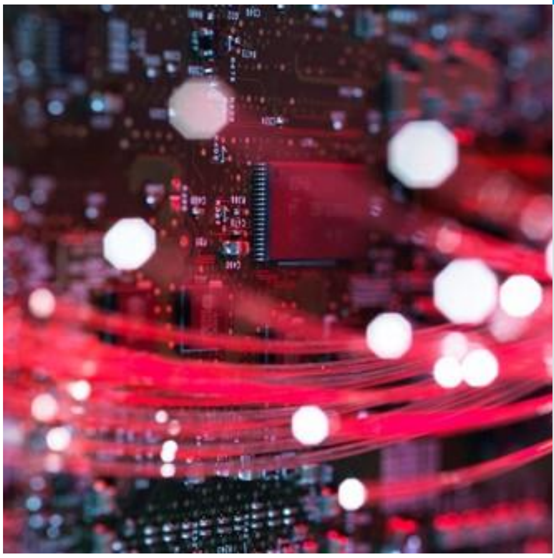

Study for the review of Commission Regulation 2019/1783 (Ecodesign of small, medium and large power transformers)

Phase 1 report – Technical Analysis - DRAFT

December 2023

Submitted to:

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Study for the review of Commission Regulation 2019/1783 (Ecodesign of small, medium and large power transformers)

Phase 1 report – Technical Analysis – Draft

A report submitted by ICF S.A.

Date: December 2023

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1 Introduction

The study for the review of Commission Regulation 2019/1783 (Ecodesign of small, medium and large power transformers) has been commissioned to update the Ecodesign regulation on power transformers. The study covers a broad range of subjects, including, amongst others, the definitions used in the regulation, the scope and exemptions granted, the energy efficiency requirements, technological improvements in the technology, usage patterns and market changes.

1.1 Aims and objectives of this report

This report covers Phase 1 of the review study. This phase of the study seeks to answer specific questions raised in article 7 of Commission Regulation (EU) 2019/1783, and other points of interest to DG GROW and other Commission Directorates.

Listed below are the items set out in Article 7 of Regulation 2019/1783:

a) the extent to which requirements set out for Tier 2 have been cost-effective and the appropriateness to introduce stricter Tier 3 requirements;

b) the appropriateness of the concessions introduced for medium and large power transformers in cases where installation costs would have been disproportionate. In particular, the analysis should investigate concessions in concrete cases (e.g., manufacturers, electricity companies, market surveillance authorities) and determine their appropriateness;

c) the possibility of utilising the PEI calculation for losses alongside the losses in absolute values for medium power transformers;

d) the possibility to adopt a technology-neutral approach to the minimum requirements set out for liquid-immersed, dry-type and, possibly, electronic transformers;

e) the appropriateness of setting minimum performance requirements for small power transformers;

f) the appropriateness of the exemptions for transformers in offshore applications;

g) the appropriateness of the concessions for pole-mounted transformers and for special combinations of winding voltages for medium power transformers;

h) the possibility and appropriateness of covering environmental impacts other than energy in the use phase, such as noise and material efficiency.

Further items to be analysed:

i) material efficiency aspects;

j) an analysis of the standards, and of their relevance for regulatory purposes;

k) technological, market and regulatory evolutions affecting environmental performance;

l) Ecodesign (or similar) requirements for power transformers in other jurisdictions, in particular the US and Japan and in comparison to current Ecodesign requirements for Tier 2.

m) strengthening potential of the existing MEPS and the potential of introducing material efficiency requirements (MMPS);

n) impact of rising electricity prices on current and potentially stricter Ecodesign requirements.

o) existing methodologies for assessing technoeconomic aspects of Ecodesign for power transformers (especially in terms of technology neutrality, circularity, MEPS and MMPS), as well as for the assessment of the costs for replacement/installation of transformers, based on the principles laid down in Regulation 2019/17834.

p) functional categorisation of power transformers (including conventional transformers, overload transformers and fire performant transformers and any others that the contractor may suggest).

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).

r) other topics, as emerged from consultations with stakeholders.

The subjects set out in this list of items, have been grouped in the report along the themes of:

- Regulation definitions and scope (items f, g and p)
- Ecodesign energy efficiency requirements (items a, e, and n)
- Existing standards and definitions (items j, k and l)
- Implementation of methodologies for Ecodesign requirements (items b, c, d, o and q)
- Material efficiency (items l and m)
- Environmental concerns (item h)
- Other topics (item r)

1.2 Methodology followed

To answer the queries set out in Phase 1, the research team used its extensive technical expertise and consulted with stakeholders through a stakeholder meeting, qualitative questionnaires, and direct 1-to-1 calls. The input from stakeholders was synthesised into answers for each item, illustrating the arguments set out by stakeholders. The research team then used their own expertise and independent research to corroborate the stakeholder inputs. For each theme, the report details the background to be aware of in the theme, develops the research results and stakeholder feedback, makes recommendations to policymakers on next steps for Ecodesign and sets out in which sections of Phase 2 the subject would be further developed in the update to the Ecodesign study.

2 Items for review

2.1 Existing standards and regulations

j) an analysis of the standards, and of their relevance for regulatory purposes;
l) Ecodesign (or similar) requirements for power transformers in other jurisdictions, in particular the US and Japan and in comparison to current Ecodesign requirements for Tier 2.

2.1.1 Background

International standards for transformers ensure the safe and effective functioning of the vital electrical grid that dictates everyday life. They provide a common framework for manufacturers, power utilities and others involved in the production and operation of transformers. Guaranteeing the reliability, efficiency and safety of these products and facilitating the international trade by harmonising the specifications of transformers. Therefore, adherence to international standards is essential to ensure these systems are kept running smoothly.

There are several different standards that exist across the world that cover many aspects such as the design, manufacture, installation, testing, commissioning, and operation of transformers. With different standards covering a wide range of power and distribution transformers.

The main standards that are adopted by regulations worldwide include the following:

- IEC 60076-X series (International Electrotechnical Commission)
- IEEE C57.12 series (Institute of Electrical and Electronics Engineers)
- EN 50708-2-1 Power transformers. Additional European requirements - Medium power transformer. General requirements
- EN 50708-3-1 Power transformers. Additional European requirements - Large power transformers. General requirements
- National Electrical Manufacturers Association (NEMA) TP-1

Following extensive market research, our conclusion is that the two most specified international standards are IEC 60076 and IEEE C57.12[1]. With most economic blocs requiring the testing of energy performance of power transformers to be performed using the IEC 60076 standard[2]. The standard which is adopted is varies based on upon geographical location. At present, most major economic blocs (excluding North America) use IEC 60076 which covers power transformers, tap changers for use in transmission and distribution. There are now 26 parts to the standard covering many details, including energy performance testing. The IEC 60076 standard is one of the most widely used, with over 100 countries adopting it[3]. Meanwhile Canada, Chile and the United States are the three economies that use the IEEE standards as a basis for their own national standards for transformers. The US uses NEMA TP-1 which is closely aligned with the IEEE standard. Canada standards are also closely aligned with the US's NEMA TP-1 test methods.

[1] U4E_DT_Model-Procurement-Specs_Final_20191002_2.pdf (united4efficiency.org)

[2] lbnl-1005067-lbnl_international_review_on_dt_sl_programs.pdf

[3] https://www.daelimtransformer.com/iec-60076-standard.html

In the EU, EN standards are fully aligned with the IEC standards while the IEEE has recently initiated alignment with the IEC standard. However, there remains some difference in certain assumptions and definitions between standard IEEE C57.12 and the IEC standard[4]. For example, one of the major differences concerns the definitions of kilovolt-ampere (kVA) and efficiency.

One of the main uses of the test standards is to determine the energy performance of transformers with each providing variations in how this is done. From research there are four main ways that the energy performance of a distribution transformers is measured[5]:

- Maximum no-load and load-losses
- Maximum combined losses
- Minimum efficiency requirements
- Peak Efficiency Index (PEI)

2.1.2 Feedback/ Research results

2.1.2.1 Standards

IEC 60076 series of standards

The IEC 60076 series was prepared by the IEC Technical Committee 14 (TC14) and covers various aspects related to power transformers, governing the safe and efficient operation of transformers. The scope of TC14 covers the standardisation of power transformers, tap-changers and reactors used in power generation, transmission and distribution[6].

The standard covers transformers with a power rating above 1 kVA single phase and 5 kVA polyphase with a higher voltage winding of 1000 Volts or more, excluding lower voltage transformers. Various types of transformers are covered including liquid-immersed, dry-type, gas-filled, self-protected and transformers for wind turbines[7]. It provides the specifications of different voltage levels and power ratings, while supplying guidelines for materials, insulation and construction methods.

TC 14 published specification PD IEC TS 60076-20, 2017 with the aim ‘to promote a higher average level of energy performance for transformers. The standard provides a method for specifying a transformers energy efficiency according to the loading and operating conditions. It also presents the minimum efficiency and maximum loses which lead to a generally acceptable balance between loses and use of other resources. In addition, the IEC standard also provides guidelines for testing and performance evaluations.

The IEC standard proposes two methods of defining an energy efficiency index and three methods of evaluating the energy performance of a transformer. These measurements are based on the existing regional practices[8]:

[4] INTAS_D2.1_Final_Annex_A.pdf (intas-testing.eu)

[5] lbnl-1005067-lbnl_international_review_on_dt_sl_programs (2).pdf

[6] INTAS_D2.1_Final_Annex_A.pdf (intas-testing.eu)

[7] https://collections.iec.ch/iec60076

[8] https://webstore.iec.ch/preview/info_iects60076-20%7Bed1.0%7Den.pdf

- The Peak Efficiency Index (PEI) including a Total Cost of Ownership approach or any other means of specifying the load factor.
- The no-load and load losses at rated power for rationalisation of transformer cores
- The efficiency at a defined power factor and particular load factor (typically 50%).

The standard provides two levels of recommended requirements for each of these three methods: Level 1 is for modest energy performance; Level 2 is for high performance.

Another key aspect of the IEC 60076 standard is the transformer code system, which presents a standardised method of identifying and specifying transformers. The code specifies many parameters to describe transformers such as rated power, voltage level, frequency, winding connection, short circuit impedance, cooling method, and temperature rise[9].

EN 60076-X series are the harmonised standards used by the Ecodesign Regulation (EU) 2019/1783. Table 2.1 provides a full list of the standards prepared by TC 14.

Table 2.1 Full list of IEC 60076 standards developed by TC 14[10][11].

Standard	Title
IEC 60076-1: 2011	Power transformers – Part 1: General
IEC 60076-2: 2011	Power transformers – Part 2: Temperature rise for liquid-immersed transformers
IEC 60076-3: 2013	Power transformers – Part 3: Insulation levels, dielectric tests and external clearances in air
IEC 60076-4: 2002	Power transformers – Part 4: Guide to the lighting impulse and switching impulse testing – power transformers and reactors
IEC 60076-5: 2006	Power transformers – Part 5: Ability to withstand short circuit
IEC 60076-6: 2018	Power transformers – Part 6: Reactors
IEC 60076-7: 2018	Power transformers – Part 7: Loading guide for mineral-oil immersed power transformers
IEC 60076-8: 2018	Power transformers – Part 8: Application guide
IEC 60076-10: 2020	Power transformers – Part 10: Determination of sound levels
IEC 60076-11: 2018	Power transformers – Part 11: Dry-type transformers
IEC 60076-12: 2008	Power transformers – Part 12: Loading guide for dry-type power transformer
IEC 60076-13: 2006	Power transformers – Part 13: Self-protected liquid-filled transformers
IEC 60076-14: 2013	Power transformers – Part 14: Design and application of liquid-immersed power transformers using high-temperature insulation materials
IEC 60076-15: 2015	Power transformers – Part 15: Transformers for wind turbine applications
IEC 60076-18: 2012	Power transformers – Part 18: Measurement of frequency response

[9] https://www.linkedin.com/pulse/introduction-international-standard-power-iec-60076-muhammad-hanif/

[10] INTAS_D2.1_Final_Annex_A.pdf (intas-testing.eu)

[11] https://webstore.iec.ch/publication/606

Standard	Title
IEC 60076-19: 2013	Power transformers – Part 19: Rules for the determination of uncertainties in the measurement of losses in power transformers and reactors
IEC 60076-20: 2017	Power transformers – Part 20: Energy efficiency
IEC 60076-21: 2006	Power transformers – Part 21: Standard requirements, terminology, and test code for step-voltage regulators
IEC 60076-22: 2019	Power transformers – Part 22: Power transformer and reactor fittings – protective devices
IEC 60076-23: 2018	Power transformers – Part 23: DC magnetic bias suppression devices
IEC 60076-24: 2020	Power transformers – Part 24: Specification of voltage regulating distribution transformers (VRDT)
IEC 60076-25: 2023	Power transformers – Part 25: Neutral grounding resistors
IEC 60076-26: 2020	Power transformers – Part 26: Functional requirements of insulating liquids for use in power transformers

While the standards shown in Table 2.1 illustrate the international standards developed by the IEC, CENELEC has fully harmonised these standards into EN standards. These standards are known as the EN 60076-X series and are the harmonised standards used by the Ecodesign Regulation (EU) 2019/1783.

The IEC 60076 series of standards are currently subject to a revision and update process, which will have implications on this technical analysis and review of the Transformers Commission Regulation No 2019/1783. The Commission closely follows the development of new IEC 60076 standards, therefore, once the new publication is released the EU will subsequently adopt it as the EU's version of the IEC standard which is EN 50708.

EN 50708 series

Previously the regulation adopted the harmonised standards from EN 50588-1 and EN 50629. EN 50588 covered medium power transformers while EN 50629 covered large power transformers with a highest voltage[12]. The EN 50708 series "Power transformers – additional European requirements" supersedes these two standards and now acts as the additional requirements for the EU regulation 2019/1783. Specifically, EN 50588-1 has been replaced by EN 50708-2-1 and EN 50629 has been replaced by EN 50708-3-1. These standards act as additional standards on top of the IEC 60078 requirements that are already in place. The technical requirements set out in EN 50708 supplement, modify or replace the requirements of the previous EN standards which were derived from the IEC standards. The technical requirements adopted from the IEC standard by the EN standard include the peak efficiency, fixed load and no-load losses. The IEC standard was chosen as the standard to harmonise to in the EU because. This it was determined that its testing methodology more closely aligned with the use of transformers in the EU.

The EN 50708 series of standards is divided into three sections, as shown below. The parts of the standard which have been adopted by the Regulation are summarised further below in the Table 2.2.

- Part 1 series – Common requirements

[12] INTAS_D2.1_Final_Annex_A.pdf (intas-testing.eu)

- Part 2 series – Medium power transformers
- Part 3 series – Large power transformers

Table 2.2 Summary of the series of standards set out by EN 50708[13]

	Common part	Medium power transformers	Large power transformers
General requirements	**EN50708-1-1** Power transformers – Additional European requirements: Part 1-1 Common part – General requirements	**EN50708-2-1** Power transformers – Additional European requirements: Part 2-1 Medium power transformers – General requirements	**EN50708-3-1** Power transformers – Additional European requirements: Part 3-1 Large power transformers – General requirements
Assessment of energy efficiency	**EN50708-1-2** Power transformers – Additional European requirements: Part 1-2 Common part – Assessment of energy performance		
Accessories		**EN50708-2-3** Power transformers – Additional European requirements; Part 2-3 Medium power transformers - Accessories	
Special tests		**EN50708-2-4** Power transformers – Additional European requirements; Part 2-4 Medium power transformers – Special tests	**EN50708-3-4** Power transformers – Additional European requirements: Part 3-4 Large power transformers – Special tests
Single-phase power transformers		**EN50708-2-5** Power transformers – Additional European requirements; Part 2-5 Medium power transformers – Single phase	
Non-conventional technologies		**EN50708-2-6** Power transformers – Additional European requirements; Part 2-6 Medium power transformers – non-conventional technologies	

The standard covers large power transformers with a power rating above 3,150 kVA or highest voltage equipment greater than 36 kV. Medium power transformers with a rated power lower than 3,150 kVA and highest voltage for equipment greater than

[13] 21-04-20_EU-Oekodesign-Verordnung_GB.pdf (sgb-smit.com)

1.1 kV or lower than or equal to 36 kV. In addition, the standard also applies to medium power pole-mounted transformers with a rated power of up to 400 kVA, suitable for outdoor service and designed to be mounted on support structures of overhead power lines.

IEEE C57.12 series of standards

In the United States, the features and functionality of most power and distribution transformers fall under the IEEE standard C57.12. This set of US standards cover power transformers and was prepared by the IEEE Transformer Committee. Within this committee there were two subcommittees one for power transformers and another for distribution transformers.

The main IEEE standards and the latest versions that are related to power transformers are:

- IEEE C57.12.00 (2020) – for general requirements for liquid-immersed distribution, power and regulating transformers.
- IEEE C57.12.01 (2020) – for general requirements for dry-type distribution and power transformers.
- IEEE C57.12.10 (2017) – standard requirements for liquid-immersed power transformers.
- IEEE C57.12.20 (2017) – for overhead-type distribution transformers 500 KVA and smaller; high voltage, 34,500 V and below; low voltage, 7970/13 800Y V and below
- IEEE C57.12.40 (2017) – for network, three phase transformers, 2500 kVA and smaller; high voltage, 34,500 V and below; low voltage, 600 V and below; subway and vault types (liquid immersed)
- IEEE C57.12.90 (2021) – test code for liquid-immersed distribution, power and regulating transformers.
- IEEE C57.12.91 (2020) – test code for dry-type distribution and power transformers.

As illustrated above, the IEEE standards split the testing methodologies for dry-type and liquid-immersed distribution and power transformers into two different standards.

The IEEE C57.12.91 standard provides a methodology for performing the tests that are specified in IEEE C57.12.01. It applies to all dry-type transformers except instrument transformers, step-voltage and induction voltage regulators, arc furnace transformers, rectifier transformers, specialty transformers, and mine transformers[14]. In addition, it also applies to liquid immersed distribution and power transformers, autotransformers, regulating transformers, single and polyphase transformers with a voltage in the highest winding of greater than 601 V[15]. Providing a description of the electrical and mechanical requirements of liquid immersed transformers.

[14] https://ieeexplore.ieee.org/document/6152116

[15] https://standards.ieee.org/ieee/C57.12.00/5268/

The IEEE C57.12 series of standards is accredited by ANSI. The IEEE standard is fully adopted by ANSI and in the US the harmonised standard is referred to as the ANSI/ IEEE C57 standard[16].

NEMA TP 1

This standard provides a guide for determining the energy efficiency of distribution transformers. This standard has been adopted by the US Department of Energy (DOE) as the national energy efficiency rule for low voltage dry-type distribution transformers, medium-voltage dry type distribution transformers and liquid filled distribution transformers[17]. It was developed following a DOE study into transformer efficiency, which revealed on average that low-voltage dry-type transformers are loaded to only 35% of its maximum rating[18]. Prior to this study transformers were usually designed for maximum peak demand. Therefore, this standard defines the efficiency of distribution transformers at 35% loading to encourage industry to improve efficiency at this loading[19].

Comparison of IEC 60076 v IEEE C57 standards

While both the IEC and IEEE standards are widely used across the world for the design and testing of transformers, there are subtle differences that distinguish them. As discussed previously there are regional preferences for the two standards, with IEC used in Europe and across Asia, while IEEE is more common in North America. There are general alignments on the design and testing of transformers however, there are certain add-ons that each makes each standard unique, as shown in Table 2.3 these differences cover aspects such as reference temperature, waveform correction, loss tolerances and excitation current. Table 2.3 describes the differences between the standard's methodology for calculating load losses of a transformers.

Table 2.3 Comparison of IEC and IEEE for the measurement of load and no-load losses[20]

Aspect	IEC 60076-1	IEEE C57.12.00
Reference Temperature	Load loss reference temperature is 75ºC. Correction equation available for load loss. No-load loss reference temperature is 75ºC. No correction equation available for no-load loss.	Load loss reference temperature is 85ºC. Correction equation available for load loss. No-load loss reference temperature is 20ºC. Correction equation available for no-load loss.

