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

Final Report

Multiple FWC with reopening of competition in the field of Sustainable Industrial Policy and Construction – Lot 2: Sustainable product policy, ecodesign and beyond (No 409/PP/2014/FC Lot 2)

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LIST OF ABBREVIATIONS AND ACRONYMS

AC	Alternating Current
AF	(Transformer) Availability Factor
AISI	American Iron and Steel Institute
Al	Aluminium
AM	Amorphous Metal
AMDT	Amorphous Metal Distribution Transformer
AMT	Amorphous Metal Transformer
AP	Acidification Potential
avg	average
BAT	Best Available Technology
BAU	Business As Usual
BEE	Bureau of Energy Efficiency
BNAT	Best Not yet Available Technology
BOM	Bill of Materials
CEN	European Committee for Normalisation
CENELEC	European Committee for Electro technical Standardization
CGO	Cold rolled Grain-Oriented Steel
CSA	conductor cross-sectional area
Cu	Copper
Cu-ETP	Electrolytic Tough Pitch Copper
DAO	Distribution Asset Owner
DER	Distributed Energy Resources
DETC	De-energised tap changer
DHP	Dry High Power
DLP	Dry Low Power
DOE	US Department of Energy
DSO	Distribution System Operators
EC	European Commission
EI	Efficiency Index
ELF	Extremely Low frequency
EMC	Electro Magnetic Compatibility
EMF	Electromagnetic fields
EN	European Norm
ENTSOE	Union for the Coordination of the Transmission of Electricity
EoL	End-of-Life
EP	Eutrophication Potential
ERP	Energy Related Products
ErP	Energy-related Products
ETSI	European Telecommunications Standards Institute
EU	European Union
EU	European Union
EuP	Energy using Products
EuP	Energy-using Products
G	Giga, 10^9
GOES	Grain Oriented Electrical Steel
GSU	Generator Step Up (transformer)
GWP	Global Warming Potential
HD	Harmonization Document
HGO	High-permeability steel
HGO-DR	Domain Refined High-permeability steel
HiB	High-permeability steel

HiB-DR	Domain Refined High-permeability steel
HM	Heavy Metals
HTS	high-temperature superconducting
HV	High Voltage
HVDC	High Voltage DC
Hz	Hertz
IEC	The International Electro technical Commission
IEE	Intelligent Energy Europe
IEEA	Intelligent Energy Executive Agency
IEEE	Institute of Electrical and Electronics Engineers
IP	Isolation Protection
JRC	Joint Research Centre
k	Kilo, 10^3 (before a unit e.g. Watt)
k	load factor
k_{eq}	Equivalent load factor
k_{PEI}	load factor of Peak Efficiency Index
Kf	Load form factor
kPEI	load factor of Peak Efficiency Index
LCA	Life Cycle Assessment
LCC	Life Cycle Cost
LHP	Liquid High Power
LLP	Liquid Low Power
LMHP	Liquid Medium High Power
LMLP	Liquid Medium Low Power
LV	Low Voltage
LVD	Low Voltage Directive
M	Mega, 106
MEErP	Methodology for Ecodesign of Energy-related Products
MEEuP	Methodology for the Eco-design of Energy using Products
MEPS	Minimum Energy Performance Standard
MS	Member States
MV	Medium Voltage
NEEAP	National Energy Efficiency Action Plan
OFAF	Oil Forced Air Forced
OFAN	Oil Forced Air Natural
OFWF	Oil Forced Water Forces
OLTC	On load tap changer
ONAF	Oil Natural Air Forced
ONAN	Oil Natural Air Natural
P	Peta, 10^{15}
PAH	Polycyclic Aromatic Hydrocarbons
PAHs	Polycyclic Aromatic Hydrocarbons
Paux	Auxiliary losses
PCB	Polychlorinated Biphenyl
PEI	Peak Efficiency Index
PF	Power factor
Pk	Load losses
PM	Particulate Matter
P0	No load losses
POP	Persistent Organic Pollutants
PRODCOM	PRODuction COMmunautaire
PWB	Printed Wiring Board
RECS	Renewable Energy Certificate System
RES	Renewable Energy Sources
rms	root mean square

