European Copper Institute
Copper Alliance

Revision of Ecodesign Regulation for Transformers

European Copper Institute position

2023

The EU Green Deal aims to establish a general reduction of final energy demand in the decades to come, combined with a shift towards electricity as the main energy carrier. Materialising this ambition will **require further efforts to increase energy efficiency, notably in the electricity grid and its applications**. In an electricity generation mix dominated by renewables, increasing the **energy efficiency translates into savings** of material and land use for generation infrastructure as well as for transmission and distribution networks.

Given the increasing share of electricity in final energy demand and its importance in heating and transport, **transformers with an increased capacity at limited cost and with minimal size and weight are needed**.

The circular economy is a key pillar of the EU Green Deal. **The use of materials must be optimised**, both by limiting their quantity and by improving their circularity (design-for-recycling).

Taking the above considerations into account, **ECI recommends the following measures:**

1) **Strengthen Minimum Energy Performance Standards (MEPS) of transformers while introducing material efficiency requirements (MMPS).** Given the need to further electrify the economy, while at the same time boosting energy efficiency; given the circular economy objectives and the fact that saved energy translates into a reduced need for electrical infrastructure; given the electricity price evolution in the past years and the recent reform of the electricity market design; we believe the minimum level of energy performance for transformers should be re-assessed, while at the same time making sure that the potential new Tier 3 requirements following from this assessment do not lead to an excessive use of materials. A preliminary modelling exercise points to **1.8 TWh/year of electricity savings and a reduction of 0.8 to 1.6 million tons of materials used if Tier 3 requirements were introduced for distribution transformers**.
2) **Allow flexibility in design.** Together with the free choice of active materials, flexible design strategies should be permitted. These strategies create an additional degree of

freedom in design, making it easier to respond to MEPS and MMPS requirements, They include approaches such as the Peak Efficiency Index (PEI) in distribution transformers and concepts such as the Sustainable Peak Load (SPL) transformer in less loaded networks.

3) **Promote the lowest life cycle cost at system level.** Allow transformer owners to make the best decision on the optimal transformer design considering both their expected load profiles and their additional investment costs in substation and cables. Operational costs should be fully considered in the decision-making process. In the case of regulated utilities, a harmonised approach should be implemented by National Regulatory Authorities to minimise net societal costs (lifetime capex + opex). In this way, measures that incentivise upfront cost minimisation at the expense of a higher cost of losses will be avoided.
4) **Introduce Design-for-Recycling requirements.** Material efficiency should not stop at the manufacturing phase (setting a limited use of materials), but it should also include the end-of-life, to ensure the reutilisation of raw materials with minimum downcycling. This requires a design and material choice that aims at easy dismantling and recycling.

1. Strengthen Minimum Energy Performance Standards (MEPS) while introducing material efficiency requirements (MMPS)

To analyse the impact of a potential Tier 3 MEPS, ECI has carried out a modelling exercise. We developed various design options for a 630 kVA distribution transformer using professional design software and based on a particular set of parameters[1]:

- Two levels of efficiency improvement were investigated:
    - Tier 3a = Tier 2 minus 5 percentage points (A0-15%, Ak-5%)
    - Tier 3b = Tier 2 minus 10 percentage points (A0-20%, Ak-10%)
- As well as two types of material for the windings:
    - aluminium
    - copper

Key findings:

- An upfront cost increase was observed when shifting to Tier 3 (due to the use of a bigger quantity or a higher quality of materials), but this was largely compensated by the reduction in the net present value of the energy losses. As a result, the total cost of ownership (TCO) fluctuates only within a +/- 5% range. This means that the introduction of Tier 3 MEPS will not have a significant negative economic impact.
- A transition to Tier 3 can result in either more or less material use in the transformer itself, depending on the conductor material and other design choices. However, the balance in terms of material use should be addressed at system level, including not only the transformer itself, but also the electricity generation infrastructure needed to generate the energy for the losses in the transformer.
- Reducing transformer losses means that less renewable generation capacity is needed, and the resulting material saving should be taken into consideration when making the balance. When taking this impact into account, a move towards Tier 3 makes sense from a material usage perspective. The net material savings per MWh of electricity saved per year, range between 400 and 900 kg[2]. This translates in a 4% to 8% material use reduction when introducing Tier 3 compared with a continuation of Tier 2.
- In case of transformer replacements, the impact of extra size and weight of Tier 3 units on existing substations is a point of consideration. This may require substation upgrades that increase the net TCO. Transformer users should therefore have the possibility to opt for compact units which avoid such upgrades and the associated extra costs. Transformers can be made more compact by using specific materials and/or additional degrees of freedom in design,