[16] https://ieeexplore.ieee.org/document/4504732

[17] 2013-ewg-meps-vol-1.pdf (unepccc.org)

[18] Increasing transformer efficiency | Consulting - Specifying Engineer (csemag.com)

[19] TP-1 product launch issues; (jeffersonelectric.com)

[20] INTAS_D2.1_Final_Annex_A.pdf (intas-testing.eu)

Aspect	IEC 60076-1	IEEE C57.12.00
Waveform Correction equation	$P_0 = P_m$ Where: P_m = measured no-load loss And d = (U'-U)/U' U = measured average voltage U' == is the measured r.m.s. voltage	$P_c(T_m) = \frac{P_m}{(P_1+kP_2)}$ Where: k = r.m.s. voltage/ average voltage T_m = average oil temperature P_m = measured no-load loss P_1 = per unit hysteresis loss P_2 = per unit eddy-current loss
Maximum waveform correction	3%	5% or less
Loss tolerances	+15 % for no load loss and load loss, provided total losses don't exceed +10%	No limit for load loss measurements. No load losses shall not exceed 10% Total losses shall not exceed 6%
Excitation current	30% of the design value	Not specified.

In addition, to the contrasts illustrated by Table 2.3 there are further terminological differences across the two standards. Table 2.6 illustrates these differences which cover certain components and tests used by the IEC and IEEE standards[21].

Table 2.4 Terminology differences between IEC and IEEE standards

IEC 60076 Terminology	IEC C57.12 Terminology
Oil level indicator	Oil level gauge
On-load tap changer	Load tap changer
Terminal box	Terminal chamber
Type tests	Design tests

The definition of the rated power is another major difference between the IEC and IEEE standards. The IEC standard considers rated power on the primary windings while the IEEE considers it on the secondary. Therefore, this is the reason countries that adopt the IEC standard such as the EU, do not use the rated power in the calculation methods for efficiency. The IEC standard calculates efficiency based on the input power, whereas, the IEEE standard calculation is based on the output power, as shown below:

$$IEC\ Definition\ of\ Efficiency = \frac{(Power\ Input - Losses)}{(Power\ Input)}$$

$$IEEE\ Definition\ of\ Efficiency = \frac{(Power\ Output)}{(Power\ Output + Losses)}$$

Although these calculations are different ultimately, if the kVA rating is consistent then the two equations will yield the same value. However, it demonstrates the different methods that exits in these two standards to calculate the efficiency.

Ultimately, countries or economic blocs will decide whether to align more closely with the IEC or IEEE standards based on the use of transformers within their respective areas. For example, it was determined for the EU measuring the load factor at 100% was more suitable, because this most closely aligned to how

[21] Differences between IEC and IEEE standards of transformers | LinkedIn

transformers are used in the EU. Whereas, in the USA measuring efficiency 50% load factor was considered more suitable.

Global comparison of power transformer testing and measurement standards

It is very clear from the research conducted that the majority of countries favour the use of IEC 60076 as the standard to harmonise their own national standard to. From country to country the efficiency requirement that is set does vary with some favouring measuring losses at 50% load (E.g., the USA) while other opt for 100% load (e.g., the EU). Table 2.5 gives a summary of dry-type transformer standards that are in place around the world. While Table 2.6 provides a summary of the liquid-filled transformer standards across the world. Essentially the requirements across the countries and economic blocs cluster together within 0.5% on the efficiency scale at any kVA power rating, with the slope of the curves being fairly consistent.

Table 2.5 Summary of coverage of dry-type distribution transformer standards[22]

Country/ Economy	Scope	Load Measurement Point	Date Launched	Standard	Adopted from (IEC or IEEE)
Australia	1 phase: 10-50 kVA 3 phase: 25-2500 kVA Voltage: 11 and 22 kV	Efficiency at 50% load	April 2004	AS 2374.1.2-2003	IEC 60076
Canada	1 phase: 15-833 kVA 3 phase: 15-7500 kVA Voltage: 20-45, >45-95; >-199 kV BIL	35% loading for low voltage (1.2kV) and 50% for >1.2 kV	April 2012	CAN/ CSA C802.2-06	IEEE C57.12
China	3 phase: 30-2500 kVA Class B, F and H	Maximum core and coil losses at 100% load	2013	GB 20052:2020	IEC 60076
European Union	3 phase: 50-40,000 kVA ≤12 kV, 17.5 and 24 kV, ≤ 36 kV	Maximum core and coil losses at 100% load	2015	EN 50588 replaced by EN 50708:2020	IEC 60076
Israel	100-2500 kVA Voltage: 22 kV or 33 kV	Maximum W losses 100%	2011	IS 5485	IEC 60076
Japan	1 phase: 5-500 kVA 3 phase: 10-2000 kVA Both 50 & 60 Hz Voltage: 3 and 6 kV	<500 kVA: 40% load >500 kVA:50% load	March 2008	Top Runner	IEC 60076
Republic of Korea	1 and 3 phase: 3.3-6.6 kV, 50-3000 kVA 1 and 3 phase: 22.9 kV, 50-3000 kVA	Efficiency at 50% load	July 2012	KS C4311	IEC 60076

22 https://united4efficiency.org/wp-content/uploads/2017/11/U4E-TransformersGuide-201711-Final.pdf

Country/ Economy	Scope	Load Measurement Point	Date Launched	Standard	Adopted from (IEC or IEEE)
US	1 phase, LV, 25-333 kVA 3 phase, LV, 30-1000 kVA 1 phase, MV, 15-833 kVA 3 phase, MV, 15-2500 kVA MV: 20-45 kV, 46-95, >96kV BIL	35% loading for low voltage (LV) (<600V) and 50% for medium voltage (MV)	Jan 2010	10 CFR 431	IEEE C57.12

Table 2.6 Summary of the coverage of liquid-filled distribution transformer standards[23]

Country/ Economy	Scope	Load Measurement Point	Date Launched	Standard	Adopted from (IEC or IEEE)
Australia	1 phase: 10-50 kVA 3 phase: 25-2500 kVA Voltage: 11 and 22 kV	Efficiency at 50% load	April 2004	AS 2374.1.2-2003	IEC 60076
Canada	1 phase: 15-833 kVA 3 phase: 15-3000 kVA	Efficiency at 50% load	April 2012	CAN/ CSA C802.2-06	IEEE C57.12
China	1 phase: 5-160 kVA 3 phase: 30-2500 kVA Class B, F and H	Maximum core and coil losses at 100% load	2013	GB 20052:2020	IEC 60076
Europe	3 phase: 50-3150 kVA Voltage 24 and 36 kV	Maximum core and coil losses at 100% load	2015	EN 50464 replaced by EN 50708:2020	IEC 60076
Israel	100-2500 kVA Voltage: 22 kV or 33 kV	Maximum W losses at 100%	2011	IS 5484	IEC 60076
Japan	1 phase: 5-500 kVA 3 phase: 10-2000 kVA Both 50 & 60 Hz	<500 kVA: 40% load >500 kVA:50% load	March 2008	Top Runner	IEC 60076
Republic of Korea	1 phase: 10-100 kVA' 1 and 3 phase: 3.3-6.6 kV, 50-3000 kVA 1 and 3 phase: 22.9 kV, 50-3000 kVA	Efficiency at 50% load	July 2012	KS C4306, C4316. C4317	IEC 60076

[23] SEAD-Distribution-Transformers-Report_Part-1_Comparison-of-Efficiency-Programs.pdf (clasp.ngo)

Country/ Economy	Scope	Load Measurement Point	Date Launched	Standard	Adopted from (IEC or IEEE)
US	1 phase, LV, 25-333 kVA 3 phase, LV, 30-1000 kVA 1 phase, MV, 15-833 kVA 3 phase, MV, 15-2500 kVA MV: 20-45 kV, 46-95, >96kV BIL	Efficiency at 50% load	Jan 2010	10 CFR 431	IEEE C57.12

Table 2.5 and Table 2.6 demonstrate that there are clearly different practices that are adopted around the world for both dry-type and liquid-filled transformers. This can be observed by the different kVA ratings that each country uses. In addition, the requirements of each regulation vary from country to country, with some measuring efficiency at 50% load while others look at efficiency at 100% load. As presented previously, the USA and Canada can be seen to be adopting a different international standard to rest of the countries listed in Table 2.5 and Table 2.6.

2.1.2.2 Regulatory Comparison: EU vs. Rest of the world

Regulations for transformers have evolved in many countries around the world during the last two decades. Although each country or economic bloc has their own method of regulating transformers. Table 2.7 provides a comparison of the MEPS for the EU's Tier 1 and Tier 2, Japan's Top Runner Programme, and the US's 10 CFR Part 431.

Table 2.7 Comparison of the MEPS from the EU (Tier 1 & Tier 2), Japan and the USA[24]

Efficiency at 50% Load							
Power	**Tier 2 Dry**	**Tier 2 Liquid**	**Japan 50 Hz Dry**	**Japan 50 Hz Liquid**	**Power**	**USA Dry**	**USA Liquid**
800	99.21	99.48	99.31	99.38	**300**	98.81	99.27
1000	99.27	99.48	99.35	99.41	**500**	98.99	99.35
1250	99.30	99.48	99.39	99.43	**750**	99.12	99.40
1600	99.35	99.49	99.43	99.46	**1000**	99.20	99.43
2000	99.37	99.49	99.47	99.48	**1500**	99.30	99.48
2500	99.40	99.50	99.50	99.50	**2000**	99.36	99.51
3150	99.43	99.51	99.53	99.52	**2500**	99.41	99.53

MEPS for Liquid-Filled Transformers

Worldwide each country or economic bloc has set minimum energy performance requirements (MEPS) which aim to increase the energy efficiency of transformers within their countries. As previously discussed, geography plays a significant role in

[24] Communicated via stakeholder feedback in the qualitative questionnaire.

how a transformer is utilised. Thus, for each countries regulation there are varying MEPS that a transformer must meet, some more stringent than others.

A comparison of the programmes has been done for the liquid-filled transformers. It should be noted that this data has been normalised to all show 50% loading, 50 Hz operation and using the IEC definition of rated power (kVA). In addition, since the US's efficiency calculation is based on the IEEE measurement method, these values have also had their load losses correct temperature altered to 75^{o}C to align with the IEC reference temperature.

The UN environment, United for Efficiency programme, published a report in 2017 presenting how, the highest efficiency curve for the small power ratings (up to 50 kVA) is set by the US's 10 CFR Part 431 2016 MEPS, which has been in effect since January 2016. The report shows this comparison graph under figure 6 on the *efficiency at 50% load (IEC) for three-phase liquid-filled transformers,* on page 36 of the report. For transformers larger than 50 kVA it is clear that the EU's Tier 2 requirements are the most ambitious. Meanwhile, the Republic of Korea and Brazil have the least ambitious MEPS with both showing the lowest efficiency curves. Both the EU's Tier 1 and Tier 2 MEPS clearly demonstrate that the EU is looking at very small power rating transformers between 5 and 25 kVA. However, there other nations don't look at transformers that go to this size therefore, it is difficult to compare these efficiency curves for small transformers. It does illustrate that the EU covers the broadest range of three-phase liquid filled transformers than any other MEPS programme as well.[25]

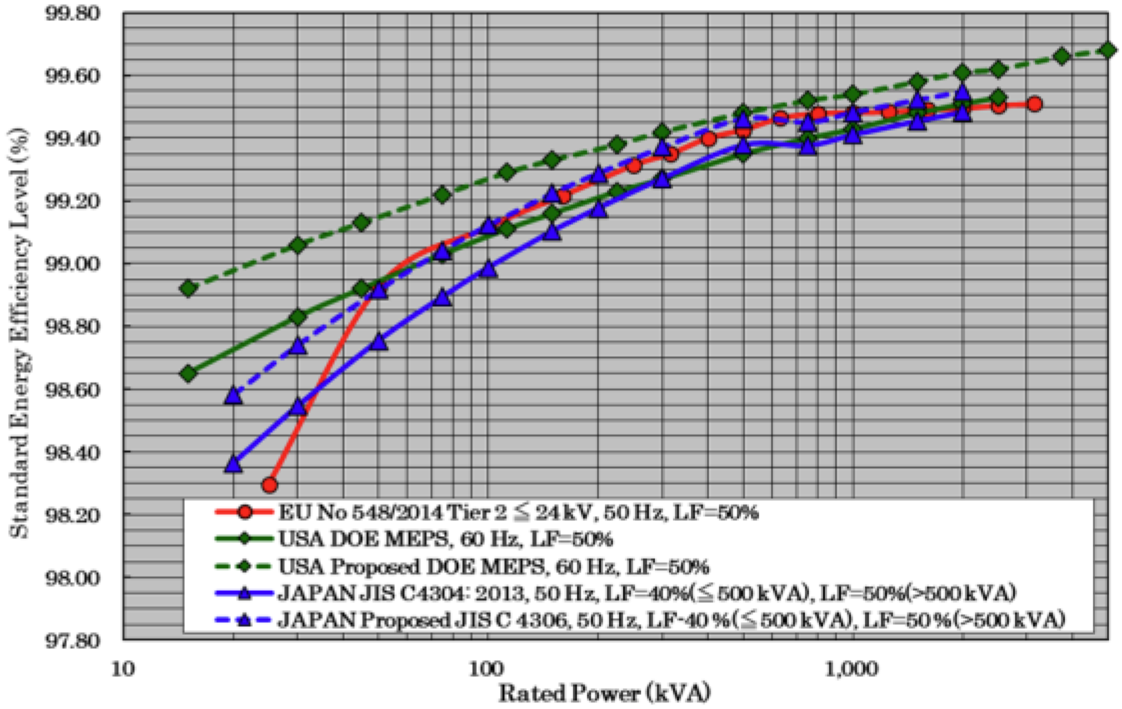
As demonstrated by the United for Efficiency programme, the Tier 2 requirements sit comfortably above both the US and Japanese MEPS at present.[26] However, the US DOE and Japanese JIS standards (Top Runner) are currently being revised and the proposed revisions are illustrated below with the dotted lines in Figure 2.1. It should be noted that the values presented in Figure 2.1 are at 50% load factor for EU Tier 2 are calculated using the Method A of IEC 60076-20. While the Japanese JIS Standard levels are calculated using the Method B of IEC 60076-20, with a load factor of 40% for 500 kVA or less and 50% load factor for over 500 kVA.

Figure 2.1 illustrates that the Tier 2 requirements are currently equivalent to the current US 10 CFR Part 431 regulation and superior to Japan's. The revisions proposed by Japan would mean that their MEPS would now align with the EU's Tier 2 requirements. Meanwhile, the revisions proposed by the US's DOE display that these requirements will be superior to the EU's Tier 2 requirements. However, despite the US's requirements being more stringent than values for the EU Tier 2, US and Japan all cluster within 0.05 to 0.5% of each other.

[25] https://united4efficiency.org/wp-content/uploads/2017/11/U4E-TransformersGuide-201711-Final.pdf

[26] https://united4efficiency.org/wp-content/uploads/2017/11/U4E-TransformersGuide-201711-Final.pdf

Figure 2.1 Comparison of EU Tier 2, US 10 CFR Part 431 Regulation and Japan's Top Runner (JIS Standard) MEPS levels for three-phase liquid-filled medium power transformers[27].



The UN United for Efficiency report also reviews the MEPS comparison for single-phase liquid-filled transformers. The report shows this comparison graph under figure 7 on the *efficiency at 50% load (IEC) for single-phase liquid-filled transformers,* on page 37 of the report. There are far fewer economies that adopt this type of transformer, mainly because most electric networks are three-phase (e.g., in the EU). The report shows that the US's 10 CFR Part 431 2010 MEPS are the most stringent MEPS, with these closely aligned with Japan. These nations MEPS almost mirror each other until it gets to the large >250 kVA transformers and then Japan's MEPS become more ambitious. Similar to the three-phase comparison, the Republic of Korea and Brazil have the least stringent MEPS. Nevertheless, all the nations cluster between 1.0 to 1.5% of each on the efficiency scale at any rated powers.[28]

MEPS for Dry-type Transformers

As with the liquid-filled transformer comparison the data for dry-type transformers has been normalised to allow comparison. Once again, the data has been normalised to 50% loading, 50 Hz operation and using the IEC definition of rated power (kVA) and efficiency. However, as dry-type transformers require insulation which has an impact on the performance the transformers have been grouped with similar voltages and insulation ratings[29]. In addition, Brazil, Mexico, and India do not have requirements for dry-type transformers.

The UN United for Efficiency report shows how the efficiency curves of dry-type transformers cluster within approximately 1% on the efficiency scale for each power

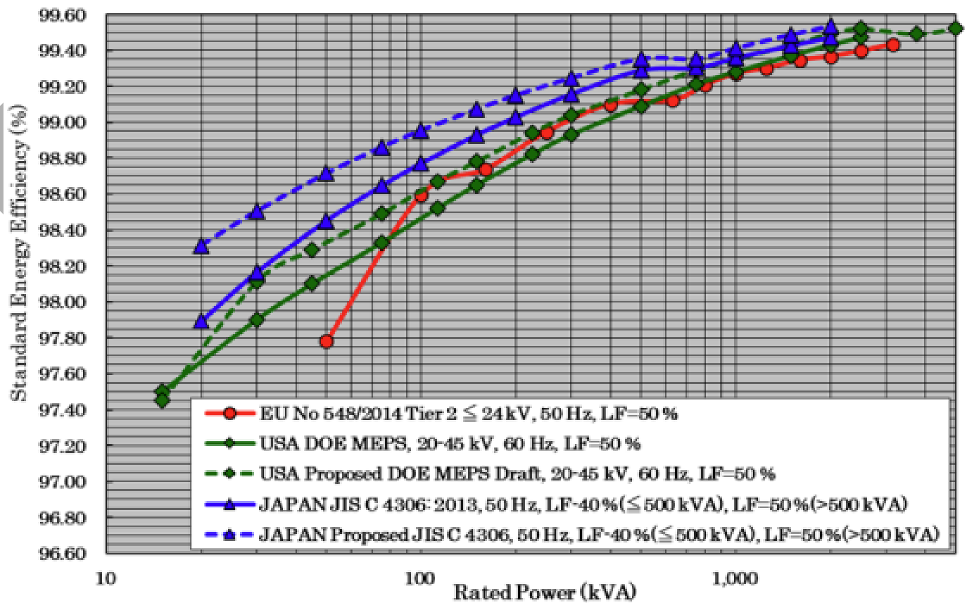
[27] Graph provided in Proterial qualitative feedback calculated from publicized standards and IEC definitions
[28] https://united4efficiency.org/wp-content/uploads/2017/11/U4E-TransformersGuide-201711-Final.pdf
[29] https://united4efficiency.org/wp-content/uploads/2017/11/U4E-TransformersGuide-201711-Final.pdf

rating (kVA). The report shows this comparison graph under figure 8 on the *efficiency at 50% load (IEC) for three-phase dry-type distribution transformers,* on page 39 of the report. From around 50 kVA the efficiency curves for all countries are consistent. However, below 50 kVA the Tier 1 and Tier 2 EU MEPS have a steep slope, this is also seen for liquid-filled transformers[30]. This perhaps shows that the EU has set low ambitions for smaller power transformers as their efficiency requirements are far less stringent. This may be an issue with smaller transformers increasing in popularity in the EU.

Similar to liquid-filled transformers the Republic of Korea has the least stringent efficiency requirements for dry-type transformers. Meanwhile the Japanese Top Runner programme sets the highest MEPS, while the US's 10 CFR Part 431 2016 MEPS sit comfortably in the middle of the field. Furthermore, there are similarities between the US and Canada's requirements for MEPS as it observed that these lines lie on top of each over, with Canada's programme applying to larger transformers also.[31]

However, as mentioned the US and Japan are currently revising their regulations and this has meant a change in the positioning of the efficiency curves. Via stakeholder feedback, we have been able to analyse that following the revised criteria for these regulations, Japan's Top Runner will remain the superior standard while the US's 10 CFR Part 431 and the EU's Tier 2 MEPS will closely align. Figure 2.2 demonstrates this visually and shows that neither the EU's Tier 2 MEPS nor the US's proposed MEPS will match those set by Japan. Despite this again these efficiency values are very clustered and for most power ratings are within 1% of each other. It should also be noted that the Japanese regulation only applies to cast resin dry-type transformers.