RoHS	Restriction of the use of certain Hazardous Substances in electrical and electronic equipment
S	(transformer) apparent power
Sr	Rated power of the transformer
SEEDT	Strategy for development and diffusion of Energy Efficient Distribution Transformers
SELV	Safe Extra Low Voltage
SF	Simultaneity Factor
Si	Silicon
SME	Small & medium-sized enterprise
T	Tera, 10^{12}
TAO	Transmission Asset Owners
TBC	To Be Confirmed (should appear in the draft version only)
TBD	To Be Defined (should appear in draft versions only)
TC	Technical Committee
TCO	Total Cost of Ownership
TOC	Total Operational Cost
TLF	Transformer Load Factor
T&D EU	European Association of the Electricity Transmission and Distribution Equipment and Services Industry
TR	Technical Report
TSO	Transmission System Operators
TWh	TeraWatt hours
V	Volt
VA	Volt-Ampere
VITO	Flemish Institute for Technological Research
VOC	Volatile Organic Compounds
WACC	Weighted Average Cost Of Capital
WEEE	Waste Electrical and Electronic Equipment
Z	Short-circuit impedance

Executive summary

This study presents a review of Commission Regulation 548/2014 "On Ecodesign Requirements For Small, Medium And Large Power Transformers". It builds upon earlier work in the 2011 Lot 2 study and the 2014 Impact Assessment that were used to inform the design of the regulation and seeks to complement them with more recent information. The objectives of the study address the requirements in Article 7 of Regulation 548/2014 for which it is required to review:

- the possibility to set out minimum values of the Peak Efficiency Index for all medium power transformers, including those with a rated power below 3 150 kVA
- the possibility to separate the losses associated with the core of the transformer from those associated with other components performing voltage regulation functions, whenever this is the case
- the appropriateness of establishing minimum performance requirements for single-phase power transformers, as well as for small power transformers
- whether concessions made for pole-mounted transformers and for special combinations of winding voltages for medium power transformers are still appropriate
- the possibility of covering environmental impacts other than energy in the use phase.

In addition, the study investigates if, in the light of technological progress, the minimum requirements set out for Tier 2 in 2021 are still appropriate based on a market assessment of the evolution in cost and performance for conventional grain-oriented magnetic steel and equally for amorphous steel.

Assessment of whether Tier 2 requirements are still cost effective from a life cycle perspective

The principal task of the study was to assess whether the Tier 2 energy performance requirements specified in Regulation 548/2104 are still cost-effective from a lifecycle analysis perspective. In the light of technological progress an assessment is made to verify whether the minimum requirements for Tier 2 are still in line with minimum lifecycle costs as well as technologically feasible.

The study discriminated greenfield from brownfield sites with space/weight constraints. This is because some of the improvement options to reduce transformer losses can increase the size and weight of the transformer. Greenfield sites are sites where transformers are being installed for the first time. Brownfield transformers are destined for a replacement project that has specific limitations of size and/or weight resulting from the need to install the transformer in an existing enclosure or substation. Of course, not all brownfield sites have these space/weight constraints because often they were oversized to host a larger transformer which is useful when the load increases. The study found that those brownfield applications with severe space/weight constraints predominantly occur for certain utilities due to them, historically, being under some pressure to limit the urban space they claim. Urban substations can have life times that are longer compared to distribution transformers (i.e. 40 years) and can cost a multiple of the cost of a spare transformer.

The assessment of the economic viability of Tier 2 compared with Tier 1 found that the lifecycle cost of Tier 2 compliant transformers for greenfield sites is always lower than for Tier 1 compliant models. This is true for medium and large transformers. It was also reconfirmed that medium power transformers remain available with much lower losses compared to the minimum Tier 2 levels based on amorphous steel, but there is currenly only modest EU sales despite their lower life cycle cost.

