Review of Ecodesign of small, medium and large Power Transformers

Eurelectric Reaction to Phase 1 Report

January 26nd, 2023

Eurelectric welcomes the initiative of DG GROW in establishing a review study and consultation forum to support the revision of Regulation (EU) 2019/1783. We value the efforts of ICF for the extensive and elaborate activities so far and for the attention and interest shown during stakeholder engagements. Members involved in the drafting of this reaction to Phase 1 Report remain available to further discuss the expressed views. We invite you to reach us through the contacts indicated below.

Eurelectric, the Union of the Electricity Industry, represents the interests of the electricity industry in over 30 European countries. Our work covers all major issues affecting our sector. We represent more than 3500 utilitites in the entire industry from electricity generation and markets to distribution networks. We stand for the vision of the European power sector is to enable and sustain a vibrant competitive European economy, reliably powered by clean, carbon-neutral energy. Furthermore, we foster a smart, energy efficient and truly sustainable society for all citizens of Europe.

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Depot legal: D/2024/12.105/3

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Main messages on the Phase 1 report

As European distribution system operators we continuously aim at improving energy efficiency, decreasing distribution losses and lowering the carbon footprint of our business operations. We are committed to minimising the environmental impact of our business as well as maintaining cost-efficient operations for our customers.

In this context, Eurelectric and welcomes the revision of Regulation (EU) 2019/1783 and affirm the importance of ensuring the effectiveness and purposiveness of the current legislation.

Eurelectric urges ICF to:

- **Adhere to the currently ambitious and future-proof efficiency requirements set by Tier 2.** This is to ensure optimised cost-efficiency and environmental considerations and to allow for the optimal evolution of technical solutions. Introducing new requirements could have unintended consequences such as further straining production lines and scarcely available materials, increasing costs disproportionally, and worsening difficulties in transportation as well as in the installation and replacement of transformers. In addition, the achievement of stricter efficiency requirements would require the use of amorphous steel which is not available in the EU. Furthermore, in the context of continued growth and capacity increase, there is a significant increase in the number of installed transformers to be expected in the coming years and it would stress the supply chains.

- **Thoroughly assess the life cycle impact of transformers.** In line with the goals set by EU climate law to reach net-zero emissions by 2050 and the resulting increase in renewable energy generation, the benefits of increasing the efficiency requirements will decrease. It is therefore important to perform a thorough analysis of the life cycle impact of transformers with different efficiency levels in regional and varying electricity mixes.

- **Perform a thorough economic assessment of transformer efficiency requirements to define the appropriate level of transformer efficiency.** Specifically, we strongly encourage performing a cost-benefit analysis of Tier 2 and the general feasibility of any increase in efficiency levels. Increasing investment costs for transformers are justified if they are balanced by a resulting extra value created for customers. This economic assessment cannot be solely substituted by a review of existing standards for transformer efficiency in other countries.

- **Further develop the assessment of inputs from stakeholders**,_particularly where a consensus among some unreferenced respondents appears to be accepted as factual knowledge for the entirety of respondents. Contrarily, in cases where there is apparent disagreement between stakeholders' views, these should be elaborated to provide a clear understanding of their position before drawing any conclusions. This is particularly relevant in the case of pole mounted transformers which the conclusions in the report are not supported by a thorough analysis of the technologies

- **In the context of the quantitative assessment, focus on the economic analysis and the divergences emerging from the stakeholder feedback.** The main focus should be put on strategic issues concerning material efficiency, fit-for-purpose for the energy transition and strategic dependence on raw materials and high-quality steels which are not produced in adequate volumes in the EU.

- **Acknowledge that the current exemptions for special transformers are justified and should be maintained.** In the Phase 1 Report, a proposal to remove concessions for pole mounted transformers was advanced without providing any justifications and in contradiction with the analysis carried out for Tier 1 and Tier 2. In the case of dual winding and pole mounted transformers, characterised by low ratings, the potential for incremental loss savings is small whereas the cost for any additional work necessary to replace existing transformers would be of a disproportionate magnitude, as validated by Tier 1 and Tier 2 studies.

- **The use of the disproportionate cost clause is not an alternative for exemptions.** Given the focus on a case-by-case approach with up-front approval and the lack of clear guidelines to evaluate what level of costs are disproportionate, a similar clause cannot by any means be an alternative for current exemptions. These provide legal certainty for all parties and allow for large-scale industrialisation through tendering, production planning and stock management for investments and urgent repairs. Hence, **the legislative exemptions are better suited for these special uses.**

Detailed commentary on Phase 1 report – Technical Analysis

The comments made by Eurelectric are submitted in accordance with the structure of the ICF 'Study for review of Commission Regulation 2019/1783 Phase 1 report, Technical Analysis, Draft'. On the other hand, Appendix 1 compiles feedback that pertains specifically to the second stakeholder meeting and the presentation slides shown during that session.

Ref: ICF 1.1 Introduction: (p. 3-4)

The review of Items (a)- (h) is listed as a requirement in Article 7 of Regulation 2019/1783, whereas items (i) – (r) are new areas which were not previously identified. This means that **the relative importance of items (i) to (r) in relation to the items in the Regulation needs to be carefully assessed for consistency and weighting.**

Regarding item (l) '*Ecodesign (or similar requirements for power transformers in other jurisdictions in particular the US and Japan and in comparison to Ecodesign Requirements for Tier 2'*:

The benefits of comparison are limited as the efficiency of Japanese/US transformers is based on a different cost-benefit analysis than the one applied in the EU. This can be exemplified as follows:

- Grids in other countries, such as the US and Japan, are much more fossil fuel intensive than in the EU, meaning that fossil fuel savings from higher efficiency transformers will be better justified.
- Load factors in the US and Japan will be significantly higher than in the EU due to greater use of air-conditioning and higher peak loading.
- Both the US and Japan have lower numbers of customers per transformer than the EU, as they generally use larger numbers of lower-rated pole mounted transformers, whereas European countries use a much smaller number of larger-rated ground-mounted transformers. This means that the basis adopted for the transformer designs is quite different, and the comparison is less appropriate.

Regarding item (m) '*strengthening potential of the existing MEPS and the potential of introducing material efficiency requirements (MMPS)':*

- Minimum Energy Performance Standards have a documented methodology for their assessment which includes the cost of the material used and end-of-life costs. As some of the costs are already incorporated in the current price of the materials and end-of-life disposal, there could be a potential "double costs counting" if Material Efficiency Requirements are also introduced.
- Eurelectric encourages ICF on behalf of DG GROW to clarify what specific 'MMPS' legislation and methodology is proposed to be applied.

Regarding item (q) *'A techno-economic analysis on the relevance and feasibility of requirements in particular for low-to-medium; and medium-to high voltage transformers related to design features aimed to increase the efficiency and lifetime of transformers when working with reversed power flows (due, for instance to electricity from renewable energy sources injected in the grid at lower voltage levels)':*

- The occurrence of reverse power flows assumes generation from renewables at a lower voltage flowing up through the transformer for onward distribution at a higher voltage. It is not clear where this requirement arose as utilities have not reported any issues in this area despite a number of years of experience with such reverse flows. Very old transformers which used “flag and pennant” tap changers had potential limitations for high levels of reverse power flows due to their design, especially if such flows would cause excessive tap changing in relation to the operational setpoint and bandwidth. However, new transformers do not exhibit any of these problems since they are equipped with vacuum tap changers to avoid critical issues.

Furthermore, transformer losses associated with renewable generation create no CO_2 emissions and the final market value of such losses is netted off the price paid to the generator without creating any additional societal cost.

Ref: ICF: 2.1 Existing standards and regulations: (p 5-25)

A comparison of international standards and regulations on energy efficiency is interesting in assessing what can be achieved and how it can be measured but does not provide a justification for applying simpler standards in the EU. This is because costs and benefits depend on the fossil fuel intensity of the grid and the nature of the transformers used, their typical load factors, the network configuration and the system frequency.

On p. 16/17 it is mentioned that for comparison of transformer efficiency levels, the efficiencies were recalculated at 50% loading, 50 Hz operation and using IEC definitions to help compare like with like. However, all this illustrates is that if the grid’s characteristics are different, then the efficiency levels of the transformers produced will also be different. **The transformers produced in North America or the EU would not be expected to have the same efficiency levels as they have been designed based on different criteria** (e.g., the discount rate used, the marginal cost of losses, the value of CO_2 emissions saved, load factor, lifetime, the relative costs of material and labour). This means that the charts provided only display what can be technically achieved in the transformer design, but not what is economically optimal for a particular location. Wording such as ‘*most ambitious’* , ‘*…US requirements being more stringent than values in EU Tier 2’* is not meaningful as it suggests that higher efficiency standards are better, whereas all that can be said is that, whilst these levels of efficiency may be appropriate for one country’s economy, they might be inappropriate for another.

The most important factor in assessing transformer efficiency is the overall benefit to society brought by the chosen efficiency level compared to the opportunity costs to society incurred for investing in the improved efficiency level.

Ref: ICF 2.1.3 Recommendations (p. 25)

Eurelectric agrees that continued use of EN 60076 is appropriate for the EU. Continued use of the standard designed for the EU, is by definition appropriate assuming it reflects ongoing EU requirements. A comparison of EU and US/Japan standards is not appropriate as designs for US/Japan may not be suitable or cost-effective for the EU.