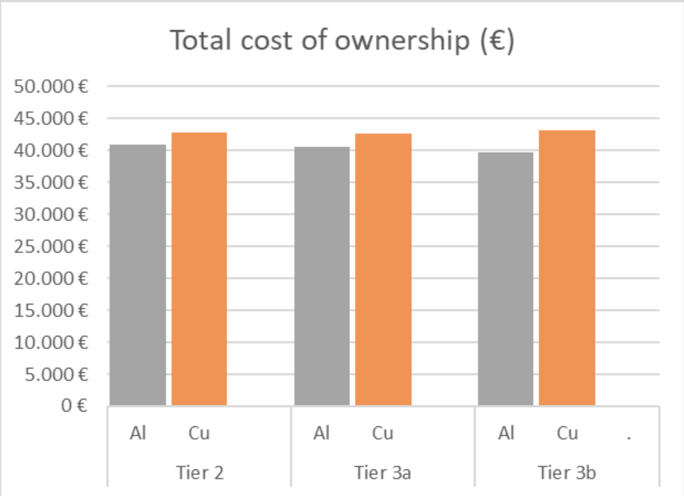
---

[1] Root Mean Square load: 30%. Lifetime: 40 years. Electricity price: 0.13 €/kWh. Interest rate (calculation of Net Present Value of future losses): 2%. Raw material prices: aluminium winding wire 6€/kg, copper winding wire 12€/kg, magnetic steel M070 5.5€/kg, oil 2€/kg, steel for tank and cover 4.5€/kg.

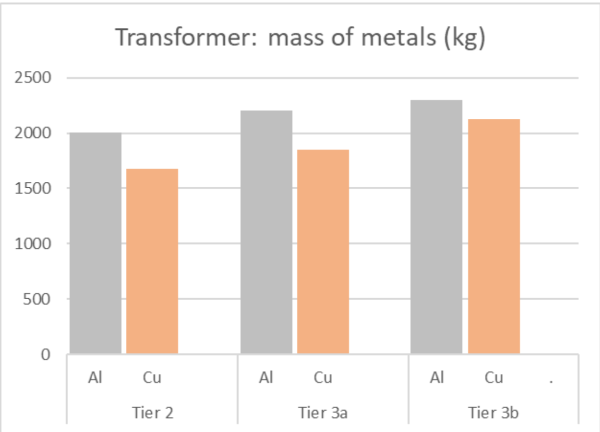
[2] Assuming that electricity is generated by onshore wind. Source: the U.S. Department of Energy (DOE) Renewable Energy Materials Properties Database (REMPD): https://www.nrel.gov/wind/materials-database.html. REMPD is a consolidated repository for data on the materials used in wind and solar plants. The database lists the type and amount of material required per megawatt (MW) of generation capacity and provides information about each material and its sources. Values for onshore wind (Table 5 of the summary report https://www.nrel.gov/docs/fy23osti/82830.pdf): steel 143 kg/kW; cast iron 12 kg/kW; composites and polymers 29 kg/kW; other metals and alloys 19 kg/kW; concrete 404 kg/kW; road aggregate 613 kg/kW; other materials 3 kg/kW. Other assumptions: annual productivity 2500 hours full load equivalent; lifespan 20 years.