Figure 2.2 Comparison of EU Tier 2, US 10 CFR Part 431 Regulation and Japan's Top Runner (JIS Standard) MEPS levels for three-phase dry-type medium power transformers[32]



30 https://united4efficiency.org/wp-content/uploads/2017/11/U4E-TransformersGuide-201711-Final.pdf

31 https://united4efficiency.org/wp-content/uploads/2017/11/U4E-TransformersGuide-201711-Final.pdf

32 Graph provided in Proterial qualitative feedback calculated from publicized standards and IEC definitions

US Regulation – 10 CFR Part 431

The first regulation that covered transformers in the USA was laid down by the Energy Policy and Conservative Act (EPCA). This regulation adopted the testing standard NEMA TP-2 1998 – "Standard Test Method for Measuring the Energy Consumption of Distribution Transformers". Subsequently, in 2005 the Department for Energy (DOE) introduced efficiency standards in the Energy Act (EPACT). This implemented the first efficiency standards for low voltage dry-type transformers in the USA[33]. EPACT 2005, also adopted the updated version of the NEMA test method, NEMA TP-2-2005 and the latest versions of IEEE C57.12.90 and IEEE C57.12.91.

The standard was then further extended to include liquid-immersed and medium voltage dry-type transformers in 2010[34]. The legislation covering distribution transformers was later redefined in 2016 by the Code of Federal Regulations (CFR), 10 CFR Part 431[35]. The most recent edition of this legislation was published in 2022 and contains the following key sections:

- The Purpose and scope of the MEPS (431.191)
- Definitions (431.192)
- Test procedures (431.193)
- Energy conservation standards and their effective dates (431.196)
- The uniform test method that has been adopted by the legislation to calculate the energy consumption of distribution transformers (Appendix A)

10 CFR Part 431 applies to the following types of transformers: all low-voltage dry type three-phase ventilated transformers from 15 kVA through 1000kVA and harmonic mitigating transformers[36]. The DOE determines that all transformers manufactured after 2016 must meet the efficiency levels with a 35% per-unit load and temperature of 75^{o}C. These transformers must also have grain oriented, non-aging silicon steel cores. Meanwhile, the regulation does not apply to machine-tool transformers, rectifier transformers, regulating transformers, sealed transformers, special-impedance transformers, testing transformers, transformers with tap range of 20% or more, uninterruptible power supply transformers and welding transformers.

Using the above-mentioned standards, the DOE determines the percentage energy efficiency that distribution transformers must meet, using the measurements of no-load and load losses. The standards specify the temperature, current voltage, extent distortion in voltage waveform and DC resistance of the windings[37].

Prior to the adoption of 10 CFR Part 431 the EPCA implemented the test procedure of NEMA TP-1 2002 on the 1st of January 2007. This followed the adoption of TP-1 by the Energy Act (EPACT), 2005. From 2007, EPACT established NEMA TP-1 as the measurement standard for the national MEPS levels for low voltage dry type transformers[38]. The test method provides a guide for determining the energy efficiency of distribution transformers, the requirements of this standard were made

[33] https://www.reginfo.gov/public/do/eAgendaViewRule?pubId=200610&RIN=1904-AB08

[34] 2013-ewg-meps-vol-1.pdf (unepccc.org)

[35] CFR-2022-title10-vol3-sec431-192.pdf (govinfo.gov)

[36] CFR-2022-title10-vol3-sec431-192.pdf (govinfo.gov)

[37] lbnl-1005067-lbnl_international_review_on_dt_sl_programs.pdf

[38] lbnl-1005067-lbnl_international_review_on_dt_sl_programs.pdf

mandatory efficiency requirements for low voltage dry-type distribution transformers. The introduction of NEMA's TP 1 test procedure into EPACT meant minimum efficiency requirements for transformers were set in the USA. Its introduction meant the conclusion of the Energy Star programme for transformers in 2007 because the MEPS set by NEMA TP-1 meant that the Energy Star become obsolete. This is determined on the DOE Test Method for Measuring the Energy Consumption specified in 10 CFR 431.193. As discussed, the test method used by the DOE are aligned with the IEEE and NEMA test methods. It should be noted that in 2006 NEMA TP-2 2005 was rescinded, therefore, the DOE no longer use this standard as a method of testing[39]. In addition, the DOE is seeking to more closely align the legislation to incorporate the most recent revisions of the IEEE standards[40].

Unlike the current Ecodesign transformers regulation, the MEPS specified by part 431 are based on the minimum efficiency values at 50% of the rated capacity and not 100% as in the Ecodesign regulation.

The efficiency is determined from the total transformer losses, which are determined from the measured value of the no-load loss and load loss power components[41]. Table 2.8 provides an example of the MEPS that low voltage dry type distribution transformers placed on the market in the United States after January 1st, 2007, but before January 1st, 2016, have to meet.

Table 2.8 MEPS set by CFR Part 431 for low voltage dry-type distribution transformers[42].

Single Phase		Three-phase	
kVA	%	kVA	%
15	97.7	15	97.0
25	98.0	30	97.5
37.5	98.2	45	97.7
50	98.3	75	98.0
75	98.5	112.5	98.2
100	98.6	150	98.3
167	98.7	225	98.5
250	98.9	300	98.6
333	98.9	500	98.7
		750	98.8
		1000	98.9

Japan's Top Runner Programme

The Japanese Top Runner Programme is a mandatory scheme that is regulated by the Energy Efficiency Act. The programme requires each manufacturer to surpass a weighted average value for all of their products per category for a predetermined

[39] Federal Register :: Energy Conservation Program: Test Procedure for Distribution Transformers

[40] Federal Register :: Energy Conservation Program: Test Procedure for Distribution Transformers

[41] INTAS_D2.1_Final_Annex_A.pdf (intas-testing.eu)

[42] CFR-2022-title10-vol3-sec431-192.pdf (govinfo.gov)

year[43]. The transformers standard has been defined by the Japan Electrical Manufacturers' Association (JEMA) and has been in effect since 2006.

The most recent update to the requirements set out in the Top Runner scheme for power transformers are from 2013[44]. This meant that Top Runner more closely aligned with the IEC standard. Top Runner applies to both 50 and 60 Hz units (there are two types of electrical distribution systems in Japan), single phase and three phase transformers[45]. Both dry-type and liquid-immersed transformers are also covered by the program. Within Top Runner transformers are classified according to their physical quantities and functions as these are both closely related to the total loss. These are classed using roman numerals (I to VIII-2). For example, class I is a single phase, 50 Hz transformer with a rated capacity of 500 kV or less.

The efficiency values specified in Top Runner are determined from aggregate core losses derived from the following equation. This is based on the transformer rating at a specific loading point.

The Top Runner program provides the maximum total losses for a transformer at 40% load and 50% load. Since the testing standards are aligned to the IEC standards, the kVA ratings are also based on the power input rather than the output. The energy consumption efficiency of transformers is considered as the 'total loss' (W)[46]. With the no-load loss and load loss measured according to the Japanese harmonised standards with IEC which are JIS C 4304 and JIS C 4306. The equation is defined as:

$$Total\ loss\ (W) = No\ load\ loss(W) + [\frac{m}{100}]^2 \times Load\ loss\ (W)$$

Where 'm' is the standard load ratio which is one of the following:

- For transformers with a capacity of 500 kVA or less: 40%
- For transformers with a capacity of more than 500 kVA: 50%

The standards JIS C4304-2013 "6kV oil-immersed distribution transformers" and JIS C4306-2013 "6k V sealed winding distribution transformers" are the two standards adopted by the Top Runner program. These specify the total loss limits of 6kV class single phase 50 Hz and 60 Hz, 10 kVA to 500 kVA distribution transformers and 6 kV class three-phase 50 Hz and 60 Hz, 20 kVA to 2000 kVA distribution transformers[47].

The United Kingdom

The Energy Networks Association (ENA) published the Technical Specifications (TS) 35-1 for distribution transformers known as ENA TS 35-1. This standard sets the UK's minimum efficiency requirements for transformers, with it closely aligning with the requirements set by the EU's Regulation 2019/1783. This standard has four parts which are broken into the following:

- Part 1 – Common clauses (published 2020)
- Part 2 – Ground-mounted transformers – not close coupled (published 2021)

43 Top Runner Programme – Policies - IEA

44 https://www.eccj.or.jp/top_runner/pdf/tr_transformers_dec2011.pdf

45 INTAS_D2.1_Final_Annex_A.pdf (intas-testing.eu)

46 https://www.eccj.or.jp/top_runner/pdf/tr_transformers_dec2011.pdf

47 Energy Efficiency Standard For Transformer In Various Countries (daelim-electric.com)

- Part 3 – Ground-mounted transformers – closed-coupled (published 2021)
- Part 4 – Pole-Mounted transformers (published 2022)

The specification applies to transformers in the range 16 kVA to 2000 kVA for continuous service at 50 Hz, for highest voltage equipment 7.2 kV, 12 kV, 24 kV and 36 kV, equipment voltage above 24 kV is considered for use on pole-mounted transformers only[48].

ENA TS 35-1 amplifies the requirements that are set in IEC 60076 and therefore, should be analysed in conjunction with this standard. The IEC standard has been adopted by the UK as the standard BS EN 60076.

Australia and New Zealand

Australia and New Zealand jointly operate the Equipment Energy Efficiency (E3) programme, which is co-funded by the Australian Department of Climate Change and Energy Efficiency and the New Zealand government. Both countries have adopted the same energy efficiency requirements to encourage the flow of trade between the two nations. For distribution transformers the first standard was introduced by Australia in 2003 called the AS 2374.1.2-2003[49]. The AS 2374.1.2 provided MEPS for dry-type and oil immersed, three-phase and single-phase power transformers with a rating from 10 kVA to 2500 kVA and a system highest voltage up to 24 kV. New Zealand then quickly adopted the same standard to align with Australia on these MEPS for distribution transformers.

The AS 2374.1.2 standard set the minimum power efficiency levels at 50% load that all transformers in Australia and New Zealand had to meet. Alongside the mandatory MEPS, the programme also identifies voluntary higher energy performance standards (HEPS) to encourage innovation[50].

The test standard for the MEPS is based on the power loss measurements that are specified in the Australian and New Zealand standard AS/NZS 60076.1, which has been adopted from the IEC 60076 standard. There are some specific variations that are specific to the AS/NZS standard, such as the commonly used power ratings and preferred methods of cooling, connections in general use and details of connection designation[51].

Brazil

Brazil has adopted MEPS for liquid-immersed distribution transformers, this regulation has been set by the Ministry of Mines and Energy and is called the Inter-Ministerial Ordinance 104/2013[52]. The legislation covers single-phase liquid-filled distribution transformers from 5 to 100 kVA, and three-phase liquid-filled distribution transformers from 15 to 300 kVA both with voltage classes of 15 kV, 24.2 kV and 36.2 kV[53]. These transformers are designed to operate at 60 Hz.

[48] ENA Document Catalogue (ena-eng.org)

[49] AS 2374.1.2-2003 Power transformers - Minimum Energy Performance Standard (MEPS) requirements for distribution transformers (saiglobal.com)

[50] 1364440 (osti.gov)

[51] 1364440 (osti.gov)

[52] Portal de Serviços do Inmetro — INMETRO (www.gov.br)

[53] 1364440 (osti.gov)

The national test standard that has been published is the ABNT NBR 5440: 2014 standard which closely aligns with the test requirements set out in the IEC 60076.1 standard. The requirements of the MEPS are presented as maximum losses in the core and coil at 100% loading[54].

In addition to the MEPS covered by the abovementioned legislation Brazil also has an energy labelling program for transformers. The label includes the following information: the manufacturer, model, type, kVA rating, and voltage class, the watts of losses at no load and total watts of loss at full load, temperature rise and basic-impulse insulation level of the transformer at both the nominal tap and the 'critical' tap[55].

Canada

The Office of Energy Efficiency at Natural Resources Canada created Canada's mandatory regulations covering dry-type transformers only with voluntary efficiency levels also being set for liquid-immersed distribution transformers. The mandatory dry-type regulation applies to single-phase or nominal power of 15 to 833 kVA, or three-phase with nominal power of 15 to 7500 kVA, a nominal frequency of 60 Hz and a high voltage winding of 35 kV or less[56]. The most recent update to the MEPS was in 2019, with this regulation applying to dry-type transformers that were placed on the market after January 1st, 2016.

In 2010 the Canadian regulation adopted the same MEPS levels as the US's 10 CFR Part 431 for dry-type distributions transformers. Therefore, it also sets the minimum power efficiency levels at 50% load. The national standard CAN/CSA C802.2-06 provides the test requirements and refers to the NEMA TP 2-2005 standard. However, since TP 2 is no longer an active standard the Canadian MEPS quote that the testing standard used by the regulation is aligned with 10 CFR Part 431 Appendix A, subpart K. Which as described previously is closely aligned to the IEEE C57 standard for dry type distribution transformers[57].

Chile

Chile has a voluntary labelling programme which covers single-phase distribution transformers from 10 kVA to 833 kVA and three-phase distribution transformers from 15 kVA to 2500 kVA, both dry and liquid-immersed distribution transformers with a primary voltage of 34.5 kV or less and a secondary voltage of 600 V or less, at a frequency of 50 Hz[58].

The test standards are defined by two national standards NCh2660 and NCh2661 which are closely aligned to and refer to NEMA TP-2-2005. Chile is yet to develop any MEPS for distribution transformers however, research is being conducted for Chiles to have MEPS in the near future.

[54] SEAD-Distribution-Transformers-Report_Part-1_Comparison-of-Efficiency-Programs.pdf (clasp.ngo)

[55] 1364440 (osti.gov)

[56] Dry-type transformers (canada.ca)

[57] Dry-type transformers (canada.ca)

[58] 1364440 (osti.gov)

China

The Chinese mandatory MEPS are applicable for liquid-immersed three-phase distribution transformers with a voltage level of 10 kV and a rated capacity of 30 kVA to 2500 kVA, dry-type distribution transformers with a rated capacity of 30 kVA to 2500 kVA, and oil-immersed three-phase transformers with a rated frequency of 50 Hz, a voltage class of 35 kV to 500 kV, and a rated capacity of 3150 kVA and above[59].

The MEPS which provides the minimum allowable values of energy efficiency are specified by the standard GB 20052-2020 & JB/T 10317-02[60]. Similar to the Ecodesign regulation's EN standards these Chinese standards broadly align with the standards set by the IEC 60076 standard series. China sets their distribution transformer MEPS in terms of maximum permitted no load and full load power loss limits[61].

India

India has adopted a mandatory labelling scheme which applies to liquid-filled distribution transformers that are oil immersed, naturally air cooled, three phase, and double wound non-sealed type outdoor distribution transformers up to 2500 kVA, 11 kV specifications[62]. The national standard IS 1180 (Part 1 and Part 2) provides the testing procedure for the distribution transformers. These standards are based on the IEC 60076 standards.

The labelling scheme in India adopts a star system to differentiate between models at the same rating, with 1 star being low efficiency and 5 stars being the highest. From 2010 the Central Electricity Authority (CEA) required all distribution transformer purchased by the utilities to have at least 3-star rating to ensure the purchase of more efficient transformers by the government [63]. The energy label indicates both total losses at 50% and 100% and are used to rate the product accordingly.[64]

Israel

Israel have adopted both MEPS and labelling requirements for distribution transformers. The ISI Standard 5484 provides the energy efficiency requirements for distribution transformers with a nominal input of 22 kV or 33 kV and a nominal output voltage of 400 V, with power rating up to 2500 kVA, operating at 50 Hz[65]. The test standard is closely aligned to the IEC 60076 series of standards.

The efficiency of distribution transformers is measured using the maximum coil losses that are measured at 100% of rated capacity. Similar to Australia and New Zealand, Israel has published a set of MEPS and HEPS both of which use the maximum losses at 100% rated capacity[66].

[59] http://www.gbstandards.org/index/standards_search.asp?word=Transformer

[60] Energy-Efficiency-EN.pdf (ececp.eu)

[61] Energy-Efficiency-EN.pdf (ececp.eu)

[62] INTAS_D2.1_Final_Annex_A.pdf (intas-testing.eu)

[63] https://ksei.gov.in/pdf/Acts%20&%20Rules/TechStd.pdf

[64] Bureau of Energy Efficiency (beestarlabel.com)

[65] Ministry of Energy and Infrastructure (www.gov.il)

[66] International Review of Standards and Labeling Programs for Distribution Transformers (Technical Report) | OSTI.GOV

The Republic of Korea

Korea's MEPS programme covers both liquid-immersed and dry-type transformers. The Korean regulations covers single-phase distribution transformers between 10 and 3000 kVA and three-phase transformers between 100 and 3000 kVA[67].

The program also has target energy performance standards (TEPS) which attempt to drive innovation in the field to push industry to improve their energy efficiency. Both the MEPS and the TEPS set energy efficiency requirements at a 50% load which is calculated using the measurement methodologies in the national standards KS C 4306, KS C 4311, KS C 4316, and KS C 4317[68]. All of these standards cross reference the standards published by the IEC 60076 series, which has been adopted without modification by the Korean national standard KS C IEC 60076-1[69].

2.1.3 Recommendations

Concluding from the in-depth analysis undertaken on the current standards present across the world for transformers and their relevance for the EU's regulatory process, the IEC 60076 standard is the most commonly used standard. Therefore, it is recommended that the EU continues to closely align to this standard with the EN 50708 standard. IEC 60076 is currently undertaking a revision which may see several changes to the standard, such as the re-defining small, medium and large transformers. It is recommended Ecodesign align with the EN standard, but also verify that the new standard definitions do not alter the scope of the regulation.

It is evident from Section 2.1.2.2 that EU's Tier 2 requirements do compete strongly with the US and Japan's current regulations. In fact, for liquid-filled transformers the EU currently sets the most stringent MEPS in comparison to the USA and Japan and across many other regulations set around the world. Conversely, for three-phase dry-type transformers the EU slips behind the MEPS set by Japan and is closely aligned to the US. However, both the US and Japan's regulations are currently under revision, and which may uplift requirements for both dry and liquid filled transformers. This would see both either align or overtake the Tier 2 requirements.

[67] http://www.kemco.or.kr/web/kem_home_new/new_main.asp

[68] INTAS_D2.1_Final_Annex_A.pdf (intas-testing.eu)

[69] 1364440 (osti.gov)

2.2 Ecodesign energy efficiency requirements

a) the extent to which requirements set out for Tier 2 have been cost-effective and the appropriateness to introduce stricter Tier 3 requirements;
e) the appropriateness of setting minimum performance requirements for small power transformers.
n) impact of rising electricity prices on current and potentially stricter Ecodesign requirements.

2.2.1 Background

2.2.1.1 Effectiveness of Tier 2, and implementation of Tier 3

Ecodesign Tier 1 and Tier 2 requirements for transformers from Commission Regulation (EU) 2019/1783 refer to the EU's energy efficiency standards and requirements for transformers used in electrical power systems. Below is a brief overview of Ecodesign Tier 1 and Tier 2 requirements for transformers:

- Ecodesign Tier 1 (2015): This initial phase of requirements, implemented in 2015, established minimum energy efficiency requirements for transformers with power ratings between 1 kVA and 2,500 kVA, as well as certain specific transformers used in special applications. The regulation set energy efficiency requirements based on loss measurements, such as no-load losses and load losses, which transformers had to meet. Transformers were classified into three efficiency classes: low-loss (Tier 1), medium-loss, and high-loss.
- Ecodesign Tier 2 (2021): The Tier 2 requirements, which came into effect in 2021, expanded the scope of the regulation and included more transformer categories. Currently it now covers transformers with power ratings from 1 kVA to 5,000 kVA. Tier 2 levels tightened energy efficiency requirements for transformers, promoting further reductions in energy losses and improvements in energy efficiency.

2.2.1.2 Energy efficiency metrics for small power transformers

The scope of the transformers regulation is for power transformers with a minimum power rating of 1kVA used in 50Hz electricity transmission and distribution networks or for industrial applications. Within this scope, the "small power transformers" are defined as those <1kVA power transformers with a highest winding voltage not exceeding 1.1kV.

Small transformers have lower power ratings resulting in a relatively smaller contribution to total power network losses compared to larger transformers. Small power transformers are commonly used in industrial power systems, including drives, rectifiers, and power converters for renewable energy applications like wind and solar. They can also serve as isolating transformers for safety on construction sites.