Ref: ICF 2.2 Ecodesign Energy Efficiency Requirements

Ref: ICF 2.2.1.3 Effect of Rising Electricity Prices

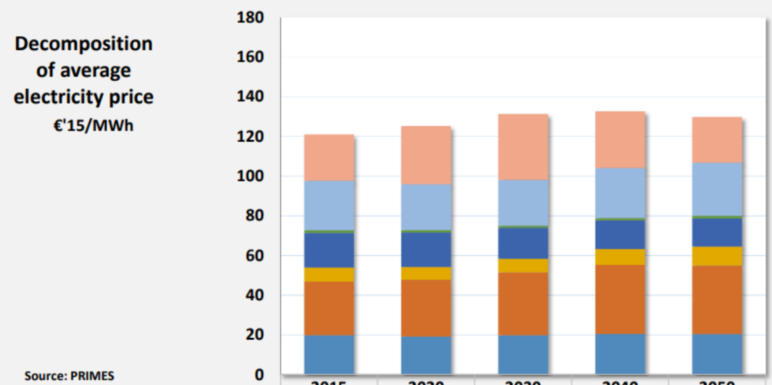
It can generally be accepted that **capitalisation of losses** is an appropriate tool for the assessment of investments and that technological advances will result in a decrease in the cost per kWh over time. However, it would be worthwhile to explain how the electricity price is developed and what savings arise for a reduction in losses.

The price of a kWh to a customer is designed to recover:

1. The fixed costs of investments in network and generation.
2. The cost of generator fuel, which varies with kWh output.
3. The operational costs of running the network and systems (unrelated to kWh).

The critical issue here is that greater transformer efficiency reduces kWh losses and hence requires less fuel consumption, but does not have any impact on Fixed Costs or Operational costs, as these are not affected by a reduction in losses.

This aspect was thoroughly investigated in Tier 2, based on an EU report on long-term fuel costs (as shown in Fig. 1). As can be seen from the graph, the price of electricity is mainly composed of fixed costs of network investment and generation plants and the associated debt servicing costs, adding taxes. To these need to be added the variable costs of fuel used to generate the electricity, which are significantly lower than the fixed costs.



	2015	2020	2030	2040	2050
Annual capital cost	23	29	33	29	23
Fixed costs	25	23	23	25	27
Variable costs	1	1	1	1	1
Fuel costs	18	17	16	15	14
Tax on fuels and ETS payments	7	6	7	8	10
Grid costs	27	29	32	35	34
Excise tax and VAT on electricity	20	19	20	21	20
Average price of electricity (after tax)	146	151	158	159	161

Figure 1. P. 100 'EU Reference Scenario 2020 Energy, transport and GHG emissions - Trends to 2050'

Increased energy efficiency in transformers reduces losses and, hence, reduces the cost of electricity produced with fossil fuels (as can be seen from the chart, these savings lead to the reduction from €17/MWh in 2020 to €14/MWh in 2050 (all in real terms)).

When capitalising the stream of savings, a discount rate is used and in Tier 2 a real 4% social discount rate was advised for use by the EU to assess the societal benefits of long-term investment returns from energy efficiency. Such societal discount rates do not incorporate any project risk premiums, and these are to be incorporated in the cash flows directly before they are discounted.

Similarly, such social discount rates are used by governments in evaluating governmental investments in societal projects, and as governments are investing there is no financial risk, as governments can always raise taxes/print money to fund the investment. However, where a utility is financing the investment there is a finance risk. For instance, the UK approach is to discount the social benefits at the social discount rate and the costs at the utilities Weighted Average Cost of Capital (WACC) so that the costs if raising finance for the investment are not understated.

The most significant impact in the assessment of cost-effectiveness arises from using the correct capitalisation methodology with the correct cost for electricity saved. Using the correct capitalisation methodology is critical to establishing the correct level of investment. An incorrect discount rate will result in a waste of money, either by an excessive cost that does not give sufficient return, or underinvestment which produces a lower return. The EU has published guidelines on the correct approach to carrying out such Cost Benefit Analyses.

Another way of establishing the value of losses is to use the price of gas and the efficiency with which it is converted to electricity by CCGT gas generation – about 49%. The price of gas per MWh in the EU is currently €35/MWh.

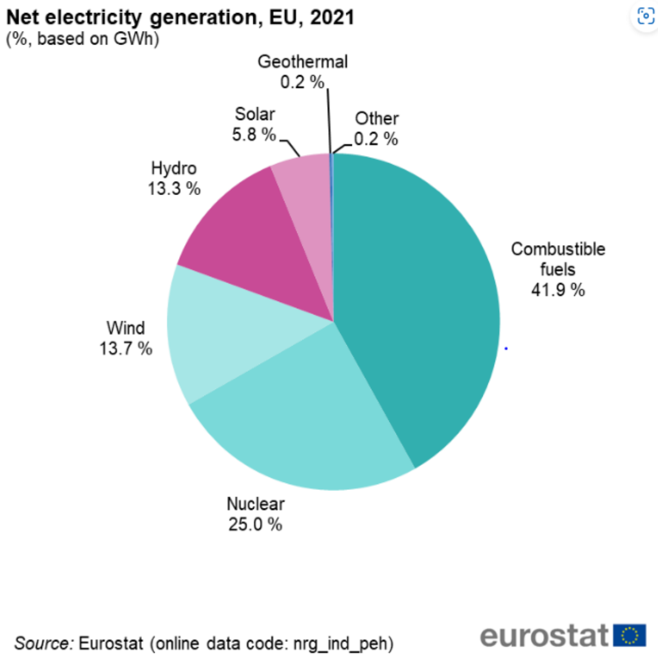


Figure 3: Net electricity generation, EU, 2021

(%, based on TWh)

Source: Eurostat (nrg_ind_peh)

The fuel mix in the EU is shown below:

The fuel mix in the EU is displayed in the figure. Consequently, the electricity generated from CCGT gas generation is €35/0.49 =7.1c per kWh

Iron losses saved by transformer efficiency will be evenly spread across all categories of generation, with 41.9% offsetting gas generation. However, peak losses (corresponding to copper losses) will probably occur at times of gas generation.

So the average cost per kWh for losses will be the weighted average of Iron losses occurring during gas generation and Copper Losses at peak generation times, so a kW of Iron losses will be worth 3c/kWh and Copper Losses 7c/kWh, so the weighted average of a kWh of losses will be between 3 and 7c/kWh depending on the proportion of iron and copper losses saved.

In the ECI example the extra losses of 888kWh pa saved by Tier 3, can be divided into savings from 76% reduced Iron losses of 674kWh (= 77W x 8,760 hrs) and the 24% balance of 214kWh from reduced Copper losses i.e. an average of 7.2c/kWh*(41.9%x 76% + 100% x 24%) =4c/kWh for all losses saved. Hence, the saving in gas fuel costs avoided from both iron and copper losses in generation is €35. (from 496kWh x 7.1c/kWh = [41.9% x 674kWh + 100% x 214kWh] x 7.1c/kWh) i.e. the overall average saving per kWh of losses is €35/888kWh = 4c/kWh. **The kWh saved during times when there is no gas generation only produces a saving in renewable inputs i.e. wind, solar, nuclear which has no variable cost**.

Ref: ICF 2.2.2.1 ***Effectiveness of Tier 2, and Implementation of Tier 3 (p27 – 32)***

It is stated that some stakeholders view Tier 2 as cost-effective and others express concern about the strain it places on the supply chain and advise caution against exceeding certain limits, the availability. The report highlights the issues at the core of the Ecodesign review – but provides little insight into which stakeholders take what position to understand the bias in the parties. Secondly, the report provides only a resumée of issues – but provides no way of weighing the different issues at hand.

On p27 it is stated that*: ''The principal concern over supply chain is that more efficiency transformer technologies rely on amorphous steel cores and there does not seem to be any amorphous steel manufacturing in the EU. Per feedback, challenges in the supply chain will also compel transformer manufacturers to use existing e-steel grade instead of opting for higher grade eustele to meet stricter Tier 3 requirements'*

Eurelectric shares the same view that there is no amorphous steel manufacturing in the EU. **In the EU, transformers are manufactured with Grain Oriented Electrical Steel (GOES), entailing that they do not have the capacity to use amorphous steel in the manufacture.** In addition, there few if any EU transformer plants even have facilities to slit amorphous steel, so design capability is limited. The concern expressed by the EU related to the unavailability of high-efficiency transformer steel, (GOES 0.23mm x 0.70w and 0.23mm x 0.73w), which is made in limited quantities within the EU by Thyssen, and imported from Japan, Ukraine and other parts of Asia.

In the assessment of Tier 2, it was presumed that such transformer steel would be widely available and the EU undertook to ensure that it would be widely manufactured within the EU to meet transformer requirements. However, such manufacturing was not established and with the diversion of high-grade steel production capacity to other uses in Asia, there is a shortage of high-efficiency transformer steel.

This meant that, to meet Tier 2 requirements, large volumes of less efficient steel needed to be used, leading to increased transformer weight, larger cores, larger tanks and more mineral oil, with cost and weight increases of up to 15- 20%. In addition, the used steel is manufactured using fossil fuels, so the embedded carbon adds to carbon emissions and is unlikely to be paid back due to reduced losses from grids which increasingly use renewable electricity.

Similarly, costs have increased by up to 40% where high-grade steel is unavailable so the Tier 2 cost-benefit assumption of high-efficiency steel use is no longer valid. Eurelectric brought this issue to the attention of the EU commission (DG Grow) who suggested that it would be an issue for DG Clima to resolve in the context of the Ecodesign review.

P.28 '*Despite these challenges, some respondents believe that the transition to Tier 2 is entirely sustainable, citing the combination of rising material costs and increased energy prices across Europe as factors that support this transition.'...'However, this cost escalation was partially mitigated by the increase in electrical energy costs'.*

The assertion that Tier 2 continues to be economical is not correct. Tier 2 was assessed as economical using long-term variable costs of electricity in conjunction with transformer designs based on high-efficiency steel. Current high electricity costs are short-term due to gas shortages arising from sanctions on Russian gas, now replaced in the short-term by LPG, and is being increasingly substituted by renewables. So the long-term trend for electricity's variable costs will be downward. However, material costs are significantly higher due to shortages of high-grade steel, and any analysis using lower-efficiency steel shows that costs are higher than savings.