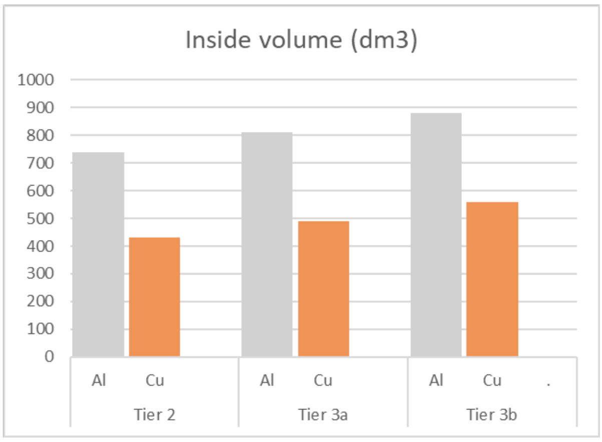
for example through a characterization based on a Peak Efficiency Index or the Sustainable Peak Load concept (see next section).

- **At EU scale, the introduction of Tier 3 MEPS for distribution transformers would ultimately lead to 1.8 TWh/year of electricity savings and would avoid the use of 0.8 to 1.6 million ton of materials**[3].
- The potential introduction of material efficiency requirements (MMPS) is compatible with Tier3 MEPS. MMPS would incentivize the development of more compact designs while still respecting the Tier 3 MEPS.



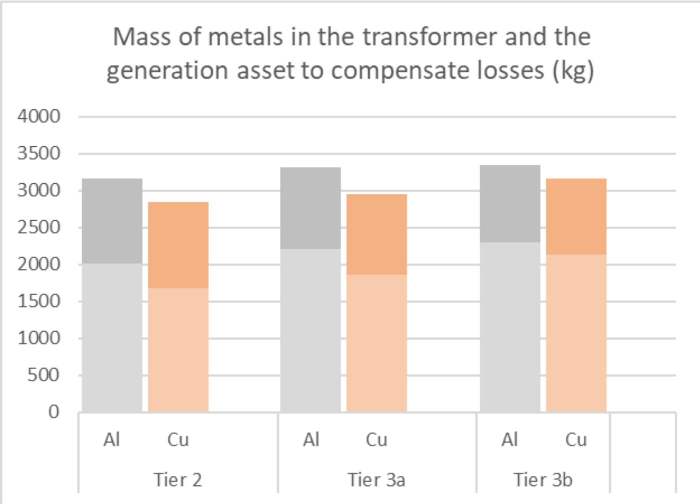
The graph above shows how the total cost of ownership remains relatively flat regardless of the efficiency level and the conductor material selected.



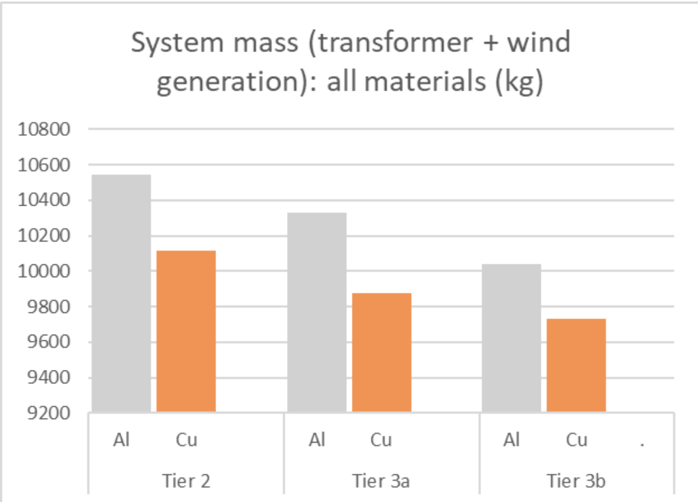


The mass of metals increases with the efficiency level, for a given conductor material. However, there are important material saving opportunities when shifting from aluminium to copper designs (about 20% reduction in total weight for Tier 2 efficiency level). The same shift also leads to a more compact unit, with size reductions in the range of 40%.

[3] EU level average capacity of distribution transformers assumed: 1250 GVA.



The graph above shows how the mass of metals in the transformer itself (light colour) increases with the efficiency level, for a given conductor material. This increase is mitigated when also considering the metal use in the onshore wind generation assets (dark colour) needed for generating the energy for the losses in the transformer, which decrease with increasing energy efficiency. For example, the extra weight for an aluminium transformer when shifting from Tier 2 to Tier 3b is 291 kg, but when considering the system impact, the extra weight of metals is limited to 167 kg.