Very small transformers (50-100W, and hence out of scope of this power transformers regulation) are used in electronic equipment, although many modern devices no longer require transformers. Some of these electronic equipment (e.g. displays), and the transformers within external power supplies, are covered by separate Ecodesign regulations.

Small transformers are used for LV (low voltage) to LV grid transitions and network compensators, particularly in the context of the energy transition, addressing issues like over- or undervoltage caused by photovoltaics and electric vehicles.

The efficiency of large transformers can be as high as 99.75% while typically small transformer efficiency is lower at around 97.5%. Considering that the suggested ideal efficiency limit lies between 98 and 99.5% for an electrical transformer[70], efficiency improvements are possible for small transformers. Small power transformers can present technical challenges related to measuring and enforcing energy efficiency standards. These transformers may have more variable and less standardised designs, making it more complex to establish uniform regulations.

2.2.1.3 Effect of rising electricity prices

Capitalisation of losses takes a long-term perspective, typically spanning several decades, to assess the financial implications and performance of an investment. This extended timeframe is particularly relevant when considering the lifespan of energy infrastructure. Capitalisation of losses is a valuable tool for assessing the financial viability and sustainability of energy investments in the context of Net Zero goals. By looking at costs over a long-term horizon, it can help investors and policymakers make informed decisions about the economic feasibility and long-term value of energy projects. As technology advances, economies of scale are achieved, and more efficient energy generation methods are developed, the cost per unit of energy (kWh) typically decreases.

2.2.2 Feedback/ Research results

2.2.2.1 Effectiveness of Tier 2, and implementation of Tier 3

There is consensus among some respondents that improving energy efficiency is essential. They emphasise looking at energy efficiency from a Total Cost of Ownership (TCO) perspective rather than just the initial transformer cost. The focus of Tier 2 is seen as reducing environmental impact by addressing power losses in power transformers.

A simplified formula for the TCO is as follows:

$$TCO = PP + A * P_0 + B * P_k$$

Where:

- PP is the purchase price of the transformer
- A is the cost of no-loa losses per Watt
- P_0 is the rated no-load loss
- B is the cost of load losses per Watt
- P_k is the rated load loss

Opinions regarding the cost-effectiveness of Tier 2 energy performance requirements for transformers are divided. While some stakeholders view Tier 2 as cost-effective, others express concerns about the strain it places on the supply chain and advise caution against exceeding certain limits. The principal concern over supply chain is that the more efficient transformer technologies rely on amorphous steel cores, and there does not seem to be any amorphous steel manufacturing in

[70] https://www.electricalindia.in/how-to-enhance-transformer-efficiency/#:~:text=Large%20power%20transformers%20attain%20efficiency,98%20and%2099.5%20per%20cent

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 e-steels to meet stricter Tier 3 requirements. This situation would cause a decrease in material usage efficiency and an increase of costs. Between Tier 1 and Tier 2, the mass of power transformers has increased by an average of 30%, and their volume by 15 to 20%. The increase in the mass is not equal for all materials. On average, the detailed increases by material are as follows[71]:

- Aluminium windings: +80%
- Steel tank: +30%
- Magnetic core: +30%
- Dielectric fluid: +20%

The assessment of cost-effectiveness is contingent on various factors, including the load and lifespan of the transformers in question. While there is acknowledgment of the importance of addressing no-load losses, there is also a strong emphasis on considering load losses. Additionally, the economic viability of Tier 2 has been impacted by significant increases in raw material prices, further complicating the assessment of its cost-effectiveness.

According to another stakeholder, Tier 2 is widely regarded as a positive step forward in terms of enhancing efficiency in the transformer industry. However, there are concerns about the economic and ecological payback times, particularly in relation to CO_2 emissions reduction, which remain uncertain in some cases. Notably, Tier 2 had minimal effects on the design of large power transformers for Transmission System Operators (TSOs), indicating that larger transformers, especially those above 100MVA, inherently exhibit greater cost-effectiveness in complying with these regulations.

However, there's a notable call for improved management of various factors such as raw materials extraction, transportation costs, and civil engineering. Additionally, concerns have been voiced regarding the effective handling of variable cooling and the management of real load conditions. 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.

Per the stakeholder feedback, the implementation of Tier 2 requirements resulted in higher transformer costs primarily due to the use of higher-grade materials. However, this cost escalation was partially mitigated by the increase in electrical energy costs. The future remains uncertain, particularly in terms of electricity pricing trends influenced by renewable and nuclear energy sources. This uncertainty necessitates a delicate balance between ensuring affordability and enhancing energy efficiency.

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%[72]. 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). Large power transformers had already been moving towards Tier 2 requirements due to a strong focus on loss reduction in their procurement processes. Nonetheless, the weight constraints imposed by Tier 2, especially for 36MVA

[71] Stakeholder feedback from Enedis

[72] Stakeholder feedback

transformers, resulted in higher prices and had implications for transportation and material selection.

Respondents expressed concerns about the difficulty of achieving further efficiency improvements beyond Tier 2, especially when it comes to reducing losses by 5%. One stakeholder stated that the efficiency levels introduced in Tier 1 and Tier 2 are now at a stage where any further increases will produce rapidly decreasing returns to scale. Some manufactures have privately indicated a figure of an increase of up to 50% in cost for a further 10% in efficiency, or for a 5% increase in efficiency. Iron and copper losses would need to be reduced by 10% each from Tier 2 levels, resulting in an increase in weight of up to 30%[73]. Scarcity of high-quality magnetic steel and difficulties in sourcing the best-quality materials are highlighted. ICF's concerns also extend to the impact on transformer dimensions and weights, particularly in large power transformers.

Some stakeholders suggest that Tier 3 requirements should focus more on material efficiency, emphasising the use of high-performance materials and reevaluating rated power selection. They believe that Tier 3 could disproportionately increase material consumption, posing environmental challenges.

Respondents raised concerns about the substantial increase in raw materials that stricter Tier 3 requirements would demand, potentially out of proportion to the efficiency gains achieved. They also highlight potential challenges related to manufacturing capacity, supply chain flexibility, and the environmental consequences of higher material consumption. Additionally, they point out difficulties in integrating larger and heavier transformers into certain applications, such as solar and battery storage systems.

Some respondents suggest that rather than strict Tier 3 requirements, the focus should remain on the repair and remanufacturing market 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.

For medium-power transformers, it is noted that Tier 2 transformers have already reached the limits of existing substations in terms of size and load. Implementing stricter Tier 3 requirements could necessitate costly replacement of substations, with significant environmental and economic implications per stakeholder feedback.

The feedback emphasises the need to establish a fixed reference temperature for assessing losses in transformers, as the current regulation allows user discretion and potential manipulation. The stakeholder recommendation is to define the reference temperature as the yearly average winding temperature, calculated at 20°C plus the guaranteed temperature rise, leading to 85°C for AN or OF cooled transformers and 90°C for OD transformers. Currently, a common reference temperature of 75°C is in use and increasing it by 10°C results in approximately a 4% rise in losses. The suggestion is to adopt the reference temperature described, in line with EN 60076-1, without modifying the PEI or loss level[74].

[73] Stakeholder feedback

[74] Stakeholder feedback from RTE

ICF understands that stricter Tier 3 requirements for large power transformers could complicate transportation and installation due to increased size and weight, posing challenges for existing infrastructure and costs.

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

Amorphous core transformers are experiencing substantial market adoption, particularly in developing countries like China and India, driven by their superior energy efficiency and competitive pricing compared to traditional core transformers. These transformers have been in production for over thirty years, with growing demand, primarily due to their successful deployment in China and Japan, as well as the increasing need for more durable transformers. Notably, in China, there is a tiered system for maximum losses, with Grade 1 being the most efficient and Grade 3 the least efficient for silicon-core steel transformers. Furthermore, amorphous-core distribution transformers, which have significantly lower losses, are classified under separate product classes within Grades 1 and 2, reflecting their remarkable energy efficiency[75]. Figure 2.3 shows the maximum no load loss (W) for different kVA ratings for both Cold Rolled Grain Oriented (CRGO) core and Amorphous Core (Grade 1 in China).

Figure 2.3 Maximum no load losses for different kVA ratings for different cores

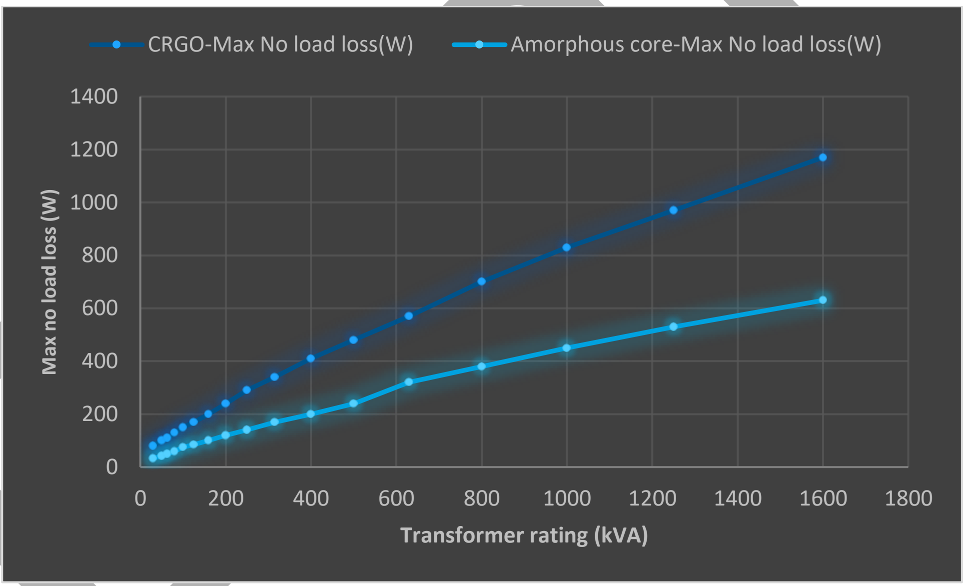
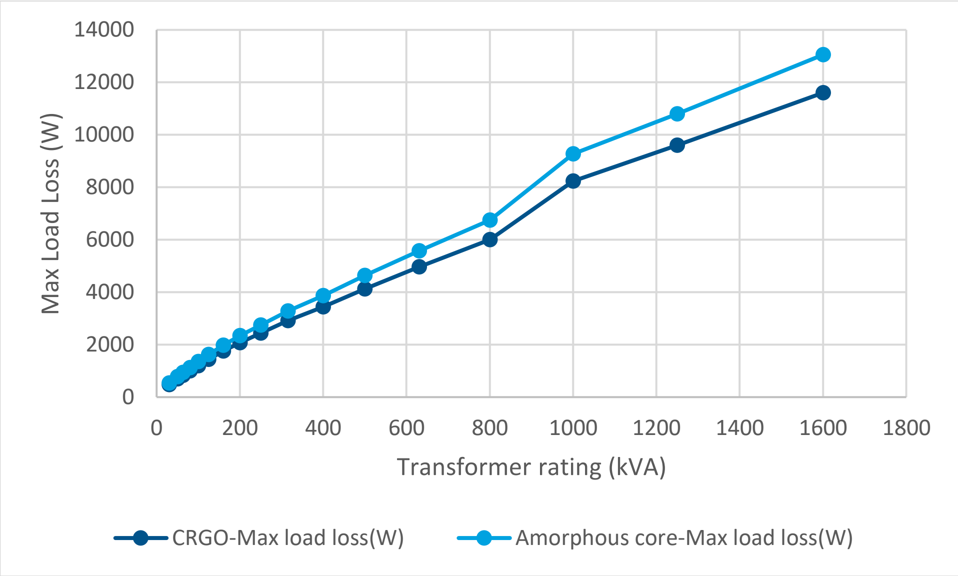


Figure 2.4 below shows the Max load loss(W) for different kVA ratings for both CRGO core and Amorphous Core (noting that amorphous core transformers typically use conductors that have low current density)

[75] https://www.clasp.ngo/research/all/international-review-of-standards-and-labeling-programs-for-distribution-transformers/

Figure 2.4 Maximum load losses for different kVA ratings for different cores



This comparison shows there is a significant scope in energy efficiency improvement when amorphous core is used in transformers. Tier 3 implementation will require a shift to amorphous core but there are certain arguments that should be considered:

- Supply of amorphous material, cost impact, industry readiness.

The European Copper Institute (ECI), an advocate for the copper industry within the EU, published a paper on the revision of the Ecodesign regulation[76] on the impact of potential Tier 3 MEPS for transformers. The paper discusses about the following areas:

- Cost of transformer
- Losses
- Material usage & efficiency

To analyse the impact of a potential Tier 3 MEPS, ECI carried out a modelling exercise. ECI developed various design options for a 630 kVA distribution transformer using professional design software and based on a particular set of parameters: Root Mean Square load: 30%. Lifetime: 40 years. Electricity price: 0.13 €/kWh. Interest rate (calculation of Net Present Value of future losses): 2%. Raw material prices: aluminium winding wire 6€/kg, copper winding wire 12€/kg, magnetic steel M070 5.5€/kg, oil 2€/kg, steel for tank and cover 4.5€/kg. The key findings from the ECI paper on implementation of a Tier 3 are as follows:

- Shifting to Tier 3 energy efficiency thresholds for transformers may involve an upfront cost increase due to the use of more or higher-quality materials, but this is offset by a significant reduction in net present value of energy losses, resulting in the total cost of ownership (TCO) fluctuating within a narrow +/- 5% range. The transition to Tier 3 can affect material use, but this should be assessed at a system level, including both the transformer and the energy generation infrastructure required to compensate for losses. Reduced losses mean less renewable generation capacity is needed, leading to material savings. This translates to a 4% to 8% reduction in material use when moving to Tier 3 compared to Tier 2. Transformer replacements should

[76] "Revision of Ecodesign Regulation for Transformers

consider the impact on existing substations, as it may necessitate costly upgrades. Compact units, achieved through specific materials and design flexibility, can mitigate this. At the EU scale, Tier 3 MEPS for distribution transformers could yield substantial electricity savings and reduce material usage. The introduction of material efficiency requirements (MMPS) aligns with Tier 3 MEPS, encouraging more compact designs while respecting efficiency standards.

In conclusion, the feedback indicates a general consensus on the importance of improving energy efficiency in transformers, especially by considering TCO rather than just the initial transformer cost. Tier 2 thresholds are viewed as a positive step in enhancing efficiency, but opinions about their cost-effectiveness are mixed, influenced by factors like supply chain disruptions, material cost fluctuations, and shifts in energy prices. However, the potential transition to Tier 3 standards raises concerns about the difficulty of achieving further efficiency gains, especially in reducing losses by 5%, driven by issues like the scarcity of high-quality magnetic steel and material sourcing challenges, as well as implications for transformer dimensions and weights, especially in large power transformers. Additionally, the 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.

Research questions to consider

Tier 2 is quite recent and represented a significant change. As such the research team should determine whether the cost of the transformer versus losses across the lifetime can be an effective measure of transformer efficacy.

In addition to above, it is imperative to source statistics on how many Tier 2 transformers have been traded? Where have these been installed? What are their capacities?

There is a lack of data on manufacturers and supply chain of amorphous steel core transformers in the EU. Furthermore, detail is needed to understand the market share of amorphous core transformers used in the EU. Please could stakeholders share their insights on both aspects. Some assumptions made in the previous study are no longer relevant due to growing electric vehicles and high renewable penetration. Can stakeholders provide data regarding the impact on transformer size, loading and utilisation due to the green transition efforts?

2.2.2.2 Energy efficiency metrics for small power transformers

Small power transformers fall outside the standardisation framework of CENELEC TC14 but align more with TC96. Some stakeholders suggest that all transformers should be included in regulation efforts, emphasising the importance of energy efficiency in transformer designs. Small power transformers are numerous but priced lower than medium and large power transformers, resulting in a smaller market in terms of value. For example, in France, around 30,000 small power transformers are traded annually[77]. Transformers used for temporary solutions, such as during grid upgrades, may not be very cost-effective over extended periods due

[77] Stakeholder feedback

to high initial costs and operational expenses per the feedback. Some argue that small power transformers used in domestic appliances or building applications should be regulated differently from other transformers due to variations in users and producers. In the context of the energy transition, small power transformers find applications in charging stations and coupling PV (photovoltaic) inverters. Sales volumes in Europe for transformers below 1.1 kV is estimated to be around 100,000 units per year, accounting for approximately 5-7% of total transformer sales in Europe[78].

ICF understands that the efficiency of small transformers is noted to depend on factors like load rating and utilisation, which can be low for intermittently used electronic equipment. Setting a general efficiency level for small transformers is considered challenging due to the varied use-cases and potential ancillary costs. Per stakeholder feedback, small transformers (50-100W) are often produced outside the EU for a worldwide market and embedded as components in other products, making it difficult to impose sanctions on manufacturers through current legislation. However, these should be noted to be outside of the scope of the transformers Ecodesign regulation as the scope is only for transformers with a kVA larger than 1.

Furthermore, grid decarbonisation is mentioned as another factor to consider when evaluating the necessity and effectiveness of increasing the efficiency of small transformers. Average efficiency of small transformers is estimated at 96 %[79]. The feedback provides some estimates of average efficiency for small transformers, which may not be as easily improved as medium or large transformers due to limitations in adding raw materials. Challenges related to materials are highlighted, including the need for higher grade e-steel, supply chain disruptions, and increased carbon emissions from materials. One stakeholder stated that the reliance on a limited number of suppliers outside the EU is noted to compromise supply chain resilience. Enhancing operational energy efficiency may inadvertently increase the carbon footprint from materials, posing environmental and social impacts. Challenges in the supply chain may lead to the use of the same e-steel grade instead of higher grades, decreasing material usage efficiency and increasing costs. Increasing material usage is seen as undermining the principles of a circular economy, which aims to minimise materials handled at the end of a transformer's life. The feedback references the effectiveness of the US DOE Regulation (See section 2.1.2.2) in covering various types of distribution transformers, implying that it could serve as a model for efficiency standards.

Some feedback suggests that small transformers could be excluded from the regulation due to the diverse nature of the market and the perceived complexity of setting performance requirements for such a wide range of products. It is argued that if energy efficiency is to be addressed, it should be done at the product level rather than regulating individual components like small transformers, which may have a relatively minor impact on overall energy wastage. It is mentioned that there may be no economic or environmental interest in regulating small transformers in this power range, and doing so may make them more complex to manufacture. Some feedback supports the idea that all transformers should be included in regulation and suggests examining the extension of tables for lower power ranges. It is noted that very small transformers often reuse magnetic steel recovered from old transformers. ICF agrees that reuse of materials can have environmental benefits.

[78] Stakeholder feedback

[79] Stakeholder feedback

In conclusion, the feedback highlights the diverse nature and use-cases of small power transformers, which play a relatively smaller role in total power network losses compared to larger transformers. The feedback discusses challenges in setting a general efficiency level for small transformers and notes that they are often produced globally, embedded in other products, making it challenging to impose sanctions on manufacturers. ICF agrees to not consider regulating at the product level and establishing performance levels for classes of small transformers instead.

What proportion of the market do small transformers occupy? What are some of the common output levels until the transformer gets embedded in a product? What is the average performance of small power transformers? Please could stakeholders share their insights on both aspects.

2.2.2.3 Effect of rising electricity prices

The feedback from a stakeholder acknowledges a lack of specific information, but it suggests that COVID-19 has likely brought about additional challenges and problems. The feedback notes that the costs of base materials have consistently increased in the last 2-3 years, which may affect the overall cost and efficiency of transformers. The capitalisation of losses over 25-40 years is highlighted, emphasising that it's not influenced by short-term price patterns. It also mentions the trend of falling energy costs within the kWh over the long term. There is a shift towards larger transformer ratings to accommodate larger loads and higher peak loads, rather than restricting the use of renewables. Copper losses are reducing not only due to loss capitalisation but also because more copper improves voltage regulation at higher loads and the transformer's capability to handle peak loads. Tier 2 requirements have led to high levels of efficiency, but further increases in efficiency may be uneconomic due to disproportionately increased transformer costs High electricity prices have influenced manufacturing costs, potentially leading to higher transformer prices and financial compensation for already produced transformers. The feedback mentions that DSOs (Distribution System Operators) have used high electricity prices as a reason to halt investments, citing reduced benefits and profitability. Despite high electricity prices, the demand for transformers has increased due to the European energy transition program. On the DSO level, Tier 2 designs have limited margins in size and weight, reducing potential gains in energy efficiency. Capitalisation is considered the best way to control the loss level of large transformers. However, there are challenges related to formula flexibility and local decision-making. Scarcity of transformer supply and extended delivery times for both small and large transformers are mentioned as challenges in the current market by a stakeholder rather than electricity prices. A stakeholder mentions that higher electricity prices can result in higher efficiency for larger transformers, but material price increases work in the opposite direction.