The suggestion that the escalation in material cost will be partially offset by savings from higher electricity prices is fundamentally incorrect – the reason is that any extra costs in materials for producing new Tier 2 transformers are incurred now for the lifetime of the transformers, yet any benefits arising from the higher value of the electricity saved is only for the duration of the price spike in gas and relates only to the fuel portion of the price of electricity,

P 28 '*The introduction of Tier 2 requirements resulted in substantial price hikes for medium power transformers , driven by the increased mass of these transformers and rising raw material costs , which ranged from 15 to 25%. Despite these cost increases, the savings achieved through reduced electrical losses helped maintain the total cost of ownership at levels like those seen in 2014 (i.e. compared with Tier 1.)*

This analysis is unclear – the cost increases on the transformers are incurred upfront for the overall lifetime of the transformers, and any extra savings in electrical energy costs only occur for the duration of the price spike, and only in relation to the fuel cost of the electricity saved.

As the requirement is for the cost-effectiveness of Tier 2 to be assessed this requires a more detailed quantitative analysis, similar to what was carried out in Tier 1 and 2 where the extra costs were assessed against the expected savings arising from these extra costs. It is not sufficient to simply provide quotes from stakeholders without carrying out an independent analysis of the costs and benefits.

Additionally, the cost-benefit analysis is not one that relates to 1-2 years – it is a long-term analysis over 25 years, in the context of the grid moving to renewable electricity so that there are little or no savings in CO2 emissions from reduced losses, that the losses saved are largely associated with reductions in renewable electricity rather than fossil fuel, so monetary savings are very low.

Moreover, given that renewable generation comes in large sizes as it has a low load factor, this means that when the sun shines/wind blows, then loads should be turned on to maximise usage. In turn, this means that the copper losses will increase very significantly due to loading – which is fine as the alternative would be to 'spill' the renewables – but also underlines the point that with renewables providing energy any saving in losses is a saving in renewable energy which must then be spilled as it is not cost-effective to store.

P. 29 "*Some respondents suggest that rather than strict Tier 3 requirements, the focus should remain on the repair and remanufacturing for older transformers. They stress the importance of considering the carbon footprint associated with material extraction and the need for new, more efficient materials."*

The feedback highlights the need for high performance materials to reduce losses, which could lead to increased material costs and concerns about raw material availability. The environmental and supply chain implications of these materials are discussed.

There appears to be an unintended conflation of comments on transformer repair and the design of transformers which would not need to be replaced and scrapped. Current Ecodesign regulations require that if a transformer needs a substantial repair then the windings/core needs to be brought up to current EcoDesign standards. However, this is uneconomic because the remaining life of a transformer is insufficient to economically justify such major expenditure for a remaining lifetime that may be determined by some other factor e.g. failure of the tap changer. Furthermore, on many HV transformers which are designed and constructed for a particular impedance and with tight clearances, attempting to redesign the core/windings to fit into an existing space will be intensive in design time and prone to unexpected failures due to tight tolerances, as well as being expensive. Accordingly, such a transformer would be scrapped and a new transformer meeting Ecodesign constructed.

However, the savings in losses from the new Transformers will at best match the extra cost of the materials in the new transformer, but will never pay back the embedded carbon that was embedded in the older transformer.

In other words, **the current policy of requiring repaired transformers to meet Ecodesign standards is unnecessarily increasing CO2 emissions and costs.** It would be cheaper, more environmentally friendly and better from a circularity view point to simply allow older transformers to be repaired using their existing design specifications and avoid scrappage and subsequent replacement by a new model.

In many cases, a major retrofit carried out after 40 years may almost double the lifespan of the product. This involves keeping the tank, 90% of the magnetic core and regenerating the oil previously contained in the transformer. By retrofitting a transformer of 400kVA it has been estimated[1] that the gain in CO2 emissions is 2896 kg, which is equivalent to the lifecycle gain obtained by The tier 2 regulation compared with the tier 1 regulation (2993 kg), but with great economy of raw materials. At the European level, this possibility could be subject to the achievement of a certain target of carbon footprint for the national electricity mix.

The second part of the statement relating to the need for more efficient materials was unrelated to issues surrounding the **repair** of transformers but instead to the pre-mature replacement and scrappage of transformers.

Major repairs are only ever relevant to HV transformers which are worth repairing, whereas with smaller transformers, up to about 630kVA, they are taken out of service not because of poor condition or fault, but generally because they need to be uprated with units of larger capacity. For example, the load on a 400kVA transformer may grow or exceed 400kVA, it is uneconomic to install a second substation, so the existing transformer is replaced by a larger rated unit i.e. the 400kVA unit is replaced by a 630kVA or 1MVA unit.

For clarity, electrification will require mass operating of most existing transformers which are installed in Packaged Substations of minimal dimensions. It will not be physically possible to install larger packaged substations, as the physical sites and footprints already exist, so any replacement packaged substation will conform to existing designs.

New packaged Substations could be larger but this would then require two varieties and designs of Substations, greater stockholding costs, increased supply chain holdings and delivery issues for very little extra benefit.

So the intention in relation to ‘high-performance materials’ was not to attempt to reduce losses, but instead to reduce embedded carbon emissions by reducing the replacement rate of existing transformers. This also increases ‘circularity’ and makes supply chains more resilient as transformers have a longer ‘useful economic life’.

It relies on using new ester transformers with Nomex papers to allow a higher power density, with lower iron losses on average but higher copper losses on peak. Currently, this option is not feasible under the Ecodesign, but should be provided in amended regulations.

p. 30 *‘The feedback suggests that introducing material efficiency requirements (MMPS) alongside Tier 3 MEPS could encourage more compact designs while maintaining Tier 3 efficiency standards’*

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[1] Internal study by Enedis, 2023

It is premature to consider new Tier 3 standards without first having assessed whether Tier 2 is still justified. Secondly, the goal of utilities for 2050 is to meet requirements for electrification and renewable connections, and this means having the ability to maximise the power density available at any site. Compact designs are considerably more expensive and have always been sought by utilities so that the power installed at a substation can be maximised.

The availability of a more compact design so that more efficient equipment (more than 99% efficient) could be installed on a site would mean that the rating of the equipment for its size was less. If the location can accommodate higher treated equipment of more compact size this will be done, but reducing the build of more efficient equipment so it can be installed on the same site would not be worthwhile.

Attempting to make equipment conform to a higher efficiency Tier 3 MEPS whilst also optimising it for material efficiency implies that material efficiency is not currently already being optimised for MEPS – it is, but any gains achieved on the equipment are used for ensuring that the equipment can fit on existing site or that higher capacity equipment can be installed.

P. 30-31 '*This comparison shows there is significant scope in energy efficiency improvement when amorphous core is used in Transformers. Tier 3 implementation will require a shift in amorphous core but there are certain arguments that should be considered: Supply of amorphous material cost impact and industry readiness.*'

Again there is a presumption that there is a justification for the establishment of a more efficient level of Tier 3 losses, yet nothing in the current draft has yet provided such justification. A more fundamental issue is that transformer losses arise from 'no Load' iron losses and load 'copper' losses, and the overall design of the transformer balances these according to the load factor, with lightly loaded transformers having low Iron losses and heavily loaded transformers having low copper losses.

It is not physically possible to specify both low iron and low copper losses, partly because it will always be more beneficial to optimise the ratio for one rather than the other, and partly because attempting to optimise for both is not physically possible e.g. a larger core to reduce iron losses will have a larger diameter and require a greater circumference for the copper winding which will increase copper losses and use more copper. This is an over simplified explanation, but when the transformer loss equations are differentiated to minimise losses the formula resulting shows iron and copper losses are interrelated and increasing one must be compensated by reducing the other.[2]

Accordingly use of amorphous is normally only justified in low load factor applications when it is most critical that Iron losses are minimised, yet with electrification it is copper losses that are likely to be most critical as load factors will be high due to EV Charging, Heat Pumps and other forms of electric heating.

This means that a more detailed analysis of the expected load factor and capitalisation rates is required and is likely to find that minimising copper losses is optimal as this maximises the capacity of

[22] Modern Power Transformer Practice – Feinberg; p 36 – 37
$P_{Cu} / P_{Fe} = 1/k^2$ where k is the fractional load at which the transfofmer normally works and P_{Cu} & P_{Fe} are the Copper and Iron losses. Then $m_{Fe}/m_{Cu} = k^2 p_{Cu}/p_{Fe}$ where $P_{Fe} = m_{Fe}\, p_{Fe}$ as p_{Cu} & p_{Fe} are specific copper and iron lsoses and m_{Fe} & m_{Cu} are the tital masses of the active iron and copper in the transformer. For minimum cost $m_{Fe} / m_{Cu} = c_{Cu}/c_{Fe}$ where c_{Cu} & c_{Fe} are the specific costs of copper and iron. It is not possible to simply design for minimum cost because requirements are for particular impedances and losses are capitalised, but the inter -relationship of copper and iron losses is illustrated.

the transformer and minimises copper losses. Correspondingly with copper losses much more signific than Iron losses it is more beneficial to reduce Copper losses than Iron losses.

This means that a more expensive amorphous core, for which few if any EU transformer factors are tooled to slit to produce optimal designs, which is not currently manufactured in the EU and which requires expensive factories, which produce heavier and more expensive transformers which are noisier unless operated well below saturation, is unlikely to be a good solution.

Ref: ICF comments on ECI Paper (p. 31-32)

The ECI paper makes no mention of the use of amorphous steel as this material is not manufactured in the EU, needs to be sourced from Asia or the US, and is incompatible with manufacturing methods in EU transformer factories.

For optimum design, transformer steel is slit into the required widths and used to assemble the core. However, EU factories do not have the specialised slitting machinery required to deal with amorphous and consequently would only be able to use standard sizes of amorphous to produce a restricted set of Iron losses. Amorphous is also heavier and more expensive than normal steel, particularly where it has to be operated at low saturation levels to avid excessive noise. This results in heavier and more expensive transformers.

