission reduction of 7,500 kg of CO2e, using an average EU electricity mix. This is a CO2e reduction of 3,750 kg/per kg of additional copper.

The method of power generation significantly affects these numbers. Greenhouse gas savings could be ten times lower in case of renewable power generation, or they could be three or even four times higher in case of coal-fired thermal power stations.

A 1.6 MVA transformer [5-7]

A 1.6 MVA oil-cooled transformer is used to connect industrial plants to the high or medium voltage public grid. Upgrading the transformer from an AA' to a CC' class, or to an amorphous iron core, results in increases in copper content of 220, and 720, kg respectively. Assuming a lifetime of thirty years and an average loading of 50% over 8,760 hours per year, the improved efficiency leads to a lifetime emission reduction, at current EU electricity mix, of 500 kg CO2e/kg copper for the CC' transformer and 280 kg of CO2e/kg copper for the amorphous core transformer.

Economic and environment sizing of wires & cables [8]

Economic and environmental cable sizing often produces positive returns. How much energy, money or greenhouse gasses are saved depends on many factors: the baseline cable to compare to, the high-efficiency solution selected, the load profile and lifetime of a cable, and the greenhouse gas intensity of the electricity mix.

An example [8] illustrates how upsizing a power cable from 70 to 150 mm2 uses an additional 0.71 kg/m of copper, requiring 2.9 kg CO2e/m to produce. Such solution however saves, per meter of cable, 21 kWh electricity per year, equivalent to 4.8 kg CO2e. The lifetime savings over 20 years are 96 kg CO2e/m and the environmental payback is 33.

New energy technologies [9-12]

Renewables

Moving to more complex systems such as renewables or electric vehicles, it is no longer possible to attribute greenhouse gas savings in these applications to copper. It remains however meaningful to compare the emissions of copper in production with the emission savings in use to identify the most suitable hotspots for improvement.

For renewables, reference [9] provides good capacity factors for solar and wind energy projects:

- Solar PV: 16.1% (within a 5-95pc range of 9.9 - 20.8%) - see p78 of [9]
- Onshore wind: 36%, within a range of 20-55% - see p57
- Offshore wind: 40%, within a range of 33-47% for new projects - see p98

Using the EU grid mix with 230 g CO2eq/kWh emissions, this yields, per MW of installed capacity:

- Solar PV: 324 tpa GHG savings
- Onshore wind: 725 tpa
- Offshore wind: 806 tpa

Considering copper use for these solutions [10] and copper's environmental profile [13], the additional greenhouse gas emissions for copper used in renewables is earned back quickly:

- Solar PV: 0.44 months or 2 weeks
- Onshore wind: 0.2 months or 1 week
- Offshore wind: 0.3 months or 1.3 weeks

It takes much more than copper to construct a renewable energy plant. Copper however consumes only 1-2 weeks of a plant's 1000-week lifetime, leaving plenty of carbon budget for other materials and still earning a net positive carbon return. Note also that greenhouse gas emission factors for electricity production can vary an order of magnitude [11], leading to emission factors and payback factors that can be a factor three lower or higher.

Electric vehicles

Cf [12], electric vehicles emit about 3 times less greenhouse gasses compared to combustion vehicles, 45 g instead of 125 g/km. And cf [10], electric vehicles use 2-3 times more copper, i.e. 62.5 - 75 kg of copper compared to 25-30 kg per vehicle.

Over a distance of 100,000 km, an electric vehicle will save 8 tonnes of emissions, for an additional copper use of 45 kg. To 'earn' back the additional copper use in the electric vehicle requires driving it for about 2,300 km.

Multi-fold environmental pay-back [13]

As the above examples demonstrate, greenhouse emission savings are the highest for devices with a high utilization rate and in countries with a high share of fossil fuels in the electricity generation mix. However, even in systems lower carbon emissions, savings remain substantial.

On the production side, approximately 4.1 kg of CO2e are emitted during the production of a kg of copper [13]. This means the carbon emission savings of additional copper usage are to be divided by 4 to calculate a carbon payback factor.

In summary, lifetime carbon emission savings and the corresponding environmental payback factors for an additional kg of copper are as follows, per application domain:

Application	CO2e emission reduction	CO2e emission savings attributable to copper	Environmental payback factor
Wire & cable	137	100%	33
Transformers	280 to 500 kg	~ 30%	21 - 36
Electric motors	1,500 to 3,750 kg	~ 30%	110 - 275

Another important environmental benefit of copper usage is its high recyclability without loss in performance, at the device's end-of-life. While aluminium is also recyclable, performance limitations prevent it from being recycled into new conductors - it is standard practice to use primary aluminium for conductivity applications.

Summary

Increasing the diameter of a copper conductor clearly significantly reduces CO2e emissions. Associated benefits include high environmental payback factors, reductions in system life cycle costs and high end-of-life recyclability.

Notes

May 3, 2022: This article was originally written in 2013 on the basis of eco-sheets for motors and transformers developed in 2006 - 2009. In the meantime, the electricity mix has been substantially decarbonized in EU and world-wide. According to the European Environmental Agency, the environmental impact of a kWh has evolved to 230 g CO2e/kWh in 2020. For the ecosheets in [4, 7], 450 g CO2e/kWh was used [1]. Therefore, CO2e emissions extracted from the ecosheets have been reduced by a factor 2 to reflect the current emission intensity of the EU-27 electricity system.

May 18, 2022: Following a question from John Fennell, this article has been updated with a section on new energy technologies, covering renewables and electric vehicles.

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