In conclusion, the feedback states that the consistent increase in the costs of base materials over the past few years, can impact the overall cost and efficiency of transformers. The feedback underscores the importance of capitalising losses over an extended period (25-40 years), emphasising that this approach is not influenced by short-term electricity price patterns. The interplay between higher electricity prices and transformer efficiency, as well as the counteracting effects of material price increases, are mentioned as important factors to consider.

2.2.3 Recommendations

2.2.3.1 Effectiveness of Tier 2, and implementation of Tier 3

A holistic approach is necessary to address the various challenges and opportunities presented by these requirements. It is important to continue to prioritise energy efficiency improvements but assess them from a TCO perspective rather than solely focusing on the initial transformer cost. This approach allows for a more comprehensive evaluation that considers energy losses over the operational life of the transformer. The potential for material efficiency requirements should be explored, focusing on high-performance materials and rated power selection. This approach may offer efficiency gains without disproportionately increasing material consumption. For distribution transformers, it is recommended to encourage more compact designs that reduce material usage while maintaining efficiency standards as it will offer efficiency gains without disproportionately increasing material consumption. Thus, a comprehensive study evaluating detailed impact of TCO should be carried out before moving to higher energy efficiency requirements as some assumptions made during the initial cost benefit analysis such as expected cost of materials, level of CO_2 emissions and energy savings no longer seem relevant.

Phase 2 will review how the Base cases and TCO calculations have changed with updated data.

2.2.3.2 Energy efficiency metrics for small power transformers

It's important to recognise the diverse nature and varied applications of small transformers, making it challenging to set a one-size-fits-all efficiency standard. Instead, it is recommended to consider a tiered approach, akin to Tier 2 Peak Energy Index (PEI), that allows for lower efficiency but within specific application areas, with input from both manufacturers and end users. Additionally, it is necessary to explore the potential to include small transformers within broader product-level regulations as opposed to this regulation for appliances, since it may be more effective in addressing energy efficiency at the overall product level. Furthermore, it's vital to consider the environmental impact, including the carbon footprint of materials, especially given the limitations in improving the efficiency of small transformers due to constraints in adding raw materials.

Phase 2 of the review will consider the market shares for small power transformers, and what conservative PEI requirement can be set.

2.2.3.3 Effect of rising electricity prices

It is essential to monitor and adapt to the impact of external factors, including COVID-19 and the fluctuations in the costs of base materials, on the transformer industry. This entails developing strategies to mitigate cost increases by potentially seeking alternative materials or suppliers. While prioritising efficiency gains remains crucial, it is especially vital to consider the potential disproportionate increase in transformer costs associated with further efficiency improvements. Given the trend toward larger transformer ratings to accommodate the growing demand for renewables, there is a need to concentrate on optimising design and manufacturing processes and disregard the minimal impact of electricity prices. This optimisation should aim to sustain cost competitiveness while upholding high efficiency standards over the transformer lifetime ensuring reliability and stability regarding pricing strategies.

2.3 Implementation of Ecodesign Requirements and Methodologies

b) the appropriateness of the concessions introduced for medium and large power transformers in cases where installation costs would have been disproportionate. In particular, the analysis should investigate concessions in concrete cases (e.g., manufacturers, electricity companies, market surveillance authorities) and determine their appropriateness;

c) the possibility of utilising the PEI calculation for losses alongside the losses in absolute values for medium power transformers;

o) existing methodologies for assessing technoeconomic aspects of Ecodesign for power transformers (especially in terms of technology neutrality, circularity, MEPS and MMPS), as well as for the assessment of the costs for replacement/installation of transformers, based on the principles laid down in Regulation 2019/1783;

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).

2.3.1 Background

2.3.1.1 Concessions for disproportionate costs

At present the regulation has a concession for derogation from Tier 2 to Tier 1 for one-to one replacements of medium transformers if disproportionate costs can be proven by the manufacturer/importer to the 'relevant authority'. Records must be kept including location or a specific installation type.

Disproportionate costs are likely where spending beyond transformer replacement is needed to accommodate larger, heavier Tier 2 transformers, e.g., for ground mount where physical barriers must be moved, or adjacent land leased to allow larger size and retain safety margins; or for pole-mount transformers where H-poles are needed rather than single poles to carry extra weight.

Disproportionate costs derogations might be requested by utilities for replacing some of these disposals, in cases where the site conditions make a Tier 2 replacement challenging. The specific definition in Commission Regulation (EU) 548/2014 updated 2019 can be seen in Figure 2.9.

Figure 2.5 Extract of the definition from Commission Regulation (EU) 2019/1783

> As of the date of application of Tier 2 requirements (1 July 2021), when the one-to-one replacement of a large power transformers in an existing site entails disproportionate costs associated to its transportation and/or installation, or is technically infeasible, the replacement transformer is, exceptionally, only required to comply with Tier 1 requirements for the given rated power.
>
> Furthermore, if the cost of installing a replacement transformer complying with Tier 1 requirements are also disproportionate, or where no technically feasible solutions exist, no minimum requirements shall apply to the replacement transformer.
>
> As of the date of application of Tier 2 requirements (1 July 2021), when the installation of a new large power transformer in a new site entails disproportionate costs associated to their transportation and/or installation, or is technically infeasible, the new transformer is, exceptionally, only required to meet Tier 1 requirements for the given rated power.
>
> In these cases, the manufacturer, importer or authorised representative responsible for placing on the market or putting into service the transformer shall:
>
> include in the technical documentation of the new or replacement transformer the following information:
>
> — address and contact details of the commissioner of the transformer,
>
> — the specific location where the transformer is to be installed,
>
> — the technical and/or economic justification to install a new or replacement transformer that does not comply with Tier 2 or Tier 1 requirements. If the transformer(s) were commissioned by a tendering process, all the necessary information regarding the analysis of bids and the award decision, shall also be provided,
>
> — notify the competent national market surveillance authorities.

Furthermore, enforcement and surveillance issues arising from Commission Regulation (EU) 548/2014 which was updated in 2019, must be examined, this is shown in Figure 2.10.

Figure 2.6 Extract from Commission Regulation (EU) 548/2014 updated in 2019

> In this case, the manufacturer, importer, or authorised representative shall include in the technical documentation of the replacement transformer the following information:
>
> — Address and contact details of the commissioner of the replacement transformer
>
> — The station where the replacement transformer is to be installed. This shall be unequivocally identified by either a specific location or a specific installation type (e.g., station or cabin model)
>
> — The technical and/or economic justification of the disproportionate cost to install a transformer that is only Tier 1 compliant instead of a Tier 2 compliant one. If the transformers(s) were commissioned by a tendering process, all the necessary information regarding the analysis of bids and the award decision shall be provided.
>
> In the above cases, the manufacturer, importer or authorised representative shall notify the competent national market surveillance authorities.

2.3.1.2 PEI usage for medium transformers

Peak Efficiency Index (PEI) is obtained when no-load loss equals load, but it does not require a specific loading point. Instead, the PEI finds the point where the no-load loss equals the load loss and calculates the value.

Commission Regulation (EU) 548/2014 which was updated in 2019, defines the formula to be used for Pead Efficiency Index is shown in Figure 2.11.

Figure 2.7 Extract from Commission Regulation (EU) 548/2014 updated in 2019

The formula to be used for the Peak Efficiency Index calculation is:

$$PEI = 1 - \frac{2(P_0 + P_{c0} + P_{ck}(k_{PEI}))}{S_r \sqrt{\frac{P_0 + P_{c0} + P_{ck}(k_{PEI})}{P_k}}} = 1 - \frac{2}{S_r}\sqrt{(P_0 + P_{c0} + P_{ck}(k_{PEI}))P_k} \ (\%)$$

Where:

P_0	is the no load losses measured at rated voltage and rated frequency on the rated tap
P_{c0}	is the electrical power required by the cooling system for no load operation, derived from the type test measurements of the power taken by the fan and liquid pump motors (for ONAN and ONAN/ONAF cooling systems P_{c0} is always zero)
P_{ck} (k_{PEI})	is the electrical power required by the cooling system in addition to P_{c0} to operate at k_{PEI} times the rated load. P_{ck} is a function of the load. P_{ck} (k_{PEI}) is derived from the type test measurements of the power taken by the fan and liquid pump motors (for ONAN cooling systems P_{ck} is always zero).
P_k	is the measured load loss at rated current and rated frequency on the rated tap corrected to the reference temperature
S_r	is the rated power of the transformer or autotransformer on which P_k is based
k_{PEI}	is the load factor at which Peak Efficiency Index occurs';

The PEI calculation brings together load and no-load losses in the same calculation for larger transformers. For medium power transformers only load and no-load losses requirements are specified within the regulation and no PEI requirement is defined.

- The 2014 regulation defines 'Medium Power transformer' as a power transformer with a highest voltage for equipment higher than *1,1 kV, but not exceeding 36 kV and a rated power equal to or higher than 5 kVA but lower than 40 MVA.*
- *The energy efficiency requirements in 2014 regulation for "Medium Power transformer' was divided into 2 components:*
  - 1. Absolute values of maximum load losses & maximum no load losses with rated power <= 3150 kVA
  - 2. Peak efficiency index (PEI) with rated power > 3150 kVA
- The 2019 regulation defines 'Medium Power transformer' as a power transformer with all windings having *rated power lower than or equal to 3150 kVA, and highest voltage for equipment greater than 1,1 kV and lower than or equal to 36 kV;*
  - 1. Absolute values of maximum load losses & maximum no load losses with rated power <= 3150 kVA with slight changes
  - Peak efficiency index (PEI) with rated power > 3150 kVA is removed since the definition has changed.

The changes are as shown in Table 2.9.

Table 2.9 Small, medium and large transformer definitions

	Ecodesign Regulation 548/2014	**Ecodesign regulation 2019/1783**	**Proposed change in the latest draft of IEC60076-1 standard**
Small transformers	*Highest voltage for equipment not exceeding 1.1 kV*	*Highest voltage for equipment not exceeding 1.1 kV*	Highest voltage for consumer circuit (or equipment) of 1.1 kV, highest rated power of the highest rated winding <= 3150 kVA three phase, or

	Ecodesign Regulation 548/2014	Ecodesign regulation 2019/1783	Proposed change in the latest draft of IEC60076-1 standard
			<= 1050 kVA single phase
	highest voltage for equipment higher than 1,1 kV, but not exceeding 36 kV	*highest voltage for equipment greater than 1,1 kV and lower than or equal to 36 kV*	
	*and a rated power equal to or higher than 5 kVA but lower than **40 MVA***	*and rated power lower than or equal to **3150 kVA***	*highest rated power of the highest rated winding > 3150 kVA but <= 31.5 MVA three phase* *or* *>1050 kVA but less than 10.5 MVA single phase*
Medium transformers	***medium power transformers with rated power ≤ 3150 kVA*** *Table I.1: Maximum load and no-load losses (in W) for three-phase liquid-immersed medium power transformers with one winding with Um ≤ 24 kV and the other one with Um ≤ 1,1 kV*	***medium power transformers with rated power ≤ 3150 kVA*** *Table I.1: 'Maximum load and no-load losses (in W) for three-phase liquid-immersed medium power transformers with one winding with Um ≤ 24kV and the other with Um ≤ 3,6 kV*	
	medium power transformers with rated power ≤ 3150 kVA *Table I.2: Maximum load and no-load losses (in W) for three –phase dry-type medium power transformers with one winding with Um ≤ 24 kV and the other one with Um ≤ 1,1 kV.*	**medium power transformers with rated power ≤ 3150 kVA** *Table I.2:* *Maximum load and no-load losses (in W) for three-phase dry-type medium power transformers with one winding with Um ≤ 24kV and the other with Um ≤ 3,6 kV*	
	medium power transformers with	*NA*	

	Ecodesign Regulation 548/2014	Ecodesign regulation 2019/1783	Proposed change in the latest draft of IEC60076-1 standard
	rated power > 3150 kVA <=40000 kVA *Table I.4: Minimum Peak Efficiency Index (PEI) values for liquid immersed medium power transformers*		
	medium power transformers with rated power > 3150 kVA <=40000 kVA Table I.5: Minimum Peak Efficiency Index (PEI) values for dry type medium power transformers	*NA*	
Large Transformers	*highest voltage for equipment exceeding 36 kV and a rated power equal or higher than 5 kVA,* *or a rated power equal to or higher than 40 MVA regardless of the highest voltage for equipment.*	*Highest rated power of the highest rated winding > 3150 kVA or a highest voltage for equipment greater than 36 kV*	*Highest rated power of the highest rated winding > 31.5 MVA three phase or >10.5 MVA single phase*

2.3.1.3 A review of the technoeconomic aspects of Ecodesign

Whilst considering regulation under Ecodesign, aspects such as the energy efficiency, the consumer purchase price, the materials included in the manufacture, the costs of installations, repair, and the end-of-life considerations. There are multiple potential methodologies to determine this, which will be considered here.

2.3.1.4 Requirements for reverse flow power transformers

Transformers will need to cope with the increasing expansion of sustainable and renewable generation within the grid system in consideration of consumers and the bidirectional flows of energy within the transformer. Traditionally, power transformers would feed power unidirectional into the grid. However, with the increasing number of renewables on the grid at varying sizes and locations this has meant transformers are having to put power back into the grid, which has increasingly become a problem due to the increase of consumers The unpredictable nature of renewable energy sources means that in some circumstances the instantaneous power demand and supply do not always match, thus, there is insufficient energy storage capacity at the renewable source which leads to a reverse in the power flow towards the grid.

2.3.2 Feedback/ Research results

2.3.2.1 Concessions for disproportionate costs

There are concessions in place to allow for Tier 1 transformers to be installed if the one-to-one replacement to a Tier 2 transformer incurs disproportionate costs.

There is a practicality concern for the MSAs to verify this as an economic calculation needs to be done to justify the “disproportionate costs”.

Disproportionate cost is defined as the installation cost of replacing the complete substation housing the transformer and/or the acquisition or rental of additional floor space are higher than the net present value (NPV) of the additional avoided electricity losses (tariffs, taxes and levies excluded) of Tier 2 compliant replacement transformer over its expected service life.

NPV should be calculated based on capitalised loss values using widely accepted social discount rates.

There is a split responsibility between the utility who buys the transformer and the manufacturer who sells it. The utility is the one that gets to make the decision of the Tier 1 instead of the Tier 2. However, the duties of documenting where the transformer ends up is up to the manufacturer, which then needs to provide information to the MSAs.

Managing spares was also an issue because of the requirement for specific location - the 'cabin model' was the get out.

To ascertain whether the concessions for disproportionate costs are required the following information must be known:

- Ground-mounted or pole-mounted transformer, building & civil costs, WACC, Capitalisation rate, load growth factor, loss load factor (LLF), site demand (MVA) etc.

*The disproportionate cost calculation does not include any additional costs for procuring a Tier 2 equivalent transformer.

Cabin model

Cabin model may be defined as where a transformer is placed inside an enclosure of Glass Reinforced Plastic (GRP)/ brick enclosure/ or any other enclosure type commonly used. Cabin models pose a challenge as it is placed inside an enclosure and has space constraints. Therefore, replacing a transformer in the cabin may pose a challenge in terms of efficiency, as requiring a higher tier performance may result in a larger and heavier device which doesn’t fit the enclosure.

Stakeholder feedback summary:

- Based on inputs from the stakeholders, the main point of concern is that there is no clear definition of “disproportionate costs “. The disproportionate cost should be clearly defined. Also, the methodology for disproportionate cost should be exhaustive and fixed. The responsibilities are not clear because the site constraints should be defined by the utilities and the manufacturer(s) has to prove that within those constraints a more efficient transformer cannot be designed. There is an overlap between the responsibilities. Wherein, the regulation puts all the responsibility on the manufacturer.
- Also, there are no clear guidelines to justify or present disproportionate costs. There can be any interpretation at any level.

- Many stakeholders also submitted that they are not aware of the number of cases where a concession for disproportionate costs was applied, which may imply it hasn't been used. There is no concrete data on the number of times the disproportionate costs exemption was allowed by the MSAs.
- Also, the responsibilities of the manufacturer versus the utility must be clearly defined.

Some key feedback points from the stakeholders are presented below:

Box 2.1 Direct Stakeholder quote from qualitative questionnaire

For large units (above 100 MVA) this was never used in France and is not necessary. For smaller units which are installed downtown this is a requirement. But the procedure to be granted exemption is not defined and allows any interpretation, cost can be judged disproportionate at any level-

Box 2.2 Direct Stakeholder quote from qualitative questionnaire

It was not useful, probably because there were no clear and transparent rules and processes (that could be unequivocally interpreted and measured) to govern these concessions. Additionally, there was no supervisor overseeing these rules, nor were there clear responsibilities assigned to each part of the process. The proportion of replacement cases where these concessions were applied was nearly zero.

2.3.2.2 PEI usage for medium transformers

At present, PEI is currently only used for large transformers.

PEI provides more flexibility in the regulation as the efficiency is determined wherever the peak occurs. PEI simply sets a peak efficiency, wherever the peak may be. This would be irrelevant of whether investment is made to reduce core losses or winding losses. There are different incentives for manufacturers and utility with regards to efficiency and PEI.

PEI favours the utility who know about the desired usage. Separate core and winding losses favour the manufacturer who can predict material needs more accurately, with the production of a standardised product.

Manufacturers can buy the materials in advance and the utility is likely to tell the manufacturer to quote a price. With fixed losses the manufacturers can standardise their products, which leads to streamline their manufacturing process and also in standardising the material purchasing.

The PEI is set by the regulation but in case where the utility specifies the peak and the PEI value, then this should result in the most efficient product spec for its usage. However, it would be more difficult for the manufacturer to meet this requirement as materials standardisation would not be feasible.

From a regulatory perspective, the PEI approach could result in a situation where there is a mismatch between where the transformer is eventually applied or used, the average load may not match where the efficiency peak is set.

Medium power transformers have the highest usage (highest sales figure)[80] in the EU and the rationale behind not using PEI for medium transformers is:

Case: If PEI is used at the *only* metric for efficiency

- 1. For a given PEI several combinations of no-load loss (P0) and load loss (Pk) with different optimum equivalent load factor (kPEI) are possible.
- 2. However, if we look at these several combinations of P0 & Pk only one might be compliant with losses in *absolute numbers as set out in regulation*.
- 3.Therefore, PEI, metric would result in many other combinations which are non-compliant for their utilisation level but meet the PEI criteria.
- 4.A loophole which would emerge from only requiring a minimum PEI to be specified is that the lowest CAPEX design could be specified simply by choosing a very low load factor at PEI (kPEI) within a tender process, This could occur by underspecifying the optimum load factor in the tender compared to the expected equivalent load factor in use, e.g. specifying kPEI=0.1 while keq=0.3 means that a 400 kVA (P0=430W, Pk=4600W) will run at real efficiency 98.83% instead of its optimum 99.30% but can result in a low cost design. Designing for a low optimum load factor (kPEI) means that one does not need to invest in conductor material (e.g., less copper) and this will therefore lower the transformer CAPEX.
- The idea behind not using PEI for all medium transformers was that most of them are used in distribution network and are manufactured in large numbers whereas large transformers is a niche market. (Sales figure of Distribution transformer for 2020 in EU was 173,891)[81]
- The PEI formula is flexible given that a minimum load factor must be specified with PEI.
- In the absence of minimum load factor, PEI can be manipulated as to achieve the minimum required PEI at less efficiency.
- It can be tested for gameability by devising a methodology where a minimum load factor can be calculated where the required PEI is met with maximum efficiency.

Stakeholder feedback summary:

- Majority of the stakeholders are of the opinion that PEI for medium power transformers is not the best option, as these operate over a wide range of load. If PEI is introduced then overall energy efficiency would be lower, losses higher.
- Also, the fixed losses lead to standardisation of the market. Introducing PEI will lead to de-standardisation of the market.