In the ICF For. 2.4 it is clear that there is very little difference in losses up to 400kVA, and at 600kVA the difference is about 700W. However, transformer sizes increase with load so above 200kVA copper losses usually predominate and become the focus for loss reduction. Typically amorphous is used on low-load transformers where iron losses predominate e.g. lightly loaded rural transformers.

Additionally, from a strategic perspective, it would be unwise for Ecodesign regulations to prescribe iron loss levels that could only be met by amorphous as access to this material then becomes critical but is outside the control of the EU. Currently, there are difficulties sourcing high-grade traditional steel, hence the prospects of sourcing more esoteric material would not be good.

Finally, any consideration of the minimisation of Iron Losses must be preceded by an analysis of future load factors which decide the balance between Iron and Copper losses, as it is more likely that Copper losses will yield greater benefits from minimisation.

In relation to the modelling carried out by ECI to justify a Tier 3a of A0-15%, Ak – 5%, or Tier 3b of A0 – 20%, Ak-10% our comments are as follows:

(a) Any proposed changes in losses should be optimal, so the relative changes in copper and Iron losses must arise from an assessment of the capitalised values of Iron and Copper losses, followed by a redesign of the transformer using these capitalised values to ensure optimality. No values for capitalised Iron and Copper losses are provided, nor the load factor at which the assessment was carried out. The overall loading was assumed to be 30%,

(b) The ECI analysis was not very detailed but indicated large increases in the amount of iron and copper used in the transformer construction and relied on the assumption that such weight increases would be offset by a reduction in the amount of wind and solar generation installed.

However, wind and solar will be installed on a commercial basis in large units and the capacity installed will not be related to any change in the amount of losses saved in transformers. This is simply because the kW of losses saved in transformer losses compared to the increased in load which drove these losses will be insignificant and will not alter the size of the generators installed e.g. if an extra load of 10 MW is 75% fed from existing transformers and 25% from new transformers, then assuming three (3) new 1000kW transformers are installed, the ***additional losses*** saved on each from moving from Tier 2 to a Tier 3 will be tiny – ***an extra saving of only about 2.5kW in total*** which will never have any effect on the size of any generation plant installed

	Iron (W)	**Copper (W)**
Tier 2	693 (A0 - 10%)	7,600
Tier 3a	654 (A0 - 15%)	7,220 (Ak - 5%)
Tier 3b	616 (A0 – 20%)	6,840 (Ak - 10%)
Change Tier 2 – Tier 3b	**77 Watts**	**760 Watts**

The value of the energy saved has been priced at 13c/kWh presumably because this was the average wholesale price of electricity in 2020, but it is not appropriate to use such a price because it includes a payback of fixed costs to Solar and wind farms in relation to the kWh they produced. However such payments are not reduced when losses decrease, so the 13c/kWh overvalues losses. Instead, a price of about 4c/kWh is more correct (in the range of 3-7c/kWh depending on the proportion of iron and copper losses).

Whilst the ECI has not given the extra cost of the transformer, they have indicated that when is an extra weight of 291 kg there is an extra cost of 19%, and with an extra weight of 121 kg there is an extra cost of 52%. Hence, for the unit with 19% extra cost, the material alone is €1,600 and installing this extra material in transformer is even greater than this again. Yet the value of the savings made is only €35 pa – even capitalising this at 2% for 40 years only gives €945 which is less than half the extra investment i.e. uneconomic.

Using 2% as the discount rate for 40 years is also unrealistic as the investment is quite risky as it depends on correctly predicting:

- The volume of electrical losses saved over the 40 years which will vary with the load factor and the loading of the transformer
- The value of the losses saved which will vary with the marginal price of electricity over 40 years.
- The extra investment cost in Copper and Iron which are committed once the transformer is made
- Any additional costs arising from a more difficult installation due to increased weight and volume.

Whilst social discount rates can be low they are not 2% - the UK currently uses 3.5% and published EU rates were 4%, but in all cases the risks associated with the project have to be built into the cash flows, so these risk costs will outweigh the very modest savings proposed.

As can be seen from the above quick analysis, **this area is critical to the justification of any loss levels proposed and requires much more detailed analysis. Particularly in relation to the value of any kWh**

saved, the discount rate used and how the associated project risks are built into the cash flows being discounted.

The ECI paper also makes other points suggesting that a system Total Cost of Ownership should be used. If this were the case transformers would be the last area in which any investment would ever take place as they are already very efficient and are at a stage where they are producing declining returns to scale – a much better investment would simply be using bigger cables to off load the transformer, or indeed investing in nearly any other plant on the network.

In some areas, it is suggested that there is 'consensus feedback' in some areas, but it is not clear where such feedback came from: '*feedback highlights the positive market adoption of amorphous core transformers, driven by their energy efficiency and competitive pricing, particularly in countries like China and India.'*

Neither the ECI paper nor the Eurelectric paper mentioned amorphous, and what may be appropriate in China and India which manufacture **amorphous may not be appropriate in EU where transformer load factors are higher.**

ICF Research questions to consider (p. 32):

In response, Eurelectric would argue that :

(a) The appropriateness of Tier 2 loss levels needs to be considered in relation to the higher-than-expected costs incurred and the valuation of loss savings in a grid which is moving to Net Zero.

(b) The need to have statistics on the number of Tier 2 Transformers which have been traded is not clear – Tier 2 has been in place since 2021 and enough Tier 2 transformers have been manufactured to give a god assessment of cost. Levels of loss savings have varied with load factor and the value of the electricity saved which is increasingly coming from renewables rather than fossil fuel generation. Consequently, these issues are critical.

(c) Amorphous steel is only an issue for consideration if load factors were to become lower so that reduced Iron losses were favoured. It was also considered in the last Vito review and not considered favourably by transformer manufacturers.

(d) The increased electrification of society where a house was designed for an average load of 1-2 kW with an occasional peak which was much higher, and where now EVs of 7kW and Heat Pumps of 3.5kW are increasingly being installed and expected to run for several hours has increased the average loading factor. In ESB houses are now designed for 5.5kW with an option to uprate the substation to provide 8kW, and with 6 cables (with a capacity of 1,200kVA) instead of 4 offloading each unit substation. As load per cable is now reduced from 25% to 16% the cable losses are reduced by more than half ($=1 - (0.16/0.25)^2$)

Unfortunately, transformer designs using fixed Losses have ensured that the transformer is only optimally efficient at a 30% load factor, not at the actual Load factor and increasingly inefficient at any higher future load factors.

Ref: ICF 2.2.2.2 Energy efficiency metrics for small power transformers (p. 32)

The savings achievable on small transformers, which have a large variety of load factors and which may not be energised for a long time, are likely not worth the cost of regulation.

In most cases the product regulation of the equipment in which the transformer is installed covers any energy efficiency requirements – in fact it would be sub-optimal to regulate the transformer efficiency in such products as by definition this is sub-optimising the overall efficiency of the produce. It is more effective to simply regulate the overall efficiency of the product and let the manufacturer decide what is the optimal method to achieve this result at least cost to the customer.

Transformers used in coupling PV inverters are connecting renewable generation which has no variable cost and no emissions to the grid – adding extra costs to save such energy is wasteful and would be better employed elsewhere e.g. a PV panel that could produce more energy. In short, there are large numbers of small transformers, all with small energy usage and diverse load factors, which in total are still insignificant when compared to all other classes of transformers and especially to other loads such as Electric Vehicles which effectively use solid state transformers.

On the query on Numbers and Ratings of small transformers - these were established in detail in earlier reports by VITO and a copy of the Table detailing numbers and types from their report '*Lot 2: Distribution ad Power Transformers Draft Tasks 1-5 Report'* attached on p. 29 – 31 of the Eurelectric Qualitative response (Sept 2023).

Ref: ICF 2.2.2.3 Effect of rising electricity prices: (p. 34)

The only additional points to make here are that, in the context of evaluating losses, **it is the avoidance of the extra cost of not producing a kWh which creates the value.** This is a crucial point because with renewable generation there are high upfront fixed costs which are incurred regardless of what output is produced, and the prime mover to generate the electricity is then just wind/sun. Therefore, not using electricity from such installations does not save costs as the infrastructure is already there.

In contrast, with a traditional generator, not only are there high initial costs but also significant running costs as fuel has to be burnt to generate the electricity, and each kWh produced has a fuel cost associated which could be saved if that kWh were not required. This entails that the value of the losses saved in the future is the value of the kWh which are no longer required to be produced form ted winding number of fossil fuel generators on the system i.e. the value of the losses saved will decrease over time. **It is therefore critical for the economic valuation of losses that the value of the electricity saved is correctly priced.**

A completely different perspective is also now arising, where with the use of renewable generation electricity is created when the wind blows/sun shines but is very difficult and expensive to store. Additionally, all the fixed costs of generation have been incurred upfront and will not change regardless of how much, or how little generation is subsequently produced. If generation can not be used by load when it is produced then it must be spilled. Hence, in contrast to a situation where a transformer is designed to save 1% of losses, a renewable generator will waste up to 100% of its output if it cannot export power.

This means that it is important to enable the load to absorb renewable generation when it is available, and this will mean that transformers and other plants should be loaded as much as possible when required because any extra losses incurred will be negligible compared to the alternative of letting the renewable generation go to waste. This is an area which has not yet been investigated but would suggest that load should not be restricted to keep within the capabilities of plant, but that instead the plant should be sized to avoid restricting the load from using the generation when available.

This would point to a need for transformers and network capable of high loadings, which given limited space means overloading and increased losses – this is beneficial because any increased losses are only a small proportion of the renewables that would otherwise be wasted.

ICF 2.2.3 Recommendations

Ref: ICF 2.2.3.1 Effectiveness of Tier 2 and implementation of Tier 3 (p. 35)

The term 'Implementation of Tier 3' assumes that a Tier 3 is required without having carried out any assessment – should be altered to read: *'Effectiveness of Tier 2 and whether any changes are required'.*

TCO has always been considered in EcoDesign as the value of the losses saved is assessed against the increased initial cost of the more efficient transformer. A 'System TCO' of the efficiency of the overall network had been proposed during the original discussions on Tier 1 as better returns in terms of decreased losses could be obtained by investing elsewhere on the system, but from the EU point of view, only the product (i.e. the transformer) can be regulated.