Finally, when considering the full bill of materials (including also other materials, such as polymers, concrete and road aggregate), the mass balance decreases with increasing energy efficiency and when shifting from an aluminium to a copper design.

BALANCE FOR A 630 kVA UNIT	Tier 3b Al vs Tier 2 Al	Tier 3b Cu vs Tier 2 Al	Tier 3b Cu vs Tier 2 Cu
Electricity saved (kWh/year)	888	888	888
Delta investment cost	19%	52%	27%
Delta total cost of ownership	-2,9%	5,7%	0,7%
Extra weight of the transformer (kg)	291	121	446
	12%	*5%*	*23%*
Extra size (dm3)	140	-180	130
	19%	*-24%*	*30%*
Upgrades in the substation	likely	not needed	likely
Additional metal used in the transformer (Al, Cu, Fe) (kg)	291	121	446
Metal saved in wind generation assets (Al, Cu, Fe) (kg)	124	124	124
Net balance of metals (kg)	167	-3	322
	5%	*0%*	*11%*
Net balance all materials (kg)	-509	-814	-385
	-5%	*-8%*	*-4%*
Net balance all materials (kg/MWh saved)	-573	-916	-434

EU-SCALE BALANCE	Tier 3b Al vs Tier 2 Al	Tier 3b Cu vs Tier 2 Al	Tier 3b Cu vs Tier 2 Cu
Energy saved (TWh/year)	1,8	1,8	1,8
Net balance of metals (kton)	332	-5	640
Net balance all materials (kton)	-1010	-1615	-764

2. Allow flexibility in design

If Tier 3 MEPS are to be combined with material efficiency promotion, all design options to minimize material use should be facilitated by regulation.

For distribution transformers, it is advised to use a **Peak Efficiency Index** (PEI) instead of a fixed combination of load losses (LL) and no-load losses (NLL).

- Current regulation is optimized for a fixed point of load, but this leads to suboptimal units in terms of energy losses and material use, notably if the average load is low.
- When the average load is low, it would be more effective to reduce the no load losses, even if this comes at the expense of slightly higher load losses.
- An option could be that regulation asks technical standardisation bodies to provide several combinations of LL and NLL, to be chosen according to the load pattern.
- Certain new types of electricity infrastructure have a lot to gain from this, including the connections of wind farms, solar farms, micro-grids and battery parks. Their load patterns are fairly well known in advance, meaning that the balance between LL and NLL can be optimised.
- This will make it easier to comply with Tier 3 MEPS while keeping material use limited.

Efficiency regulation according to a PEI becomes even more powerful if combined with the **Sustainable Peak Load** concept (SPL)[4].

- This concept is useful in a network with a low average load, which is often the case in EU distribution grids. In this concept, a higher power ("peak power") is permitted for a limited time, resulting in a higher temperature rise in the unit than normally allowed (above 65°C) and in higher load losses.
- Thanks to new insulation technology (natural ester and thermally upgraded paper), the higher temperature rise does not result in a loss of reliability or lifetime of the unit. And thanks to the reduction in no-load losses, the increase of the load losses does not lead to an increase of the total annual energy losses of the unit. In a network with a low average load (typically below 30%), the total annual energy losses of a sustainable peak load unit are similar to those of a conventional unit.
- The unit follows the conventional MEPS at lower temperature rise (65°C).

---

[4] References:

- Transformers Magazine – Sustainable peak load transformers – July 2022 (https://transformers-magazine.com/magazine/sustainable-peak-load-transformers/)
- International Smart Grid Action Network. Webinar June 2022 – Sustainable Peak Load Transformers (https://www.iea-isgan.org/webinar-sustainable-peak-load-transformers/)
- Maximizing distribution transformer resource-efficiency - Potential contribution to EU Green Deal objectives – October 2021 (https://help.leonardo-energy.org/hc/en-us/articles/4409606711570--Cu0277-Maximizing-distribution-transformer-resource-efficiency-Potential-contribution-to-EU-Green-Deal-objectives);
- Power Transformer News - The sustainable peak load concept and public distribution transformers – December 2021 (https://www.powertransformernews.com/2021/12/13/the-sustainable-peak-load-concept-and-public-distribution-transformers/)
- Revolve - No need to compromise for public electricity distribution – February 2022 (https://revolve.media/no-need-to-compromise-for-public-electricity-distribution/)