[80] PREPARATORY STUDY FOR THE REVIEW OF COMMISSION REGULATION 548/2014 ON ECODESIGN REQUIREMENTS FOR SMALL, MEDIUM AND LARGE POWER TRANSFORMERS- 2017

[81] PREPARATORY STUDY FOR THE REVIEW OF COMMISSION REGULATION 548/2014 ON ECODESIGN REQUIREMENTS FOR SMALL, MEDIUM AND LARGE POWER TRANSFORMERS -2017

Box 2.3 Direct Stakeholder quote from qualitative questionnaire

The advantages of loss levels for medium-power transformers are:

- *Rationalizing product ranges to optimize manufacturing processes and guarantee mass production.*
- *To have a tool for controlling cost changes in raw materials, which have an impact on unit costs.*
- *To control the quality and reliability of mass-produced products*
- *To facilitate the management of losses at national level between manufacturers*
- *To avoid possible drifts with the use of a PEI that allows manufacturers to influence design and use of raw materials.*
- *To sub-optimize efficiency for highly variable load factors*

- While some of the stakeholders are in favour of combination of PEI and losses for Medium Power transformers as it would help to optimise the design of transformers.
- Some other stakeholders are of the opinion that using only PEI without absolute values is a good option as it gives more flexibility and possibility to optimise the design. Also, it would help to design the transformer as per the application.

Box 2.4 Direct Stakeholder quote from qualitative questionnaire

The introduction of PEI requirements would make it easier to make design adjustments in edge cases where strict adherence to the absolute values, unduly increases the size and price of a transformer. This is especially the case with non-standard voltages.

2.3.2.3 Techno economic methodologies to review Ecodesign considerations for transformers

The Ecodesign methodology is designed to account for the energy consumption of a device, the material components during the manufacturing process, the packaging, the end-of-life of the device, and the total cost to the end user.

Stakeholders suggested that the study looked into the use of the measures:

- Total Cost of Ownership (TCO)
- Alignment with the UN sustainability goals
- An LCA analysis
- Environmental Conscious Design considerations
- Digital Product Passports

Furthermore, the EN standard 50708-1-1 has recently been amended to include new ratings with regards to sustainability, including not only energy performance but also material efficiency concerns. A standardized quantitative parameter or rating to bring these together is under study.

Following the Ecodesign Methodology and the Ecoreport tool, some of these considerations are already included. The methodology determines a Base case for

an average transformer product, which will represent the average material composition, energy efficiency, utilisation rates and end of life practices. This will then also be represented against the cost to the consumer, allowing for a TCO analysis to be completed. Different impacts are calculated for aspects such as greenhouse gas emissions, but also toxicity and water usage, which accounts for some of the UN sustainability goals, and LCA considerations. Further LCA concerns are difficult to evaluate as this analysis is done for the base case product and not for each product placed on the market.
Digital Product Passports (DPP) are currently not in scope of Ecodesign. However, the implementation may be covered under the powers of the upcoming Ecodesign Sustainable Products Regulation, and hence may become a useful mechanism for future Ecodesign regulation.

2.3.2.4 Are there requirements when using reversed power flows transformers due to increase of imbedded generation?

The increase in embedded generation (e.g., renewables at the distribution network level of the grid) is leading to increasing scenarios of reverse power flow (RPF) across electrical networks, which historically were designed for single direction flow, from large generators at transmission level, through step-down transformers to distribution networks and local circuits.

RPF scenarios could impact transformers throughout the network, e.g.:

- Domestic rooftop solar exports, reversing flow on 10 kV / 0.4 kV transformers within the distribution network.
- An excess of distributed wind and solar power to a distribution network, leading to reverse flow across 110 kV / 10 kV transformers into the transmission network.

RPF across transformers can lead to changes in the flux leakage pattern, core loss, the temperature of the core, metal parts and windings. These changes can lead to reductions in transformer life, as well as increases in losses from the transformer[82,83].

Reverse power flow can cause additional winding loses thus affecting the transformers insulation[84]. Consequently, the increased losses and thermal cycling that occurs because of bidirectional power flows reduces the life expectancy of transformers. This is caused by increases in the excitation voltage above the limits of a transformer leading to significant magnetising current increases and harmonics which ultimately causes significant core losses[85]. The life expectancy of transformers has been observed to reduce due to the impact of reverse power flows, in particular older transformers are more vulnerable to failure. This poses a more significant threat to aging transformer fleet in the EU, however it is considered that for a new transformer designed appropriately to match the system requirements these losses can be avoided[85].

[82] On the Effects of Solar Panels on Distribution Transformers | IEEE Journals & Magazine | IEEE Xplore

[83] https://www.mdpi.com/1996-1073/15/23/9238#:~:text=Results%20revealed%20that%20significant%20reversed%20power%20flow%20can,transformer%20results%20in%20an%20increase%20in%20winding%20losses

[84] https://link.springer.com/article/10.1007/s40998-019-00300-9

[85] der_reverse_power_flow_impacts.pdf (energycentral.com)

As discussed, the stresses caused by a reversed power flow prematurely decrease the life expectancy of a transformer therefore, manufacturers have explored ways to withstand these stresses. One technique is to increase the steps for on-load tap changers, full-load voltages regulators, or reduced flux densities to compensate the over-voltage saturation of the core[86]. The harmonic stresses on a transformer can be reduced by integrated inductors and increased k-factor designs[85]. One of the major problems experienced in the electrical network is that often reverse power flows are not communicated across the network. Therefore, smart transformers which automatically monitor for example the voltages a transformer receives can help provide a better prediction of potential transformer failures[85].

Stakeholder feedback summary:

Many stakeholders are of the opinion that "reverse power flow" must be defined and its condition clearly set. Also, the RPF will impact the lifetime of the transformer. Reversed power flows may lead to increased loading and potential overheating of transformers. It might also require redesigning protection and control system to ensure safe and reliable operation. A transformer can handle both flows if properly designed and specified.

Also, for reverse power flow the transformers would need an on-load tap changer which might increase the cost of the transformers.

Box 2.5 Direct Stakeholder quote from qualitative questionnaire

"Setting an efficiency is a robust but simplified way for eco design. In real life transformers can see different operating conditions such as low load, overload

What are the number of cases where reverse power flow transformers were installed? Are there special design considerations to be had for these devices?

Please could stakeholders share their insights on these both aspects.

reverse power flows lead to voltage fluctuations requiring voltage regulation equipment to better manage these fluctuations. At the same time transformer protection and control systems might need to be reconfigured or updated to handle the altered operating conditions and ensure safe and reliable operation. All the differences have an economic impact from higher energy consumption, higher operational costs and capital expenditure."

2.3.3 Recommendations

2.3.3.1 Concessions for disproportionate costs

It is recommended to keep the concessions for "disproportionate costs" for cases where 1-to-1 replacement of Tier 1 to Tier 2 transformer is not possible due to physical constraints. However, the definition of disproportionate cost and methodology to calculate it should be clearly defined. Also, the procedure to apply for concessions to MSA must be outlined and the responsibility of as to who should seek exemption for disproportionate cost should be set.

[86] https://www.daaam.info/Downloads/Pdfs/proceedings/proceedings_2012/134.pdf

Although, there is not much information on the number of times concession was granted but it should be kept for the cases where it might be required.

2.3.3.2 PEI usage for medium transformers

The medium transformers have one of the largest number of installations in the EU and they affect the grid losses to a significant extent.

The absolute value of losses for medium transformers is recommended since using only PEI may give several combinations of no-load loss (P0) and load loss (Pk) with different optimum equivalent load factor (kPEI). However, if we look at these several combinations of P0 & Pk only one might be compliant with losses in absolute numbers as set out in regulation.

Also, absolute values of losses are important for market standardization.

Therefore, it is recommended to keep only absolute values of losses for medium transformers without PEI.

2.3.3.3 Techno economic methodologies to review Ecodesign considerations for transformers

The study will progress under the analysis scope of the Ecodesign methodology. However, Phase 2 sensitivity analysis will be done to determine the TCO of the base cases and the suggested changes to the regulation, this will include the changes to material content, but also the effects of increased lifetime through recycling.

2.3.3.4 Are there requirements when using reversed power flows transformers due to increase of imbedded generation?

As the grid would eventually keep getting greener (i.e., more renewable sources being connected to the grid) there would be growing need for reversed power flows transformers.

It is recommended that Reverse Power Flow (RPF) be defined to ensure manufacturers can accommodate appropriate protection and control systems, minimising the effects of RPF. This would help in safe and reliant operation. This action is not for Ecodesign but for the technical standards body to define RPF and its other modalities as deemed necessary for safe and reliant operation.

2.4 Regulation definitions and scope

d) the possibility to adopt a technology-neutral approach to the minimum requirements set out for liquid-immersed, dry-type and, possibly, electronic transformers;

f) the appropriateness of the exemptions for transformers in offshore applications;

g) the appropriateness of the concessions for pole-mounted transformers and for special combinations of winding voltages for medium power transformers;

p) functional categorisation of power transformers (including conventional transformers, overload transformers and fire performant transformers and any others that the contractor may suggest).

2.4.1 Background

2.4.1.1 Offshore wind exemption

The Ecodesign regulation 2019/1783 on small, medium and large power transformers sets out requirements for power transformers in the EU with a minimum power rating of 1 kVA used in 50 Hz electricity transmission and distribution networks or for industrial applications.

"*Transformers specifically designed to be installed on fixed or floating offshore platforms, offshore wind turbines or on-board ships and all kinds of vessels*" are specifically exempt from the regulation.

2.4.1.2 Pole-mounted transformer exemptions

The regulation also defines "*medium power pole-mounted transformer*" as *power transformer with a rated power of up to 400 kVA suitable for outdoor service and specifically designed to be mounted on the support structures of overhead power lines.* These medium power pole-mounted transformers are subject to a concession, for one-to-one replacements of existing medium power pole-mounted transformers with a power rating between 25 – 400 kVA. Maximum allowable losses for these transformers follows those set in Table 2.10, where those not explicitly mentioned are obtained by linear interpolation or extrapolation.

Table 2.10 Maximum load and no-load losses (in W) for medium power liquid immersed pole-mounted transformers

Rated Power (kVA)	Maximum load losses (in W)	Maximum no-load losses (in W)
25	B_k (725)	A_0 (70)
50	B_k (875)	A_0 (90)
100	B_k (1475)	A_0 (145)
160	C_k + 32% (3102)	C_0 - 10% (270)
200	B_k (2333)	B_0 (310)
250	B_k (2750)	B_0 (360)
315	B_k (3250)	B_0 (440)

2.4.1.3 Concessions to medium transformers with special combinations of winding voltages

The regulation also sets out concessions for medium transformers with special combinations of winding voltages. These are defined in Table 2.11.

Table 2.11 Correction factors applied to the load and no load losses for medium power transformers with special combinations of winding voltages

Special combination of voltages in one winding		Load losses (P_k)	No load losses (P_o)
For both liquid immersed and dry type			
Primary highest voltage for equipment Um ≤ 24kV	Primary highest voltage for equipment Um ≤ 24kV	No correction	No correction
For liquid immersed			
Primary highest voltage for equipment Um = 36kV	Secondary highest voltage for equipment Um ≤ 3,6 kV	10 %	15 %
Primary highest voltage for equipment Um = 36kV	Secondary highest voltage for equipment Um > 3,6 kV	10 %	15 %
For dry type			
Primary highest voltage for equipment Um = 36kV	Secondary highest voltage for equipment Um ≤ 3,6 kV	10%	15%
Primary highest voltage for equipment Um = 36kV	Secondary highest voltage for equipment Um > 3,6 kV	15%	20%

2.4.1.4 A technology neutral approach

Liquid-immersed and dry-type transformers currently have minimum requirements which are different, but not hugely so, across different kVA ratings in various programmes globally. Comparison of MEPS for liquid-immersed and dry-type transformers of different kVA ratings for different global programmes is covered in section 2.1.2.2.

2.4.1.5 Functional categorisation

Transformers are categorised in the Ecodesign regulation according to their size: small, medium and large. These are split according to their voltage and power ratings. Functional categorisation is not yet something implemented in the regulation, apart from some specific exemptions.

2.4.2 Feedback/ Research results

2.4.2.1 Appropriateness of the exemptions for transformers in offshore applications

Transformers in offshore applications are used in a wide range of processes, from the distribution of electricity to platforms used for the extraction of crude oil from oil fields, or as collector step-up transformers on fixed or floating offshore platforms, to being used on ships and wind-turbines. Such transformers are often exposed to harsh, marine environments.

The discussion regarding exemptions for offshore transformers revolves around several key points. These exemptions primarily stem from the need to meet compact dimensions and weight requirements for offshore platforms. Offshore transformers typically have power ratings in the range of several MVA, with specialised cooling methods employed to reduce their size and weight.

In Europe, offshore transformers with ratings from 3 MVA to 20 MVA constitute a significant market share; these are used as step-up transformers for each wind turbine. These are typically dry type, 3-phase transformers, designed to be smaller, lighter, and more salt-resistant than standard transformers.

Larger collector transformers may vary from 200MVA to 500MVA. These high-power transformers are used as part of the offshore collection system, which collects the generated electricity from groups of wind turbines, steps up the voltage and transmits the current efficiently to the onshore grid over connecting cables.

The market share of offshore wind transformers is estimated between 5-7%[87] of the total annual European transformers market volume. The market share of offshore wind transformers (by value) is likely to remain significant, with much more capacity expected to be installed over the coming decades.

One of the biggest issues with offshore transformers is that the transformer weight can cause serious design problems for installers. System designers must consider the weight of the offshore transformer when determining the design and cost of the support platform[88]. On average, for each additional tonne a transformer weighs, an additional 1.5 to 2 tonnes of material is needed in the platform to support the transformer. Furthermore, offshore transformer installation and maintenance tends to be complex, hazardous and expensive.

Certain respondents advocated for maintaining these exemptions, particularly within the offshore wind energy sector. They contended that accepting slightly lower efficiency levels to enable wind energy to be transmitted, aligns with environmental goals. This perspective reflected particularly larger capacity collector transformers, where raising efficiency requirements could result in the need for expensive, larger supporting structures, which contribute additional environmental impacts.

However, others questioned the need for these exemptions, advocating for kVA ratings to depend on the application's power requirements, whether offshore or onshore. For onshore wind, the same constraints of placing the transformer within the nacelle would apply as for offshore wind. The ongoing debate centres on the unique constraints of offshore applications, such as size, weight, and environmental conditions, and whether these justify maintaining exemptions. Some believe that exemptions are essential to ensure the reliability and cost-effectiveness of offshore projects, while others argue that they may not be appropriate as the capacity of offshore transformers continues to grow, emphasising the importance of considering environmental factors in transformer design.

[87] Stakeholder qualitative questionnaire feedback

[88] 418.14-Reyes.pdf (icrepq.com)

There is a concern that increasing regulatory pressure on offshore transformers may be seen as a barrier to develop offshore wind resources, inhibiting renewable energy policies. Furthermore, offshore wind generators are incentivised to use efficient transformers in order to export the most power.

> To further evidence the offshore transformers, stakeholders are asked to contribute data on the market share offshore transformers represent, their rated powers and the increased cost, space and weight required to shift from Tier 1 to Tier 2 transformers. Please be sure to distinguish transformers used in Offshore wind nacelles (compared to onshore), and those used in collector stations.
>
> Furthermore, please clarify what are the special protections required for marine environment operation, if any.

2.4.2.2 Pole-mounted transformers concessions

Data from 2021 show that around 47% of distribution transformers in European utilities are pole-mounted, 53% are ground-mounted, of which 8% are either indoors or underground (and therefore have additional space restrictions)[89]. The term distribution transformers here is assumed to refer to medium sized transformers.

Concessions are made for pole-mounted medium power transformers, as there is a concern that increased efficiency requirements would mean the transformers would be much heavier. This additional weight might be able to be taken by the existing pole or might require the transformer to need either a 2-pole + tray installation in a "H" formation, or to be replaced by a ground-mounted transformer facility, which has a cost of €25-30k against €4-9k for pole-mounted.[90] The ground-mounted facility would also have safety concerns. The concessions were made to ensure that pole-mounted transformers can be replaced like for like on a single pole.

Most stakeholders are in favour of these concessions, stating the above costs. With some even suggesting that despite the concessions, the Tier 2 efficiency requirements require larger and heavier transformers, meaning that installations need to be switched to "H" pole, even with the existing concessions. There is a trade-off between the cost of adding support for heavier, more efficient transformers, (requiring more time to install for H-pole or ground-mounted setups) or accepting the losses for like-for-like replacement. One can note that the methodology to shift to Tier 1 on medium power transformers under "disproportionate costs" was set up to accommodate these concerns.

[89] Microsoft Word - Ester Oil Penetration in Europe's Transformer Market.docx (ptr.inc)

[90] Stakeholder Qualitative questionnaire feedback

A key aspect of pole-mounted transformers is that they are often used for remote rural connections. In Ireland, they are used for small villages where there is only one 50kVA, 3-phase transformer. This is enough as the grid is designed to accommodate 1.5kW per household. However, with the transition to electric vehicles and heat pumps, 6-7kW per household may soon be required. For this reason, stakeholders indicate that rural transformer capacity is typically being shifted from 50kVA to 300kVA.[91]

> Stakeholders are also invited to provide data to indicate the rate at which distribution transformers are being upsized to accommodate increased demand from electrification of heat and transport, along with other related characteristics (such as number and capacity of the new transformers; whether this means transformers are being replaced ahead of their useful lifespan; and what happens to the displaced transformers).

There are regional differences, as although the Ecodesign regulation allows for concessions for pole-mounted transformers to up to 315kVA, France has a limit of pole-mounted transformers at 160kVA and of maximum weight of 560kg. Stakeholder feedback indicates that there are no Tier 2 compliant (without concession) transformers that would meet this pole-mounted weight criteria. However, conflicting feedback also states that utilities (notably in Spain) already require Tier 2 pole-mounted transformers without the concession, implying that either Spain uses a stronger pole type, or that these more efficient and light transformers can be manufactured.

> Stakeholders are invited to provide feedback on whether the Spanish pole configurations are different than in other European countries, allowing for heavier transformers to be fitted.
>
> Otherwise, stakeholders are asked for confirmation that Tier 2 compliant pole-transformers can be created, and in which countries are these being deployed.

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.

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.[92] 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.

[91] Stakeholder meeting feedback

[92] Tier 2 Fixed loss levels on distribution and power transformers implementation, Eurelectric proposals, Oct 2017 , tier_2_fixed_loss_levels_on_distribution_and_power_transformers_implementation-2017-030-0687-01-e-h-C7672AA6.pdf (eurelectric.org)

Note: The introduction of Tier 1 efficiency under Ecodesign in 2014 is indicated to have increased the mass of transformers by 20-40% depending on the range.[93]

2.4.2.3 Concessions to medium transformers with special combinations of winding voltages

Most stakeholders strongly advocate for the retention of correction factors, emphasising their crucial role in accommodating the unique characteristics of transformers with special voltage combinations. They stress that correction factors are indispensable for specific applications, where dual-winding transformers are vital for voltage conversion, such as transitioning from 10kV to 20kV networks, or shifting from 230V to 400V using dual secondary windings. Allowing for these higher voltage operations delivers efficiency savings on the grid level. These stakeholders contend that while it is technically possible to design transformers without concessions, doing so would result in larger and heavier units.

The example of Belgium is provided, whereby two secondary voltages 230 V and 400 V are connected to appropriate loads in parallel. New networks will only be at 400 V, but it will take decades to switch all 230 V customers to 400 V. The change of network is done gradually, and the footprint of the substations is often kept fixed, meaning more efficient (and usually larger) transformers need to be fitted into the same spaces. Thus, stakeholders have indicated that without the correction factor to avoid costs of transformer efficiency and footprint concerns, new transformer installation would increase by 10-20%.[94]

Certain stakeholders advocate for the elimination of special voltage combinations in transformers, citing declining demand and the potential advantages of long-term voltage standardisation. They assert that transformers with special voltage combinations can attain equivalent efficiency levels as standard two-winding transformers from a technical perspective, therefore the regulation should not provide the concession, even if it results in higher prices due to winding complexity. It should also be noted that similar markets such as the US, do not have concessions in place for special voltage combination transformers.