Utilities already seek to use the most compact and efficient materials on transformers in order to increase capacity, as there is seldom space available to increase the footprint of the transformer site.

Ref: ICF 2.3 Implementation of Ecodesign Requirements and Methodologies (p. 37)

Ref: ICF 2.3.1.1 Concession for disproportionate costs (p. 37)

It is important to appreciate that ultimately it is the customer, not the utility or the manufacturer who bears all the costs and in turn expects to receive proportional benefits.

For clarity, the intention of Ecodesign is not to inflict costs on customers which do not produce benefits. Assessment of proposals should show them to have a possible economic impact on society in the widest sense of the term 'economic', but in carrying out such assessments the externalities which may affect costs may not have been considered, and in cases where these are expected to arise concessions are built into the regulation, and where more unusual derogations can be requested. The alternative would be to simply proceed blindly and inflict signifying extra costs on customers in general, or on some customer classes in particular, which would bring EU Ecodesign into disrepute.

Ref: ICF 2.3.1.4 Requirements for reverse flow Transformers (p. 41)

Reverse flow can occur and could have been a problem on HV transformers with flag and pennant tap changers, or if tap changing because excessive and vacuum tap changing was not present. It has not come up as an issue of any significance as yet.

Ref: ICF 2.3.1.1 Concessions for disproportionate costs (p. 42)

It would be expected by manufactures that utilities requiring a non-compliant design requiring derogation would provide the manufacturer with the business case required to justify the derogation. Normally the manufacturer would also contract an indemnity with the utility to cover any costs the manufacturer would incur if the derogation were refused and any penalties imposed.

Refusing to provide such an indemnity would be the equivalent of admitting that the derogation was not expected to be justified. Justifying a derogation involves a lot of work and time by the utility, so, unless there is a commensurate benefit, the utility will find it more economic to simply proceed with the standard design. In addition, where a derogation is required it is usually a 'black and white' case where the costs are large and clearly evident.

In relation to 'Cabin model' fitting the enclosure is one issue, a second is fitting the land space available and the planning permission requirements. So if the substation requires extra land this needs to be purchased form the landowner, which as it is the only land available will come at a price which is many multiples of the cost of the substation. Similarly, in some jurisdictions, there is a limit on the volume of the substation e.g. in Ireland $11m^3$, and if above $11m^3$ by any amount, Planning Permission which can take years to obtain, is required.

Consequently, if such enormous costs are delayed are required to ensure that €35 pa in losses savings are obtained it is clearly better to provide a derogation. If a derogation were not available the substation would instead be grossly overloaded with very significant losses, or if the extra loading was not possible another substation would be provided at high capital costs and with a doubling of the Iron losses, adding the embedded CO2.

On the term 'Disproportionate costs'. Costs are disproportionate when the extra costs incurred are greater than the benefits provided. In the Tier 1 and Tier 2 analyses by the EU the approach to the justification of the efficiency levels proposed was that the cost of the increase in Transformer costs would be balanced by the capitalised savings in the value of the electrical energy saved, and the value of CO2 emissions saved (- typically, for simplicity, the cost of Carbon emissions was embedded in the cost of the electricity used).

Now in moving from Tier 1 to Tier 2, from Tier 2 to Tier 3, it is the value of the **additional capitalised losses saved which must be balanced against the additional investment costs in the transformer** so that the exercise is at least cost neutral to the customer.

However, this balance can be upset in two ways:

(a) Additional costs are incurred in the installation of the transformer which outweigh any benefits from losses saved.

(b) The costs of the transformer increase more than was expected or the value of the losses saved is less than expected e.g. the price of electricity is lower, or the load factor on the transformer is different than expected.

Disproportionate cost arising from (a)- Additional Installation costs:

These are easiest to identify as they are grossly disproportionate. They arise in cases which are not. expected to be typical because in the VITO report the assumption made was that the extra losses saved would not typically result in extra installation costs, just in extra transformer costs. However, in cases where additional installation costs arise, they are generally so large that they completely outweigh any value arising form loss savings e.g. taking an example from the VITO Final report on Tier 2 below illustrates the issue well.

Therefore, in Vito final report on Tier 2 levels for a 400kVA transformer the value of the extra reduction in losses from improved efficiency was about €1,100 over the transformer's lifetime, where the lifetime capitalised losses reduced from €7,327 to €6,229 over a 40 year period. This infers that the extra cost for the transformer should not increase bey more than the same amount in order that value is created for the customer. Typically such a Tier 1 Transformer would cost in the order of €10,000, and so for Tier 2 should not cost more than €11,100. Meaning that, if the transformer can no longer fit through the steel door of some substations, or into underground vaults, because it is now physically larger, the costs of installation would be very high, which is:

- The substations would need to be switched out and customers supplied from standby sources
- Civil works would need to occur to enlarge the size of the door opening
- A new bespoke door would need to be designed and purchased to fit the new ope

Following transformer installation, the network would then be re-sectionalised to restore normal supply.

This is a very simple case and costs would be about an additional €5,000. If the substation would not fit though the existing opening into an underground vault the costs would be significantly higher as the vault ceiling/floor would have to be redesigned in terms of support for an enlarged opening (assuming clearances in the vault were adequate). This is no-standard work with high safety considerations so costs will be high on technical engineering design and also on civil works and engineering – probably around €15,000 at least per substation.

If the transformer is too large to be retrofitted in an existing packaged substation then the issue is whether the existing site is large enough to allow the existing packaged substation to be removed and replaced with a larger-sized substation with the higher efficiency transformer. The removed packaged substation would be scrapped as the extra costs of reusing older equipment which had a short remaining life (particularly after being physically relocated) would not be economic.

So costs are now the costs of installing a new package substation minus the scrap value of the old one which is low. Hence extra costs incurred in this instance would be over €25,000. If the new packaged substation does not fit on existing site then costs will be considerably greater.

From above **it is evident that if the value of the capitalised losses saved over the transformer lifetime matched the extra costs of the transformer investment, then all the extra costs incurred in installation are a loss to the customer.** Even if lower loss transformer should be designed with no extra cost and save €1,100, the installation costs could be 5 – 25+ times the value of the losses saved.

Similar situations occur with Pole Mounted Transformer which are much lower cost items – say €2,000 - €6000 – with smaller ratings and less scope for any loss savings. Yet if an extra pole were required for installation of a larger transformer then this would require a new 2 pole platform with new permission form the landowner to be erected, the old pole and transformer to be scrapped, and the new one erected and reconnected using new wiring to the new action. This would involve a cost of at least €4,000 just for the new platform and extension of wiring and would never justify the requirement for extra loss saving.

All of these costs are disproportionate and the use of higher-efficiency transformers is clearly not justified in any of these cases. Justifying the disproportionality is simple because it is significant – if the net value of losses saved is less than €1,100 (usually less than €50 or negative) yet the extra costs of installation are multiples of the net saving, the costs are disproportionate.

(c) Costs of the Transformer are disproportionate due to changes in costs of material, different transformer loading patterns, changes in price of electricity

These are generic changes and will apply to all transformers in a particular category. So the type of derogation required will be more widespread and require a higher level of technical analysis. Such issues might increase the costs of the transformer by around 40% which on a €11,100 400kVA unit would be €4,400 meaning that the expected breakeven from losses saved has now turned into a net loss of €4,400.

Due to the unavailability of high grade steel on which Tier 2 was based, lower grade steel in higher quantities is now used to construct larger transformer where greater volume requires more mineral oil, more transport costs and more structural steel, with a much greater content form the amount of embedded carbon in the extra steel.

Such transformers take many years to payback on the extra embedded carbon as grid electricity saved is increasingly CO_2 free, and the savings in the value of losses can never pay back the extra initial costs – the savings were based on just saving €1,100 of extra transformer costs but these are now €5,500 (= €1,100 + €4,400).

Eurelectric brought this issue to DG Grow who stated it is not their area and instead it should be DG Clima or DG Ener, so whilst the justification is simple and clear, the path to a derogation is less clear. In the interim, such transformers are being bought at a large costs to the customer and with no net savings or carbon emission reductions.

Similarly, where Transformers designed for a load facto of 30% are being used to feed loads whose load factor is much higher at for instance 60%, then the transformers are less efficient than expected and do not make the savings required. Instead, transformers with lower copper loss should be used but this is not possible under the regulations.

Ref ICF Box 2.3: (p. 45)

The advantages of Fixed Losses listed largely apply to the reduction in manufacturing costs as designed is standard, less variation and innovation required and component sizes such as steel widths are the same for all manufacturers. However, savings in manufacturing costs are limited – about 5% for steel was what came up in VITO report – and these costs are small compared to the value of the losses saved i.e. they are not a justification for any significant decision.

Ref ICF PEI Usage for medium transformers (p. 44)

Eurelectric members support the use of absolute values of losses for medium transformers without PEI.

Ref ICF 2.3.2.3 Techno Economic methodologies to review Ecodesign considerations for transformers (p 45-47)

VITO originally did an extensive investigation of all the aspects of issues associated with transformer materials and concluded that they were environmentally acceptable and no changes were warranted (see VITO Tier 1 report). Attempting to include and cost the effects of embedded materials within transformers will be impractical because these will depend on the country and conditions under which they are produced (e.g. if the country uses steel produced using fossil fuel or using hydro there will be two different answers). Additionally, the cost impact of items which are already environmentally acceptable for transformer use in the EU will be minor and outweighed by the overall impact of losses saved or extra manufacturing costs.

The mechanism for assessing the volume of electricity used and then capitalising the costs of losses saved was set out in earlier EU reports on Tier 1 and Tier 2. There, the critical aspects are the values of the inputs to be used:

- Discount Rate.
- Cash flows, which must be added for risk, and finance costs if a social discount rate is used.
- Fuel cost of electricity, which will be saved by reduced losses.
- Variation of Fuel costs as Net Zero is approached.
- Lifetime.
- Terminal costs.