- It results in a more compact unit for the same capacity, which can be very useful in retrofit cases where space is limited. Such retrofits will become increasingly important while adapting the grid to the growing use of electricity. The material savings potential of sustainable peak load transformers is substantial, with reductions in total weight of 11 – 15% compared to the equivalent conventional designs.
- The concept can also be useful for the connections of renewable energy systems, as they often have high peaks but a low average load.
- The purchase cost of a sustainable peak load transformer is comparable to that of a conventional transformer if all other parameters are kept the same.

3. Promote least life cycle cost at system level

Focusing only on the investment cost of the transformer is poor asset management, as its minimisation usually leads to a unit with high life-cycle costs for energy losses. Also, the unit risks being inadequate to cope with the predicted rising occurrence of peak loads. Moreover, investing less in transformer efficiency will result in higher investments to be made in electricity generation.

Private operators will more naturally tend to consider full life cycle costs when deciding on the best design for a transformer. However, regulated utilities tend to apply the incentive schemes set by National Regulatory Authorities[5] (NRAs). It is therefore important to have a harmonised approach at EU level in order to provide the appropriate signals to minimise net societal costs (lifetime capex + opex). The revised Ecodesign regulation should provide a guidance to NRAs on this aspect, so as to avoid contradicting signals between Ecodesign and the regulation of electricity infrastructure.

With the appropriate incentive schemes, transformer operators and utilities will be able to make the best decision considering their expected load profiles, their additional investment costs in substations and cables, and their operational costs (including the cost of losses).

4. Introduce Design-for-Recycling requirements

The benefits of promoting a reduction in material use for a given transformer with a given efficiency level have been presented above. However, true material efficiency does not remain limited to the manufacturing phase. Materials should also be easy to recover and reuse with minimum downcycling at the end-of-life. Materials should be chosen and designs should be made in a way that dismantling and material recovery is made easy and economical.

According to a survey carried out by the European Copper Institute in 2021[6], liquid-filled medium-power transformers have a high degree of circularity at end-of-life. About 75% of the material can enter an

[5] https://www.ceer.eu/eer_about/members#
[6] References:
- Transformers Magazine – The circularity of medium-power electrical transformers - January 2022 (https://transformers-magazine.com/magazine/the-circularity-of-medium-power-electrical-transformers/)
- Revolve - The case for 'design-for-recycling' of electrical transformers – January 2022 (https://revolve.media/the-case-for-design-for-recycling-of-electrical-transformers/)
- Medium power transformers recyclability – October 2021 (https://help.leonardo-energy.org/hc/en-us/articles/4409228735250--Cu0278-Medium-power-transformers-recyclability)
- Recycling Magazine – The circularity of medium-power electrical transformers - April 2021 (https://www.recycling-magazine.com/ausgabe/recycling-magazine-04-2021/)

entirely circular process, either re-used for a similar application or recycled into the same material (1st degree recycling). Almost 100% of the metals are recovered for either 1st degree or 2nd degree recycling. However, cast-resin dry type transformers pose a major difficulty to recycling, because the windings are over moulded with resin. Separation is complex, energy consuming, and not economically viable within the EU. As a result, coils covered with cast resin are sold along with other electromechanical scrap for export outside the EU, where a generally low-paid workforce separates the resin from the metal coils in semi-automated processes.

This situation calls for a regulatory intervention, so as to make dry transformers easier and more economical to recycle. Technology options exist to cope with such requirements (such as shifting from cast resin to silicon rubber or alternative materials easier to dismantle).

About the European Copper Institute

The European Copper Institute (ECI) is the leading advocate for the copper industry in Europe and the European arm of the International Copper Association (ICA). Our members mine, smelt, refine and recycle copper for use across the economy, in the electricity system, buildings, transport and industry.

Contact

Fernando Nuño, Clean Energy Transition Programme Manager
Email: fernando.nuno@copperalliance.org
Transparency register: 04134171823-87
Find us on copperalliance.eu / LinkedIn / Twitter