Stakeholders have also indicated that there is limited presence of transformers with special voltage combinations, underscoring that applying correction factors to these transformers has minimal effects on overall loss levels. However, this may soon change as most grids are transitioning to higher voltages in order to increase system efficiency. There may therefore be more special combination windings transformers installed to accommodate for these voltage shifts.

> To further evidence the special combinations of windings, stakeholders are asked to contribute data on the market share of existing stock, sales and growth for the special combinations of windings transformers.

2.4.2.4 A technology neutral approach

Currently, liquid and dry-type transformers have separate efficiency requirements.

[93] Stakeholder feedback

[94] Stakeholder qualitative questionnaire feedback

The concept for technology neutral approach is more relevant if specifying what the transformers are being used for i.e., their functionality.

- The current regulation specifies different MEPS for 'liquid-immersed transformer' and 'dry-type transformer'. This approach was taken to avoid excessively high cost where specific performance levels- such as fire-safe behaviour and leak-proof design were required. Dry-type technology was probably the only technology available for achieving the required fire behaviour at the time when the regulatory process started[95].
- New technologies are emerging or are expected to emerge, providing the same performance that had been exclusive to one particular technology until recently. Examples include electronic power transformers and ester-insulating liquids.
- Drawing comparisons between maximum-load losses and no-load losses are provided in the below tables. It is the ratio of maximum-load losses (Table 2.12) and no-load losses (Table 2.13) allowed for dry-type transformer under Tier 1 of regulation (EU)No. 2019/1783, and those allowed for liquid-filled transformer.

Table 2.12 Ratio of Maximum load losses for dry-type transformer to liquid-filled transformer under Tier 1 of regulation (EU)No. 2019/1783

Rated Power(kVA)	Load losses (Liquid filled)	Load losses (Dry type)	% variation of load losses for dry type to liquid-filled
50	1100	1700	155%
100	1750	2050	117%
250	3250	3800	117%
400	4600	5500	120%
630	6500	7600	117%
800	8400	8000	95%
1000	10500	9000	86%
1250	11000	11000	100%
1600	14000	13000	93%
2000	18000	16000	89%
2500	22000	19000	86%
3150	27500	22000	80%

Table 2.13 Ratio of Maximum No- load losses for dry-type transformer to liquid-filled transformer under Tier 1 of regulation (EU)No. 2019/1783

Rated Power(kVA)	No-Load losses (Liquid filled)	No-Load losses (Dry type)	% variation of No-load losses for dry type to liquid-filled
50	90	200	222%
100	145	280	193%
250	300	520	173%
400	430	750	174%

[95] https://hrcak.srce.hr/file/443567

Rated Power(kVA)	No-Load losses (Liquid filled)	No-Load losses (Dry type)	% variation of No-load losses for dry type to liquid-filled
630	600	1100	183%
800	650	1300	200%
1000	770	1550	201%
1250	950	1800	189%
1600	1200	2200	183%
2000	1450	2600	179%
2500	1750	3100	177%
3150	2200	3800	173%

ISO/IEC standards formulated the performance principle: 'whenever possible, requirements shall be expressed in terms of performance rather than design or descriptive characteristics like a technology'.

In general, this technology-neutral approach should be used to balance Ecodesign requirements with other performance factors. It should be taken into account when evaluating the adequacy of all upcoming regulatory documents and technical standards. The choice of performance factors to be included would first require rigorous investigation and diligent deliberation and might include but not necessarily – fire-safe behaviour, internal arc safety, leak-proof design, and noise restriction, among others. A technology-neutral approach and harmonised test procedures facilitate technological innovation along with fair trade conditions. Well-designed regulations and standards encourage trade, the execution of conformity assessments, performance level comparisons, technology transfer, and the adoption of best practices. Governments, as much as manufacturers, stand to gain from neutral, harmonised, consistent, and stable standards.

Benefits to governments include:

- The ability to incorporate innovative technical solutions;
- Reducing the number of exceptions in regulations;
- The ability to adopt a common set of upper thresholds that can be used for market pull programmes, such as labelling and incentive schemes; and
- Faster and less costly testing – for compliance and other purposes — since harmonised testing leads to a wider range of laboratories able to conduct product testing.

For manufacturers, having one harmonised test method with specified measurement uncertainties used by markets around the world will reduce testing costs associated with demonstrating regulatory or product labelling compliance. In an ideal world, every manufacturer would always conduct exactly the same tests in exactly the same way, and the results would be universally accepted as being accurate and representative of the performance of their product. A harmonised test method also means they can look forward to long-term rewards for innovative product designs.

There are few possible technology neutral scheme[96] as shown in Table 2.14.

[96] https://hrcak.srce.hr/file/443567

Table 2.14 Possible technology neutral scheme

Requisite	MEPS	Applicable technologies
No particular requirement	Level 1	Liquid-filled, dry-type, and other emerging technologies
Fire performance without the presence of people	Level 2	Dry-type and other emerging technologies
Fire performance/explosion proof (involving the presence of people)	Level 3	Dry-type, other emerging technologies
No environmental damage in case of leakage	Level 4	Ester-filled, dry-type, and other emerging technologies
Low noise	Level 5	Oil-filled, ester-filled, dry-type, and other emerging technologies
…	…	…

Stakeholder feedback summary:

Some of the stakeholders are of the opinion that technology neutral approach won't be appropriate as these are different technologies and have different standards for each technology and also applications. Requiring dry type transformers to have same energy efficiency requirement as liquid immersed would result in increase in weight, cost and volume.

Also, fire resistance characteristic is also critical when selecting and transformer and its application. Different technologies have different applications, and each has its own advantages and disadvantages.

Box 2.6 Direct Stakeholder quote from qualitative questionnaire

Our experience as DSO shows that the fire resistance characteristics of dry-type transformers are not matched by latest oil-type transformers with improved resistance characteristics (flash point). Moreover, French regulation for high-rise buildings imposes dry type technology, with no exemption.

Some of the stakeholders submitted that the technology neutral approach is appropriate, and transformer should be selected based on functionality rather than technology as certain functionality can be provided by different technologies.

Regarding electronic transformers, some stakeholders submitted that the technology of electronic transformers is not mature enough at this point.

Stakeholders are invited to provide feedback on the functionalities which dry and liquid type transformers exclusively provide. What are the standards which define these functionalities? Are there functionalities where either of them can be used and what would be the effect on energy performance in cases where either of the two technologies can be used?

2.4.2.5 Functional categorisation

Current categorisation of transformers in the Ecodesign regulation is done for the size of the transformer (load rating and voltage), dry-type versus oil-immersed, and single versus 3-phase systems.

Nearly all of the stakeholders consulted agree with this approach, as these are based on physical characteristics of the transformers and additional categorisation may lead to confusion within the regulation. There are concerns that adding new categories might lead to a long list of exemptions, potentially undermining the main scope of the regulation. Some stakeholders advocate to look at technology-neutral requirements rather than introducing additional functional categories. Therefore, the recommendation would be for the Ecodesign regulation not to make functional categories, beyond those existing and those covered under the IEC 60076 standard.

Some stakeholders did suggest potential transformer categorisation based on function or applicability. These are listed here:

- **Overload Transformers**: designed for applications where they may be subjected to overload conditions, such as temporary high loads. This would allow for specific requirements tailored to transformers used in overload scenarios, optimising performance and safety. Overload capabilities are already defined under IEC 60076-7.
- **Ultrahigh Voltage Transformers:** designed for extremely high voltage applications, typically exceeding 800 kV, which are relatively rare but may have distinct requirements. This can accommodate for ultrahigh voltage transformers used in specialised applications. UHV transformers allow the efficient transmission of large amounts of electricity over long distances. The higher voltage levels enable a lower transmission loss over longer distances[97]. It is especially useful for transmitting renewable electricity to large cities situated far from the source (such as a hydroelectric dam or solar farm). However, it is noted that these are covered under the PEI rules from the large transformers in Ecodesign, which are straightforward to meet at such voltages. There therefore is no need for this categorisation.
- **Fire Performant Transformers:** designed with enhanced fire safety features, particularly applicable to dry-type transformers. Fire performant transformers are defined by standard EN 60076-11 and are dedicated to dry type transformers, because other transformers cannot reach the required level of fire safety. Therefore, although there is a legitimate case to distinguish fire performant transformers, it seems these are already covered under the IEC standards and Ecodesign.
- **Transformers for Renewable Energy Applications:** specifically designed for use in renewable energy systems, such as wind turbines and photovoltaic plants. These could address the unique characteristics and requirements of transformers in renewable energy applications, promoting efficiency and reliability. However, providing special criteria to this category would prove difficult to differentiate with other generator capabilities, and hence difficult to monitor their end use is as intended.
- **Transformers for Rectifier Applications:** designed for use with rectifiers to provide a DC power supply. This category seems difficult to define as the

[97] http://www.chinatoday.com.cn/ctenglish/2018/ln/202102/t20210226_800237464.html

distinction for them is their pairing with a rectifier, which is outside of the scope of Ecodesign.

- **Generators Excitation Transformers:** designed for excitation systems for large rotating machines, to help them meet appropriate performance standards. A definition for this type of transformer could not be identified, making their categorisation difficult.
- **Bank of Single-Phase Transformers:** configured as a bank of single-phase units, as opposed to traditional three-phase transformers. This could be for two or three, single-phase transformers are interconnected via a Delta or Star connection. This configuration can be useful instead of using a three-phase transformer, where there are size or weight constraints, allowing for three separate transformers to be transported independently rather than one large three-phase transformer.
- **Auxiliaries' Transformers for Nuclear Safety Applications:** used as auxiliaries in nuclear safety systems, requiring specific safety and performance criteria.
- **Fault Current Limiting Transformers:** designed for the purpose of limiting fault currents in electrical systems, which are typically used to improve safety and reliability of power distribution. It should be noted that transformers are often used for this application, it would therefore be difficult to identify designs specifically for this usage only.
- **Step-up Power Transformers for Electricity Production/Generation:** specifically used for stepping up voltage in electricity production or generation applications, often found in power plants to enhance efficiency of electricity transmission. As this is one of the typical transformer applications, this functional categorisation seems redundant. There are already concessions set for transformers with special windings configurations.
- **Transformers for Railway Feeding Systems:** designed for use in railway power supply systems.
- **Earthing or Grounding Transformers**: designed for earthing or grounding applications, often used to ensure electrical safety.
- **Transformers Specifically Designed for Explosion-Proof and Underground Mining Applications:** designed for use in hazardous or underground mining environments. These could warrant review but under the needs for safety, which would require additional protections to the transformer system. However, stakeholders would need to specify why this additional protection would change the internal mechanism of inside transformers.
- **Transformers Specifically Designed for Deep-Water (Submerged) Applications:** used in submerged or underwater applications. These may warrant review but under the needs for safety and isolation from the water. However, stakeholders would need to specify why this additional protection would change the internal mechanism of inside transformers.
- **Medium Voltage (MV) to Medium Voltage (MV) Interface Transformers up to 5 MVA:** designed for medium voltage interface applications with a capacity of up to 5 MVA. As the Ecodesign regulation currently has an allowance for special combination windings of up to 3.1MVA, this is categorization suggestion would need to review if this allowance should be brought up to higher rated power transformers.

2.4.3 Recommendations

2.4.3.1 Offshore wind exemption

As offshore transformers represent a non-negligible share of the market and is set to continue to occupy a strong share of sales with more offshore wind installations, it is recommended to bring these back into the scope of the Ecodesign regulation. This is corroborated by the fact that for the transformers used within the nacelle, 3-20 MVA, they have the same space and weight constraints within the nacelle as onshore wind turbines of comparable capacity, which are not exempt. For larger transformers used of 200 – 500 MVA used in collector stations, the disproportionate costs mechanism could be used in case the platform reinforcement needs are too high.

More data is being sought out from stakeholders to clarify the concerns above.

2.4.3.2 Pole-mounted transformer concessions

As the pole-mounted transformers make up a significant part of the distribution market, it would be inappropriate to maintain a permanent concession which may result in a loophole for users. Instead, it is recommended that the disproportionate costs approach is used to consider exemptions, as is the case for Tier 2 concessions.

Phase 2 activity will focus on engaging with MSAs to ensure the mechanism of disproportionate costs is clear for all stakeholders.

2.4.3.3 Concessions to medium transformers with special combinations of winding voltages

To consider action on this concession, the research team must verify some of the stakeholder claims, such as to estimate the energy benefits of switching from 10kV to 20kV network in dual wound transformers, compared to the efficiency losses the concession provides. The team should also investigate and quantify the market share of transformers for which meets the concession.

From these results in the Phase 2 activity, the research team can consider the possibility of removing the concession for special combinations of winding voltages or placing a requirement to provide evidence for disproportionate costs, as is done for the Tier 1 to Tier 2 concession.

2.4.3.4 A technology neutral approach

A completely homogeneous approach to transformer regulation may be problematic as there is a need to differentiate technologies such as dry type and liquid immersed, in order to allow properties such as fire safe and leak-proof devices to be on the market. However, these properties should not be defined by the regulation to products of a particular type, but rather those who can meet the final property. Therefore, requirements for fire safe transformers could be set in a technology neutral fashion, whilst the fire safety property is preserved.

From an Ecodesign perspective, it is recommended not to change performance requirement levels, but rename categories for dry type and liquid immersed to align with properties of fire safe or not fire safe. This will allow for new technologies capable of meeting the standard to enter the market. This alignment should be done in line with relevant EN standards.

2.4.3.5 Functional categorisation

As there is little appetite from stakeholders, no technical reason and no definition in the IEC 60076 standard to introduce new functional categories of transformers, it is recommended not to investigate this concern further. The issue should be reviewed if, and when, IEC 60076 introduce new categorisations.

2.5 Material Efficiency

i) material efficiency aspects;
m) strengthening potential of the existing MEPS and the potential of introducing material efficiency requirements (MMPS).

2.5.1 Background

Material efficiency goals are broadly set in measures to minimise our usage of materials in products. This can be done with various methods, such as by increasing product lifetime, tracking materials of particular environmental concerns, improving recuperation and reuse of devices/parts, increasing recycling of materials. Reducing the usage of materials has beneficial effects to reduce the emissions, energy consumption, biodiversity loss and pollution that may be associated with their manufacture.

The transformers Ecodesign regulation 548/2014, only had one mention of material efficiency, which was for product information to be provided regarding the weight of all the main components of a power transformer (including at least the conductor, the nature of the conductor and the core material).

The Ecodesign regulation 2019/1783 also included a mention with regards to repair of transformers, included Article 1.3 stating:

Medium and large power transformers, regardless of when they were first placed on the market or put into service, shall be reassessed for conformity and comply with this Regulation, if they are subject to all of the following operations:

(a) replacement of the core or part thereof;

(b) replacement of one or more of the complete windings.

This is without prejudice to the legal obligations under other Union's harmonisation legislation that these products could be subject to.

However, this statement is not intended to ensure improved material efficiency, but rather to close a loophole such that repaired transformers will still meet the Ecodesign regulation.

With other technologies, the Ecodesign framework directive has been used to boost circular economy and recent Ecodesign regulations, published (e.g., smart phones) or in development. Notably measures adopted have been the requirement for providing spare parts, information provision on material content and disassembly requirements. We shall investigate these options below.

2.5.2 Feedback/ Research results

2.5.2.1 Increasing product lifetime

Before discussing how to increase the product lifetime, it is good to understand current transformer lifetime. These are currently estimated at 180,000 hours when operating at rated temperature, mean full load and yearly average temperature. This is equivalent to approximately 20 years. These transformers are on average operating at 30 to 60% load range, so their lifetime should be higher.[98] This results

[98] Stakeholder feedback

in the typical life expectancy of medium transformers to be 40 years, 30 years for large transformers and 10 to 20 for small transformers.[99]

Typically, the damages which reduce the lifetime of a transformer are linked to damages to the materials in the windings, core or insulation. Damage, or stress, can be caused through mechanical, temperature or electrical nature. Most of the failure origins are accessories, like bushing, tap changer, and leakages. The following are the factors which may negatively affect the life expectancy of transformers:

- **Overloading** the transformer, making it operate at load levels above its rated capacity, leading to excessive heat generation and insulation deterioration.
- **Environmental factors** such as high humidity, extreme temperatures, or corrosive substances which will deteriorate materials, like the core, windings and insulation (paper or oil).
- **Electrical disturbances** such as voltage surges, load cycling, partial discharges, short circuits, transients, and electrical faults, which can deteriorate materials (notably insulation), cause mechanical stress on the transformers and damage to windings and core.
- **Oil maintenance** through contaminated oil can be more susceptible to breakdown or insufficient oil levels which would result in inadequate cooling.
- **Inadequate cooling systems** can lead to overheating and the deterioration of materials.

To increase the lifetime of transformers, the following can be considered:

- Increasing the efficiency of transformers will mean that more electrical energy is transferred, and hence not converted to heat or mechanical stress within the device. It is noted however that higher efficiency likely uses more materials in the transformer itself.
- Improved insulation systems can be used which can withstand stress better. These include high-performance liquids, thermally upgraded paper.
- Improving the assembly of the coils, for them to be supported with appropriate wood cheeks (rather than simply using strapping) and for appropriate wedges to be used between the coils. These measures will ensure the integrity of the coils to withstand electrical shocks and mechanical resistance during transport.
- Increasing the rate of retrofitting and repairs can expand the average lifespan. This can be done by recuperating key components such as the tanks and magnetic core and regenerating the transformer oil. Stakeholders indicate that up to 90% of a medium liquid immersed transformer can be recuperated (tank, magnetic ore and regenerating the oil). This is equivalent to 2896 kg of CO2 emissions, the same as the savings obtained from Tier 1 to Tier 2.[100]
- Designing transformers to operate at lower temperatures will increase their life expectancy.
- Digital monitoring solutions are proposed to control temperature hotspots, allowing for better modelling and control of the insulation lifetime. This would improve maintenance activities to happen before any damage occurs to the transformer.

[99] Lot 2 preparatory study: distribution and power transformers, 2011.

[100] Stakeholder feedback

Stakeholders are asked to provide feedback on any standards with regards to the assembly of transformer coils, along with their protection providing the integrity of the coils to withstand electrical shocks and mechanical resistance. To further evidence the offshore transformers, stakeholders are asked to contribute data on the market share offshore transformers represent, their rated powers and the increased cost, space and weight required to shift from Tier 1 to Tier 2 transformers. Please be sure to distinguish transformers used in Offshore wind nacelles (compared to onshore), and those used in collector stations.

Furthermore, please clarify what are the special protections required for marine environment operation, if any.

2.5.2.2 Improved repair

If a transformer fails, it is likely to be a concern with the windings, rather than the core. Therefore, a repair is likely to be requiring a rewinding of the copper windings. However, there is a risk that this repair may result in improper matching, which would mean an inefficient running transformer.

Some suggestions to improve the repair rate are to have measures to:

- Ensure that repair staff have access to technical documentation which would include instructions how to disassemble the transformers and provide a winding plan.
- Design transformers such that they can be disassembled without destruction.
- Ensure that the disassembly can be done be professional repairers with standard repair tools.

Another suggestion was to ensure that transformer manufacturers would have spare parts available for repairs. However, as transformers have lifespans of 20 to 40 years, with some even reaching 60 years, having spare parts available for manufacturers can be difficult as it would require foresight for decades.

2.5.2.3 Repair requirements under article 1.3

A key concern raised by stakeholders is the article 1.3 of the Ecodesign regulation 2019/1783, which states:

Medium and large power transformers, regardless of when they were first placed on the market or put into service, shall be reassessed for conformity and comply with this Regulation, if they are subject to all of the following operations:

(c) replacement of the core or part thereof;

(d) replacement of one or more of the complete windings.

This is without prejudice to the legal obligations under other Union's harmonisation legislation that these products could be subject to.

There is a concern that it is unclear who the responsibility of making these reassessments would fall to. For example, repairers (especially if they are on site), may not be capable of testing energy efficiency for conformity. It is also important to ensure that product information is maintained such that records are available regarding who was the original equipment manufacturer, and who was the repairer, along with the performance records for each.