Additionally, the extra costs of modifying the transformer to decrease losses must be further taken into account, and this is especially important due to the high costs which will be encountered due to declining returns to scale.

Other factors which have a very significant impact must also be considered:

- As renewable energy increases in the grid, the value of the electricity saved decreases, as the amount of fossil fuel decreases and is replaced by wind/solar which has no fuel costs to save
- Very high levels of Renewable Generation and the inefficiency of using electrolysers to produce hydrogen (30% efficiency) may mean that to effectively use renewable generation, loads must be turned on when renewable sare available. This will greatly increase the peak loading and hence losses on all plants, but in turn, will avoid a much greater amount of renewable electricity being constrained off the system.

A more detailed assessment of issues which arise in the valuation of Transformer losses is given in Appendix 2.

Ref ICF 2.3.2.4 Are there requirements when using reversed power flows transformers due to increase in embedded generation? (p. 47-48)

A reverse power flow condition assumes generation from renewables at a lower voltage flowing up through the transformer for onward distribution at a higher voltage. It is not clear where this inquiry arises from since utilities have not reported any issues despite several years of experience with reverse power flows.

Very old transformers which used "flag and pennant" tap changers had potential limitations for high levels of reverse power flows due to their design, especially if such flows would cause excessive tap changing in relation to the operational setpoint and bandwidth. However, new transformers do not exhibit any of these problems since they are equipped with vacuum tap changers to avoid critical issues.

Furthermore, transformer losses associated with renewable generation create no CO_2 emissions and the final market value of such losses is netted off the price paid to the generator without creating any additional societal cost. The potential extra losses produced by changes in flux leakage patterns and core losses due to reversed power flows (referenced in the footnote on p.46) are very small in proportion to the main losses on a transformer and, additionally, can only occur during the short periods of time when generation exceeds load. Typically, for rooftop PV, export prices are much lower than the value of displacing imported electricity, and with the increase in loads such as heat pumps and EVs, diverters are used to reduce exports and maximise self-consumption. As a consequence, the number and duration of reverse power flows is reduced.

The life expectancy of transformers is not significantly affected by core losses, thanks to the efficiency of the employed steel and the reduced heat it produces, but it is more likely affected by rust on the cooling fins or by the necessity of early replacement due to load growth over the transformer's capacity. Hence, it would not be economical to design a transformer in order to minimise losses associated with reverse power flows.

Harmonics are also mentioned as a source of losses, with reference to the Australian power system, characterised by a significantly higher density of solar PV. In Europe, harmonics are not emerging as a concern, probably because the design of the inverters has significantly improved and the levels of harmonics produced are well below the levels allowed by standards. As an example, while standards in the UK allow for a short circuit ratio (RSC) of 33 for typical EV loads of 7kVA, measurement of actual harmonics showed an RSC of 15 (i.e. less than 50% of the allowed threshold).

All in all, from an economical perspective, the installation of a larger transformer to cope with future load growth would best address all transformers' ageing and heating issues.

In the *Stakeholder Feedback Summary* section, the report states that *'for reverse flow, the transformers would need an on-load tap changer which might increase the cost of the transformer'.*

On-load tap changers are already standard on all HV transformers. On MV and LV transformers, on-load tap changers are occasionally used for voltage control (e.g., where high EV loads require a higher voltage setting or when PV generation is high and load is low). However, this is not related to losses and transformer heating and just to maintaining voltage standards.

Ref ICF 2.4 Regulation definitions and scope (p. 49)

Ref ICF 2.4.2.1 Appropriateness of the exemptions for transformers in offshore applications (p. 56)

The fundamental point of discussion here is whether transformer switches used to transmit renewable energy should be required to minimise losses according to Ecodesign efficiency levels.

In such applications, the energy lost in the transformer is produced from wind or solar and has no associated CO_2 emissions. Hence, there is no variable loss cost to be saved as there would be in the case of fossil fuel generation. Additional costs incurred for the installation and/or reinforcement of offshore platforms to accommodate a more efficient transformer could not be justified by the achievement of any benefit.

It remains in the commercial interest of the owner of the transformer to assess whether there are commercial losses worth mitigating by installing more efficient transformers. In such cases, a loss reduction would much more likely be achieved by acting on the cabling to the transformer within the wind farm rather than in the transformers themselves, as these are already highly efficient.

Ref 2.4.2.2 Pole-mounted Transformers Concessions (p. 52)

In relation to pole mounted transformers, an increase in transformer weight will for many countries require either the replacement of the existing pole or the installation of a second pole. The cost of either option would completely outweigh the value of the saved losses which are limited due to the low rating of pole mounted transformers. Additionally, the environmental costs (i.e. embedded emissions) of adding or replacing a concrete pole and the ones necessary for the disposal of the existing pole would completely outweigh any attainable environmental benefits. Lastly, works necessary for the replacement or addition of new pole mounted substations will inevitably delay electrification and the processing of new connection requests.

We disagree with the statement "*Considering the size of the pole mounted distribution transformer market, the savings of shifting the savings would be non-negligible. There may be a case to review if the market can be encouraged to shift towards ground-mounted transformers".* Rather than the volume of savings, what is relevant to consider is the ability to economically attain such savings. As pole-mounted transformers have small ratings and are generally used in rural areas characterised by lower load factors, actual losses per transformer are very low. Consequently, the value of any saved losses would also be very low, whereas the costs of work associated with the replacement of the transformer could be around a hundred times the ones of energy saved. Hence, rather than assessing loss savings per transformer, what needs to be assessed is how costly it would be to achieve such savings and with what environmental impact. Analogously, the financial and environmental costs associated with a shift to ground-mounted substations would be enormous and unjustifiable. In fact, ground-mounted substations are accessible to the public and need to be completely enclosed in a steel box, placed on a concrete foundation and equipped with cabled connections in metal trunking up to the overhead MV lines. The LV side of the transformer must either be run up an additional pole or run underground in ducts, requiring costly civil work. Even bigger issues can arise from land purchase negotiations with landowners, often costly and time-consuming.

The Report further indicates that *"Some stakeholders stated that the concession limit of 400kVA is too high as the current like for like replacements are typically of 50 to 200 kVA. Consideration could therefore be given to reducing the concession limit to 100 or 200kVA as higher loads (typically for <250kVA) are being moved to ground based setups. It was also suggested that the need for the concession could be determined case-by-case under disproportionate costs, as was done for the Tier 2 concession".* Pole mounted transformers present many advantages, especially in rural areas where they limit the use of ground surface and concrete substations to the benefit of cultivated land. Moreover, pole mounted transformers are particularly fitting in isolated areas delivering a limited number of customers. The reason behind the concessions for replacements above 200kVA is that, when a capacity of 200kVA is exceeded, the only solution is to install a second transformer with a second set of installation costs, iron losses and embedded steel. In a village where a 200kVA transformer is at full load, electrification could rapidly increase the load and easily cause capacity to be exceeded. The identification of a suitable location for the addition of a second transformer in an already highly constructed area would be difficult and would likely require additional installation and connection costs. Without the concessions, it would be necessary to install a 400kVA ground-munted substation, which would lead to the same issues mentioned above. The most economical solution is to allow the installation of larger pole-mounted transformers to replace the existing ones.

Tier 2 has already created a technological deadlock for new installations. No manufacturer has been able to manufacture a pole mounted transformer that complies both with Tier 2 Regulation (Table I.1) and the technical specifications for the pole mounted configurations with regards to weight. In order to guarantee security of supply in isolated areas along with the energy transition, it is of paramount importance to preserve existing pole mounted transformers by maintaining the Tier 2 concessions and disproportionate cost derogations as existing. Without these, the replacement of pole mounted transformers would lead to the additional emission of 200-300 kg CO_2 and an additional cost of € 8'000-16'000 per transformer. Hence, a case-by-case assessment of the need for concessions is not necessary: any situation where a large pole-mounted transformer is not permitted will inevitably result in disproportionate costs.

Moving on to the query on transformers' replacement ahead of their useful lifespan due to load electrification, the answer is that if electrification is successful, transformer loads can be expected to greatly increase and exceed current transformers' capacity. This loading increase could be minimised by controlling the load profile to spread it more evenly during the day. However, considering an average of 7kW for an EV charger power rating, 3kW for a heat pump, 3 kW for a backup immersion heater, and the fact that historic designs were made based on a 1.5kW average per customer, transformer replacements will likely need to take place with future load electrification. Displaced transformers could be reused if they had a remaining useful lifetime, otherwise, they would be recycled for material recovery.

Ref ICF 2.4.2.3 Concession to medium transformers with special combinations of winding voltages (p. 54)

In the case of Ireland, since 1995, virtually every transformer has been produced with dual 20/10kV windings, with around 50% of the 60,000 km of MV network currently converted to 20kV. The shift from 10kV to 20kV saves 75% of all copper losses on the circuits leading from the transformers. Consequently, maintaining concessions for this type of transformer helps ensure that the conversion to 20 kV remains economic, does not imply a change in the dimensions of the transformer, and hence allows the replacement of existing transformers with dual ratio units on the same pole and with the same connections. This, in turn, accelerates the voltage uprating and minimises costs. Attempting to change transformer designs on units that are already efficient and save large amounts of circuit losses is not worthwhile. This is one of the reasons such concessions were granted for transformers with extra windings.

Ref ICF 2.4.2.4 A Technology Neutral Approach (p. 54)

In relation to the use of dry-type transformers against liquid-immersed transformers, customers choose dry-type solely due to their fire performance, as it would be otherwise cheaper to buy liquid-immersed transformers. This indicates that safety bodies require the use of dry-type transformers.

If, at the European level, it was unequivocally stated that liquid-immersed transformers are suitable as an alternative for dry-type in case of fire, then liquid-immersed transformers compliant with Ecodesign would be used everywhere. This is not the case, presumably because in situations where higher fire performance is required dry-type transformers are required for safety reasons.