Furthermore, if an old transformer is being repaired, it is difficult for the repair team to upgrade the transformer from Tier 1 to Tier 2. This could be mitigated by requiring that the repair bring performance to the original Tier level, with a minimum to meet Tier 1 performance. This would ensure that repair does not provide a loophole for less efficient transformers to be on the market, ensures that poorly performing products are removed from the market, and that the repair team are not required to upgrade performance of transformers beyond their means.

In the US, the transformer needs to be upgraded to the latest efficiency requirements if it re-enters the market. With that in mind, if a utility is able to be repair a transformer themselves, then the repaired transformer is not required to meet a performance standard. However, if the transformer ownership changes hands (such as to a repair firm), then, after repair, the product would re-enter the market and would need to meet the regulation efficiency standards.

Stakeholders are invited to provide feedback on the typical repair concerns under article 1.3. How are these repairs tracked? Who would deliver these? Can these repairs be made to repair transformers to their original performance levels? What are the testing requirements to be able to verify new efficiency performance standards?

2.5.2.4 Materials with environmental impacts

The materials of concern for transformers, with regards to their potential impacts on the environment are the insulation materials, specific oils and cast resin products.

The first and most prevalent is with regards to the insulating oil. These are mainly mineral oils which can contaminate the local environment if there is a leak. These require to be bunded around the transformer to ensure any leaks do not go into the environment. This mineral oil can be cleaned and regenerated to be reused in the transformer. IEC 60296 catalogues recycled oils as equivalent to virgin oils.

Certain oils, such as PCBs (Polychlorinated Biphenyls), pose a health risk due to their toxic and bio-accumulative properties. PCBs were used as a dielectric filler liquid in transformers but have been very heavily regulated in Europe since 1985.[101] In 1996, the disposal of these products was regulated under Directive 96/59/EC.[102] These have now been included within the Persistent Organic Pollutants (POPs) regulation of 2019. These are relevant, as although these chemicals have not been used in manufacture for a long time, the high lifespan of transformers means that there are still some products is use with them inside.

Other non-mineral oils are suggested which are less flammable, such as silicone, synthetic ester or natural ester (FR3). Ester is a biodegradable oil, which is more expensive but has a lower environmental risk if a leak were to occur.

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[101] https://environment.ec.europa.eu/topics/waste-and-recycling/pcbspcts_en

[102] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A31996L0059

Other insulating materials such as cellulosic (paper/cardboard) or synthetics (plastics/rubber) are of concern as these are difficult to reuse or recycle. One example is cast resin, composed of quartz flour and epoxy resin. It has strong insulating properties but cannot be easily recycled or separated from transformer coils. Their difficulty to recycle is because they are moulded within the windings. This separation is not economically viable within the EU.

Most of these products of concern are regulated by the European Chemicals Agency (ECHA) through the REACH or RoHS directives. The SCIP provides a database with information on these substances of concern. France also has an example of Extended Producer Responsibility for mineral oils.

2.5.2.5 Recycling

Transformers are made of materials which are largely recyclable or reusable. The main components are the magnetic core, the windings, the enclosure and the insulation materials. The magnetic core is typically iron, amorphous metals or ferrite ceramics, which can be recovered, and typically is downcycled as the recycling process may remove the magnetic properties. The windings are either aluminium or copper, which are recovered and both highly recycled. The enclosure is typically made of iron or steel and is similarly recycled. The insulating material is where there is difficulty, as for liquid immersed transformers, the oils can be recuperated and regenerated for reuse. However, solid insulator like epoxy resin, paper, wood and pressboard are not recycled. Windings covered in epoxy resin may also not be recycled due to the difficulty to separate the materials.

For liquid immersed transformers, the ratio of materials is typically in the range of 40-50% for the magnetic steel core, 12-18% structural steel, 12-22% aluminium or copper windings, 16-25% dielectric fluid.[103] The composition for dry type transformers is similar, only that the epoxy resin is lighter than the dielectric fluid and hence can be as little as 8% of the total mass.

The core which is made of steel is the most valuable aspect in large transformers. It is also difficult to reuse in other products, and hence is often downcycled. The copper/aluminium windings can easily be recovered and used elsewhere. Common practice is to recover the windings and send the core steel overseas.

2.5.3 Recommendations

To improve material efficiency of transformers, we recommend first to discuss with CENELEC if a standard exists, or can be developed, to improve for transformers the insulation materials, assembly of the coils with wood cheeks and wedges for electrical and mechanical safety.

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). A review is required to ensure that this can also be done for epoxy resin transformers, allowing for disassembly and easy separation for recycling purposes. Technical documents with instructions for disassembly and the winding

[103] Stakeholder feedback

plans shall be made available to registered repair staff to ensure products can be adequately repaired.

Under Phase 2, a review of the implementation of article 1.3 is required to determine common practice and responsibilities of the process. Furthermore, the team would review the efficacity and Total Cost of Ownership measures such that:

- Assessment is done by repairers, only if the repair is done ex-situ (and ensure appropriate information tracking).
- Make the efficiency requirement meet the original equipment performance, or Tier 1 (whichever is higher).

To improve sustainability of the mineral oil, the research team recommend reviewing if the recovery and regeneration of oil can be encouraged.

2.6 Environmental considerations

h) the possibility and appropriateness of covering environmental impacts other than energy in the use phase, such as noise and material efficiency.
k) technological, market and regulatory evolutions affecting environmental performance;

2.6.1 Background

The Ecodesign regulation 2019/1783 currently has no requirements with regards to environmental impacts such as noise.

The EU does have the Directive 2000/14/EC on 'noise emission in the environment by equipment for use outdoors', however transformers are out of scope.

2.6.2 Feedback/ Research results

2.6.2.1 Noise considerations

Although Ecodesign does not directly have measures on the noise of transformers, there are indications that the efficiency requirements of Ecodesign have had a consequence of reducing noise levels. Indeed, as transformers become more efficient, the designs will minimise the magnetostriction within the core, which in turn minimises the vibrations of the core (and hence the noise). Furthermore, the reduced losses means that less resistive heat is emitted by the transformer. There will therefore be less of a need for cooling and ventilation systems.

Another method to reduce noise levels is to include a sound barrier around the transformer itself to attenuate the sound propagation.

Stakeholders have pointed out that there are local regulations around noise, such as in Germany, France and Belgium. Some of these are national, but also some are applied within urban areas to reduce noise levels, defined by local authorities.

Stakeholders have also indicated that noise testing would provide an additional charge for testing at certified laboratories.

2.6.2.2 Oil considerations

A key environmental concern for transformers is to ensure that there are no oil leaks into the environment. For this reason, transformers with oil are bunded, such that if there is ever a leak, the oil is captured within the transformer enclosure, and does not spread to the local environment. This is done for all oil transformers, though it should be noted that the environmental risk is lower for biodegradable oils.

2.6.2.3 Temperature and climate considerations

With regards to temperature operation of transformers, IEC 60076-1 already states operating ranges for transformers. For dry-type transformer, IEC 60076-11 defines climate classes, covering transformer storage down to -60ºC and transformer energization down to -50ºC. Furthermore, the PEI methodology for large power transformers also considers the cooling systems operation within the test procedure.

The considerations of climate change mean that transformers will need to operate at more extreme temperatures, for sudden cold snaps, respond to heat waves and periodic overheating. For higher temperatures will cause a challenge to transformers as it will affect the capacity and life expectancy of devices.

In colder climates, climate change will heighten the risk of ice storms, resulting in adverse effects such as gasket damage, hastened aging of sealing systems, and complications for various insulating fluids. These issues are particularly concerning in instances where the insulating fluids have higher pour points, denoting the lowest temperature at which they remain in a liquid state. For instance, natural esters remain fluid at temperatures as low as -10°C, whereas synthetic esters can withstand temperatures as frigid as -45°C, and mineral oil maintains its liquid form down to -40°C. Furthermore, in dry-type transformers subjected to low temperatures, the potential for the development of cracks in the windings becomes a prominent concern.

Mandating temperature operating ranges for transformers may be counterproductive as it may go against the exiting standards and would not allow utilities the flexibility to adapt to changing climate conditions. However, Ecodesign currently does not set any information requirement on temperature. Setting a requirement to provide information such as operating and storage temperature ranges for transformers, would allow for utilities to adequately track and plan their inventory of transformers in line with current and expected weather conditions.

2.6.3 Recommendations

With regard to noise, it seems that the increase in efficiency from Ecodesign is already having an effect on reducing the noise of transformers. Furthermore, there are separate regulations from national and local governments which provide a maximum noise requirement. It is therefore recommended not to include this metric within Ecodesign.

With regards to climate adaptation, we recommend including within the transformer’s information provision requirement, the operating and storage temperature range of the transformer.

2.7 Other topics

s) other topics, as emerged from consultations with stakeholders.

2.7.1 Ecodesign Considerations for the use of SF6 in Gas-Insulated Transformers

2.7.1.1 Background

SF6 (Sulphur Hexafluoride) is a potent greenhouse gas, with a GWP_{100} of 23,500 (i.e., the release of 1 kg of SF6 has equivalent warming impact over 100 years to releasing 23,500 kg of CO_2). The reduction in emissions of SF6 from equipment either through venting or leaking is a key net-zero consideration for policy makers.

In electrical power equipment, SF6 has been widely used in high voltage switchgear, owing to its chemical stability, arc quenching properties and fire resistance. In transformers it is only applicable in gas-insulated transformers.

2.7.1.2 Feedback/ Research results

***Prevalence of SF6 Gas-Filled** Transformers*

Gas-Filled (or Gas Insulated) transformers are seldom in use within Europe:

- In the 2011 pre-study it was noted by the stakeholders ORGALIME there were less than 100 large gas-filled transformers across the EU [104].
- In responses to the qualitative questionnaire distributed in 2023, multiple stakeholders noted that gas-filled transformers are seldom used except in rare exceptions, with one noting they had never seen one, and that 'they do not exist in Europe', and that 'except Japan, nobody else uses SF6 transformers.
- It was also noted by a stakeholder in the 2023 questionnaire responses that liquid immersed and dry-type transformers can fulfil all existing technical requirements without the need for SF6.

Given the qualitative evidence provided by a range of stakeholders, which remains stable between the 2011 to 2023 period, it can be broadly concluded that the prevalence of SF6 gas-filled transformers is low and is likely to remain low.

Applicability of F-Gas Regulations

The F-Gas Regulations[105] (Regulation 517/2014) place controls on switchgear that utilise fluorinated greenhouse gases (F-Gasses, which includes SF6), depending on the amount of F-Gas such as:

- Prohibiting the intentional release (where not technically necessary)
- Requiring leak tests (unless tested to have a rate of <0.1%/year and has monitoring devices or less than 6kg of F-Gas).

[104] 2011 Transformers Preparatory Table p39

[105] REGULATION (EU) No 517/2014 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL, of 16 April 2014, on fluorinated greenhouse gases and repealing Regulation (EC) No 842/2006

- Monitoring and record keeping, including the quantities of F-Gas installed, added and recovered through equipment life.
- Ensure F-Gases are recovered from equipment.
- Labelling of F-Gas containing equipment.

An update to the F-Gas regulation has been proposed[106,107,] which will prohibit the placing on the market of switchgear containing gases with a GWP of 10 or more (from 2026 onwards, depending on the rated size) unless evidence is provided that no suitable alternative is available based on technical grounds within the lower GWP ranges referred to above.

Switchgear is defined under these regulations as:

'*electrical switchgear' means switching devices and their combination with associated control, measuring, protective and regulating equipment, and assemblies of such devices and equipment with associated interconnections, accessories, enclosures and supporting structures, intended for usage in connection with the generation, transmission, distribution and conversion of electric energy".*

Given power system transformers are not generally considered as switchgear, this definition suggests that transformers are not within the scope of the updated F-Gas Regulations, therefore the consideration under Ecodesign requirements would not be an overlap of regulation with respect to the specific prohibitions on placing on the market of equipment.

The F-Gas regulations do however put in place constraints on the overall quantity of Hydrofluorocarbons (HFCs) that can be placed on the EU Market, which by default would reduce the availability of SF6 containing transformers.

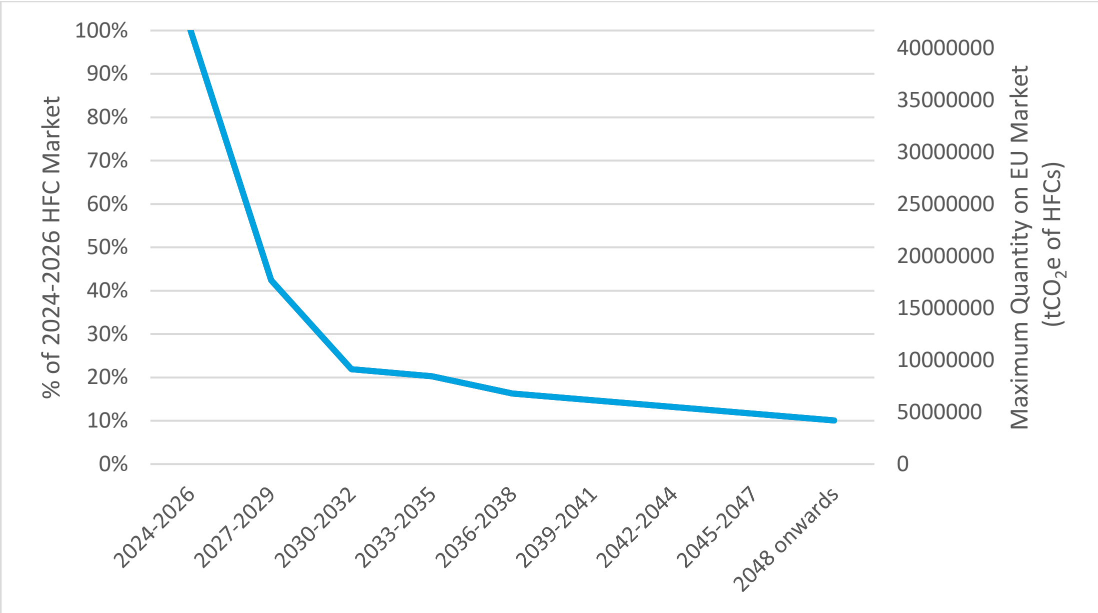
Figure 2.8 below replicates the limits on the complete HFC market in the EU (not product specific) defined in Annex VII of the proposed regulations, showing the maximum quantity of HFCs (in tonnes of CO2e equivalent) that can be placed on the EU Market across different time period on the right-hand axis, and the percentage reduction in market size relative to the first 2024-2026 period on the left-hand axis. The regulation requires that by 2030-2032 the maximum quantity on the market will be 20% of that in 2024-2026[108].

[106] Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on fluorinated greenhouse gases, amending Directive (EU) 2019/1937 and repealing Regulation (EU) No 517/2014

[107] ANNEXES to the Proposal for a Regulation of the European Parliament and of the Council on fluorinated greenhouse gases, amending Directive (EU) 2019/1937 and repealing Regulation (EU) No 517/2014

[108] ANNEXES to the Proposal for a Regulation of the European Parliament and of the Council on fluorinated greenhouse gases, amending Directive (EU) 2019/1937 and repealing Regulation (EU) No 517/2014

Figure 2.8 Curve of allowable KFCs on EU market till 2050 according to the proposal on fluorinated Greenhouse gases



2.7.1.3 Recommendations

Given the stakeholder feedback outlines that there is a very low prevalence of gas-filled transformers utilising SF6 in use or on the market within the EU, and that there is 'by default' a phasing out of the use of SF6 within the EU market, there would be limited benefit to regulating the use of SF6 specifically within the Ecodesign regulation.

2.7.2 Methodology concerns to determine kPEI under different cooling conditions

2.7.2.1 Background

A concern was raised to CENELEC with regards to the determination of the kPEI. The standard EN50708-1-1 sets out determining the kPEI as being for the "optimum value", which is where the efficiency curve would be highest. Unfortunately, this does not account for the cooling of the transformer, which would activate at different load values, requiring power and hence making the curve discontinuous. This results in multiple values of PEI depending on the load when there are different stage/modes of the cooling system being activated.

2.7.2.2 Feedback/ Research results

Figure 2.9 shows a graph which represents the concern of whether the kPEI is being set at the right location under the methodology. In the example, if the transformer is operated without considering the cooling capacity, then the kPEI would be set at approximately 0.5 load factor on the continuous curve. However, when considering the cooling contributions, the curve is discontinuous, and the optimum PEI would be found for a kPEI approximately at 0.4, which does not represent a real-world consideration.

Figure 2.9 Illustration of kPEI variation dependent on cooling contributions - Extract of EN50708-3-1 clause A2.3

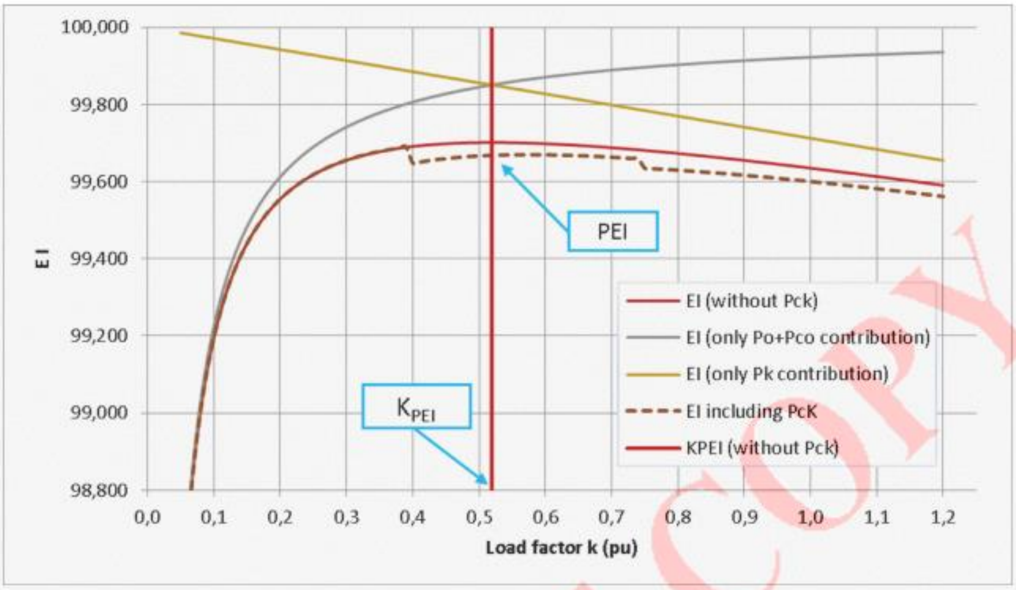


Figure A.2 — Graph illustrating relationship between efficiency index and load factor

Under the current constraints of arranging for an update for the standard. Proposals have been set including for the standard could be reviewed to measure only the PEI when cooling is not included, to leave the method as is, or to determine the kPEI when all cooling is included. A resolution has not yet been found to this concern. Therefore, the kPEI is currently calculated at the most efficient point on the discontinuous curve.

2.7.2.3 Recommendation

The methodology is currently functional, but imperfect at delivering the best energy efficiency savings. The standard bodies have yet to resolve this concern. It is recommended for the Ecodesign regulatory body to be aware of this concern as the efficiency standards are set, but not to try to set the methodology instead of the standard bodies.

2.7.3 "Sustainable Peak Load" as substitute to rated power

2.7.3.1 Background

Currently the rated power of a transformer is used to determine what is the maximum load that should be set through it. This power rating is measured for a given temperature which is set in the testing standards under the use of mineral oil and paper insulators.

2.7.3.2 Feedback/ Research results

Stakeholders have indicated that the rated power methodology of transformers may no longer be appropriate. This is because there are now new insulation materials that can operate at higher temperature than what is required in the testing standard. With this in mind, some transformers are capable of operating at higher load ratings that their rated power (or in overload), without suffering thermal damages. For this reason, a new rated power metric decried as “sustainable peak load”, may be developed to appropriate describe what can be used safely in the grid.

There is currently no definition set out by any standard for “sustainable peak load”.

2.7.3.3 Recommendation

Although there is a need for such a new power rating to be developed, this metric is still in its infancy, with no standard in place. Therefore, it is recommended for the next review of the Ecodesign regulation on transformers to consider the implementation of sustainable peak load as a power rating tool, once the standard is in place.