Ref ICF 2.4.2.5 Functional Categorisation

The list of function-specific transformer categories is long, but the absolute numbers of units installed for each category are small, and any existing concessions were originally provided because of clear cases justifying them as reported in the original VITO assessments performed for Tier 1 and Tier 2. The review of such concessions is probably not worthwhile due to the amount of work which would be required against the very limited scope of their application.

2.4.3 Recommendations (p. 60-61)

Ref ICF 2.4.3.2 Pole Mounted Transformers

As detailed above, concessions for pole mounted transformers are not inappropriate and do not constitute a loophole.

Rec ICF 2.4.3.3 Concessions to Medium Transformers with special combinations of winding voltages and Ref ICF 2.4.3.5 Functional Categorisation

The assessment of disproportionate cost is a case-by-case approach and therefore it is unsuitable for widely common transformer applications. The disproportionate cost approach is focused on individual cases with up-front approval and provides no clear guidelines to evaluate what level of costs is inappropriate. Currently, disproportionate costs have been applied in limited individual cases – and even some cases have been rejected by the relevant authorities, as mentioned during the 2nd stakeholder meeting. Therefore, this approach cannot be treated as a standard solution for special transformer exemptions. Special use exemptions provide legal certainty for all parties. For instance, decisions related to disproportionate costs are made by the utility, while documentation and reporting to the MSA are carried out by the manufacturers. Both utilities and manufacturers require working with large batch approaches and it would be very challenging for them to cover all cases up-front (e.g. replacement of a transformer or investment to solve an urgent demand of a customer).

Hence, the legislation exemptions are better suited for special uses, for instance, in the case of pole mounted transformers equipped with special pole accessories (e.g., internally mounted fuse) or dual winding transformers. In case a misuse of these exemptions is suspected, we could gladly provide post-factum reports providing details on installations and justifications for applying the exemptions.

The savings arising from the conversion from 10kV to 20kV are easily assessed: at 20kV losses are reduced to a quarter (i.e., 75% savings in line losses) of what they would be at 10 kV (e.g. moving from 10kV and 55A, to 20kV and 27.5 A, losses are reduced from 55^2 R to 27.5^2 R).

Regarding functional categorisation, we agree with the recommendation that it is not worth pursuing this review further.

Ref ICF 2.5 Material Efficiency (p. 62-67)

Ref. ICF 2.5.2.1 Increasing Product lifetime

The stated lifetimes of transformers will have a significant effect on the capitalisation of losses, which are currently capitalised over 40 years for all transformers. **Consequently, we assume that the proposed lifetimes for capitalisation will be in line with these figures.**

The typical utility experience in the past has been that where transformer failures occurred it was generally due to poor design or manufacture, not in accordance with standards and specifications. For instance, HV Transformers, due to their cost and importance are manufactured with greater capability and seldom fail.

The list of issues provided by ICF which accelerate transformer failure probably relates to transformers which failed under warranty and were returned to manufacturers, but are seldom seen as common issues in utilities.

The main reason why a transformer is replaced and scrapped is because its capacity was exceeded by the load and it needs to be replaced with a larger unit, but the remaining lifetime is such that it is not worth reusing. This mainly occurs with smaller transformers up to 1MVA where the installation costs can be a significant portion of the value of the transformer and the risk that the transformer will fail early due to a shorter remaining lifetime make this risk unattractive. Another reason is rust on corrugated fins of MV/LV transformers which are very difficult to repair and could result in an oil leak, pollution and overheating.

With HV transformers, failure which would require a redesign of the transformer to bring it up to current Ecodesign standards makes repair uneconomic and risky, because the transformer design and clearances and type testing does not facilitate such ad hoc changes.

ICF Ref 2.5.2.2 Improved Repair

Hence, this requirement for upgrading Ecodesign to current loss levels is misconceived and would result in unnecessary scrapping of transformers. Typically, only HV Transformers are worth repairing internally. For all other transformers replacement of broken bushings is all that is economic as such transformers are typically in the price range to €2k - €15k. Any work on the windings/core can require the transformer to be brought up to current ecodesign standards. With HV transformer repair could be worthwhile, but having to redesign the transformer and then take the risk that such a one off which was retrospectively imposed within the existing tank will work is not worthwhile – it requires transformer experts to do a one off design, specialists to implement and test it, and a risk that failure occurs immediately or in the near future as the unit is of a bespoke type.

The proposal not to require such an upgrade unless the transformer is to be put on the market again is a positive step forward. However, as it will still be uneconomic to repair and meet Ecodesign standards it will either be scrapped or sold outside the EU. Yet the embedded carbon in the steel would justify repairing to the original standard and continuing in use rather than being replaced.

The original proposal was in the context of old transformers being retired in the tens of thousands and then being refurbished and put on the market with original losses, higher than Ecodesign. This would not happen because repair is uneconomic, and customers do not want transformers which could fail prematurely. Therefore, it is an ineffective rule.

Ref ICF 2.5.2.5 Recycling

Recycling could become a problem in 20-40 years, or even sooner if the transformer capacity is exceeded. Utilising higher transformer capacities, such as through the use of ester, would postpone retirement and provide more immediate environmental benefits than recycling, which could involve very different technologies in 40 years.

Ref 2.5.3 Recommendations

'Furthermore, Ecodesign can include a requirement that transformers need to be disassemblable without destruction to allow for repair. This requirement would be set up such that an expert (class C, with specific training and/or experience relate to the product category), can perform the repair with tools of class C (commercially available tools)'

Transformers should not be built on the basis that they can be repaired – they should be built on the basis that they should not fail. If the design of a transformer incurs additional costs for the purpose of repair, but the transformer still fails after 20-40 years with only a small residual life remaining after repair, then it may only last for an additional 2-3 years. This would not be a cost-effective approach. **Eurelectric endorses the recommendation of the study of having the efficiency requirement not exceed the original equipment performance.**

Appendix 1 – Reaction to ICF Recommendations of the 14/01/24 Stakeholder Meeting

This appendix reports the comments by Eurelectric to the ICF recommendations and proposals presented on the occasion of the Stakeholders Meeting held on 14/01/24. References to the meeting slides are made to facilitate the reading.

Ref Slide: Existing Standards and Regulation

"EU Tier 2 competes strongly with Japan and US regulations".

EU Tier 2 should not be regarded in competition with Japan and US Regulations. The appropriate levels of efficiency depend on the carbon intensity of the local grid and the costs incurred for producing more efficient transformers in that specific market. A higher share of fossil fuels in the electricity mix can justify the requirement for more efficient transformers and vice versa.

Ref Slide: Ecodesign Energy Efficiency Requirements

"To review the TCO for raising Tier 3 under the Phase 2".

It is premature to consider new Tier 3 requirements without having first thoroughly assessed the outcomes of implementing Tier 2.

"Also consider the concerns with regards to the amorphous steel supply chain. - Please provide feedback with regards to the supply chain of amorphous steel".

The use of amorphous steel would not be in line with the EU policy on Critical Raw Materials as this is only manufactured outside the EU *in* India, China, Japan and the US. Furthermore, European transformer manufacturers do not have the manufacturing capability to slit amorphous steel and optimise transformer design. Hence, transformer designs are limited to standard sizes. Lastly, amorphous steel is designed to minimise iron losses (albeit with an increase in weight, size and noise impact). Nevertheless, with an increased load due to electrification, copper losses would become increasingly impactful.

"Total Cost Ownership concerns for transformers are mostly on the material costs, due to the lifetime of the asset, the short-term variability of electricity prices are of minimal concern".

Total Costs of Ownership are assessed based on the initial material costs and the long-term variable cost of electricity which decrease as net zero generation is approached. While it is correct to say that short-term variability is not an issue when capitalising over 40 years, it is necessary to remark that electricity prices are a very significant input to TCO calculations.

Ref Slide: Implementation of Ecodesign requirements and methodologies (1/3)

"Recommendation to keep the concession for "disproportionate costs" for cases where the 1- to-1 replacement is not possible, Phase 2 to engage with MSAs to clarify the mechanism for the concession".

We strongly disagree with the assertion that retention of concession for disproportionate costs is not possible. This concession was analysed in great detail in Tier 1 and Tier 2 reports and was well justified. Disproportionate costs arise when installation costs in particular circumstances are inordinate (e.g. when transformers will not fit into an underground vault and costs of installation would be many times the order of magnitude of saved losses) and for common designs such as pole mounted transformers, for which the absolute valued of saved losses is low, the absolute cost of the transformer is also low, yet the additional cost necessary to replace the transformer pole can equal 50% or more of the total cost of the transformer.

These cost issues are expected to generally arise for the mentioned applications due to common design features. The requirement for an individual assessment for disproportionate costs would be practically impossible to fulfil due to administrative burdens and delays and to the fact that high volumes of such transformers are produced in series. The resulting delays would in turn negatively affect electrification and produce inordinate costs for the customer. If a detailed cost-benefit assessment was carried out to justify this recommendation this should be clearly reported, specifying the type of transformer for which it applies.

"This clarification is needed to ensure that stakeholders can use the existing regulatory exemption. We currently have had no written evidence of the successful use of this mechanism".

The use of regulatory exemptions involves very bureaucratic and slow procedures resulting in high costs and delays. Regulatory authorities would not have the in-house competencies to deal with the specific and detailed techno-economic assessment required and would likely need to tender for consultants to carry out the work. Consequently, **the use of regulatory exemptions should only occur in unusual circumstances and where the need for concessions had not been foreseen.** As in the case of pole mounted transformers, the elimination of concessions for extra losses would result in the application of regulatory exemption in all cases and in numbers which would be processable. The lack of evidence of the successful use of regulatory exemptions actually indicates the appropriateness of the concessions already provided, not the lack of a need for such exemptions.

Ref Slide: Implementation of Ecodesign requirements and methodologies (2/3)

"Medium transformers represent the largest market share of transformers and hence affect grid losses significantly. Recommendation to keep the absolute values of losses for medium transformers without PEI. Phase 2 will include a review of TCO of the base cases modelled, which will include material concerns such as increased lifetime and recycling considerations."

Eurelectric members support the use of absolute values of losses for medium transformers without PEI.

Ref Slide: Regulation definitions and scope (1/2)

"As offshore applications are a non negligeable share of the market, with strong growth, these are recommended to be brought back into the regulation. More data is sought on offshore applications via the quantitative questionnaire."

The justification for including offshore transformers in regulation is difficult to justify as their extra weight will add inordinately to the cost of accommodating them offshore, and as they are mainly used for offshore wind turbines for which losses are CO_2 emissions-free, have no variable costs and no opportunity cost. If a thorough cost-benefit analysis was undertaken to justify the proposed change this should be clearly reported.

"Pole mounted transformers are recommended to have their concessions removed from the regulation".

No justification has been provided for this proposal which contradicts the analysis carried out in Tier 1 and Tier 2. A very detailed cost-benefit analysis is required to justify such a change involving each rating of transformers used, its installation method and costs, and the incremental savings in losses.

"The concession for the combination of winding voltages requires review under Phase 2 to justify the concession from Tier 2 to Tier 1".

Similar to the previous case, **no justification was provided for this proposal which contradicts the analysis carried out in Tier 1 and Tier 2.** A very detailed cost-benefit analysis is required to justify such a change involving each rating of transformers used, its installation method and costs, and the incremental savings in losses. In addition, the benefits arising from the use of such windings would also need to be taken into consideration, including the 75% saving in MV lines losses achieved with dual winding 20/10kV transformers, as well as more specialised transformers used to accommodate increased electrification in older LV urban networks.

"For all of the above cases, the exemption under the disproportionate costs mechanism could be used to justify performance changes. This brings in focus the need for review of the mechanism under Phase 2".

As already described above, **the use of the disproportionate costs mechanism would be strongly inappropriate in these cases.** The resulting costs, delays and complexity would make the process unfeasible. The proposal to adopt such an approach should be backed up by a detailed mapping of the process and the associated timeline so that both the associated direct and indirect costs could be assessed.

Ref Slide: Regulation definitions and scope (2/2)

"There is little appetite from stakeholders to have functional categorisation of transformers. Transformers are currently classified under a dry or liquid immersed categorisation. Ecodesign should only follow a functional, technology-neutral approach if standard IEC 60076 were to create those framework definitions. This would lead Ecodesign to rename performance requirement tables under the new standard definitions. This is not expected to change performance requirements but may allow for other transformer technologies to enter the market".

We generally agree with the recommendation.

Ref Slide: Material Efficiency

"Phase 2 will review the potential benefits of disassembly requirements to allow for repair. Base Case modelling will determine the impacts of lifetime extension. Phase 2 will review the implementation of the article 1.3 to determine common practice and responsibilities of the repair process. This will inform recommendations on potential changes to article 1.3. Stakeholders are invited to provide insight into current practices. The benefits of recovery and regeneration of mineral oil will be included under Phase 2 modelling".

This area is covered in detail in the body of this document. However, **in summary, transformers are generally very reliable and it would be inordinately costly to change the design of the transformer to facilitate a load that is unlikely to ever be required.** If in good condition, most transformers are re-used with minor external repairs (e.g. paintwork) either in new or existing substations. Older or damaged transformers are scrapped because it is too risky to move and reinstall them in a new substation due to their limited remaining lifetime. In these cases, it is more practical to simply install a larger rated transformer ab initio as this new transformer would age more slowly and would take much longer to reach full capacity.

Ref Slide: Environmental Considerations

"It is recommended that Ecodesign not include a requirement regarding transformer noise, but rather leave these to existing national and local governments".

We agree with the recommendation that noise levels should be covered by national standards.

"It is recommended for transformer operating and storage temperature range be made a provision requirement".

Temperature ranges are fundamental to the design and operation of the transformer and have profound impacts on its design. They are best assessed in Cenelec Standards by national expert committees following detailed technical assessment and review by experts. **It is not appropriate to make provisions for temperature ranges in the Ecodesign assessment**, which should rather consist in a cost-benefit analysis.

Ref Slide: Other Topics

"It is recommended that Ecodesign not include a requirement to regulate SF6 as these are covered by other regulations".

We agree with the recommendation.

"It is recommended Ecodesign not set their own test methodology for determining kPEI. CENELEC has been engaged in reviewing this methodology for Ecodesign to align with".

We agree with the recommendation.

"It is recommended that Ecodesign regulation not consider the use of sustainable peak load until a standard for the metric has been developed"

We agree with the recommendation.

Appendix 2 - Economic aspects of transformer loss assessment

Phase 1 Report did not include an economic assessment to justify the currently used level of losses, nor any indications on how the economic efficiency of different loss levels would be assessed. Such analyses formed a major part of the earlier Tier 1 and Tier 2 studies and a similar economic justification should now be required. This is especially true given the significant impact that the long-term trends in fuel mix variations, discount rates and declining return to scale have on the cost-benefit justification required to support the choice of transformer loss levels.

Transformers are now generally above 99% efficient, so that the cost of any further improvements in transformer efficiency increases sharply due to the law of diminishing returns. However, the benefits brought about by increased efficacy in terms of CO2 emissions saved and electrical energy saving are rapidly diminishing as Renewables Generation comes in large tranches which have high economies of scale and very low costs of producing electricity once installed

With this in mind, we call attention to two main points:

(a) The value of saved losses in the future zero-marginal electricity cost scenario should be clearly assessed.

The value of "saved losses" has previously been assessed as the capitalized value of the costs saved by not burning fossil fuels and the associated savings in CO_2 emissions. In line with the EU goal to reach net-zero emissions by 2050, fossil fuels will be progressively phased out and electricity production will be moved to renewable sources, characterised by zero variable cost and CO_2 emissions. This means that, while the production of a more efficient transformer will entail additional costs, use of material and labour, the related energy savings will be insufficient to offset them.

An additional factor to consider in the analysis is that load profiles are changing with the integration of solar PV and EVs in the network and they will be further influenced by the increasing availability of flexible tariffs. Furthermore, In view of the future load electrification (e.g. switch from gas to heat pumps, transition to electric vehicles), the main focus of DSOs should be rather put on investments to increase overall network capacity.

(b) Acknowledge that imposing higher transformer efficiency requirements will lead to steeply declining returns to scale.

In most cases, transformers already attain an efficiency of 98-99% or above. Hence, the cost necessary to produce even more efficient transformers would grow disproportionately. As well established in the literature, a 5% increase in efficiency would roughly lead to a 50% increase in costs. In this scenario, it is imperative to provide a sound basis to justify any requirement to move from the loss levels currently allowed.

Considering the above factors, the cost-benefit analysis performed as part of the work of Tier 1 and Tier 2 should now be thoroughly reviewed, as required by the Ecodesign legislation, to ensure that any existing or proposed requirement entailing an investment remains effective and creates value for the customer.

An updated cost-benefit analysis is required to assess whether the value of the losses saved is matched by the associated direct and indirect costs. Moreover, it should take into account the effect of volume increases on the thermal balance of the transformer which has an impact on its lifetime and the location of its installation.

The evaluation of transformer losses involves:

(a) Establishing the volume of kWh which will occur as losses in the transformer over its useful economic life.
(b) Costing these losses each year using the marginal cost of the energy saved and the associated value of CO_2 saved.
(c) Discounting these cash flows using an appropriate interest rate.

There are different methodologies for carrying out these calculations, it is of key importance to properly motivating the choice of methodology. One example is the CIGRE Green Book[3].

in carrying out this methodology, the significant variables are:

(i) **Discount rate** to be used – the social discount rate previously used has now changed significantly and must also be combined with the long-term EU inflation rate to estimate a nominal social discount rate. However, this must only be applied to the societal benefits produced (i.e. the value of the losses).

The costs incurred by utilities for the extra investment required must be discounted at the utility WACC as the social discount rate does not take into account the financial risk which a private utility faces, see the EU Methodology.

(ii) **Loss volumes**, which depend on transformer iron and copper loss levels but also on initial loading taking into account the daily and seasonal fluctuations and load growth rates based on the decarbonisation scenarios proposed by the European Commission.

(iii) **The marginal price of electricity** used each year associated with the fossil fuel burnt to provide the losses. This is decreasing as the marginal cost of a kWh of wind/solar is zero.

(iv) **The value of the CO_2 saved,** which is approaching zero as the grid decarbonises completely by 2050.

As introduced in the Commission regulation (EU) 2019/1783, amending Tier 1 into Tier 2, we would like to remark the importance of the three following points when carrying out a thourough economic assessment:

"(5) It is generally recognised that the most appropriate method to optimise transformer designs in order to minimise electricity losses continues to be the valuation and capitalisation of future losses using proper capitalisation factors for load and no load losses in the tendering process. However, for the purposes of product regulation only the use of prescribed values for minimum efficiency or maximum losses is feasible."

"(7) The study analysed the economic viability of transformers compliant with minimum requirements set out in Tier 2 applicable as of July 2021 and found that lifecycle costs for compliant medium and

[3] *Transformer and Reactor Procurement* (2022). Editors Gilson M. Bastos, Tom Breckenridge, Mike Lamb, Tara-Lee MacArthur, Simon Ryder

large power transformers are always lower than Tier 1 compliant models, when these are being put into service in new installation sites. However, in specific situations where medium power transformers are being installed in existing urban substation locations, there can be space and weight constraints that affect the maximum size and weight of the replacement transformer to be used. Therefore, when the replacement of an existing transformer is technically infeasible or entails disproportionate costs, a regulatory relief should be justified."

"(8) An existing regulatory exemption for the replacement of large power transformers related to disproportionate costs associated with their transportation and/or installation should be complemented by an exemption for new installations, where such cost constraints are also applicable."