The study found that for medium power transformers there are sufficient techniques available today to enable space/weight constraints in brownfield sites to be satisified with Tier 2 compliant products; hence there are no purely technical grounds for the introduction of any new exemption in the regulation. However, our analysis showed that the Tier 2 compliant, space-constrained brownfield distribution transformer applications were uneconomic for utilities under the specific case when the use of copper is the only technical solution and the economic scenario which assumes a 4% discount rate and low wholesale electricity prices (0,05 euro/kWh). Nevertheless the sensitivity analysis shows that Tier 2 compliant products are economic in these cases under the scenarios which assume a lower WACC or discount rate (1,1%) combined with PRIMES2040 reference electricity prices assumptions (0,098 euro/kWh) or higher load factors (0,40 instead of 0,18), that can be achieved for example by selecting a lower rated power. It was not possible to gather data on what proportion of the total EU medium power transformer sales for utility brownfield sites is so affected by these constraints that they would require solutions which are not cost effective for the utility from their life cycle perspective. An analysis also estimated that utility brownfield sites account for 27% of total EU medium power transformer sales when expressed by their kVA (rated capacity). Even under the extremely unlikely scenario that all of these sites are required to use non-cost effective solutions (most probably it is only a small fraction that might be) the macroeconomic analysis shows that the Tier 2 requirements are cost effective for the EU as a whole, thus the only issue to be resolved is whether this concern merits the development of a site-specific exemption process or not. Introduction of such an exemption process on economic grounds will complicate market surveillance, for example switching the onus of requirements from an assessment of the product as it is placed on the market by a supplier to one where the tendering process and site-specific economic details need to be controlled. It will also require that market surveillance authorities are granted full access to relevant utility economic data. Moreover, granting such exemptions may in turn decrease demand for compliant products and therefore reduce the beneficial impacts of economies of scale in the transformer production process that are likely to be necessary to render Tier 2 cost effective. On the other hand requiring utilities to use Tier 2 products in these specific severely space and weight constrained environments could increase the lifecycle costs of the transformers concerned by up to 20% under the worst case utlility cost scenario. Regulators will need to balance these issues in deciding how to proceed. Potential responses include maintaining Tier 2 for all current requirements, or introducing targeted exemptions, for which some options are set out in the report.
Also, the study identified many new techniques apart from using copper to produce compact and light weight transformers that are not yet on the market today. This could provide competition and lower the estimated price for the worst case scenario.

Lastly, for very large power transformers the study noted that there may be issues associated with Tier 2 size and weight increases that affect the ability to transport the product to the site. Exemptions are discussed in these very specific instances.

Requirements for medium power transformers based on the Peak Efficiency Index

An assessment was conducted for low and medium power transformers of whether it was appropriate to switch the expression of the Tier 2 minimum energy performance requirements from absolute levels of losses to relative ones, expressed through the

Peak Efficiency Index (PEI). Regulation 548/2014 already specifies Tier 2 requirements for large power transformers in terms of the PEI but those for medium power transformers are expressed in terms of maximum permitted load and no-load losses.

The distinction between the minimum PEI approach and the current maximum load and no load losses approach is rather technical because it concerns the nature of these energy performance metrics and how they relate to each other. This is examined in detail in the study and it is found that if the PEI were to be used instead of a combination of load (Pk) and no load losses (P0) many other borderline Tier 2 combinations would be possible that are non-compliant today. Herein it is important to understand that the real transformer efficiency (EI) for a given combination of load (Pk) and no load losses (P0) depends on the loading and the peak or maximum efficiency always occurs at the point where no load losses are equal to load losses. This point is called the load factor of the Peak Efficiency Index (kPEI). Also it should be noted for every combination of PEI & kPEI there is a corresponding combination of Pk & P0.

Thus, were it permitted to attain the Tier 1 and Tier 2 via the PEI rather than continuing with the current load and no load loss limits the impact of the regulation could result in a loophole wherein one seeks for a low cost fit with a real equivalent load factor (k) that differs from the load factor of the Peak Efficiency Index (kPEI). This can result in a performance gap with a real Efficiency Index (EI) being very different from its Peak Efficiency Index (PEI). The study pointed out that low cost solutions might be found at low kPEI and therefore proposed also to limit kPEI. Minimum kPEI limits for medium power transformers (set at >0,19) and for large power transformers (set at >0,25) are proposed. On the other hand the use of the PEI allows freedom to design a range of borderline compliant transformers with different combinations of Pk & P0 to match the real load factor (k) at PEI, which will result in lower losses when loaded at kPEI. For example, based on the distribution transformer base case of Lot 2 (2011), which had k=0,19, there is an argument to allow a borderline Tier 2 PEI compliant transformer (PEI = 99,44%) with kPEI=0,25 or A0-35%/Ck because its annual losses will be lower compared to A0-10%/Ak (kPEI= 0,34), which is the current Tier 2.

It should be noted that different business stakeholder groups expressed divergent views on this topic, with some utilities and DSOs preferring the extra flexibility that the PEI metric would allow, whereas transformer manufacturers favour the maximum load and no load losses approach due to the economies of scale in production it permits. A potential compromise solution articulated by the study team would be to allow the specification of the requirements in terms of two or more series of load/no load losses limits, for example set at A0-35%/Ck and A0-10%/Ak, but this was not supported by either utilities or manufacturers in the stakeholder dialogues.

Energy performance requirements for single-phase transformers

Single phase transformers are covered by Regulation 548/2104 but do not have minimum energy performance requirements specified. This was due to there being a lack of data on these products during the Lot 2 and Impact Assessment studies. In the current study it was established that these products are only used in remote rural locations in Ireland and the UK and nowhere else in the EU. The sales are very modest and account for just 0.2% of all EU low and medium power transformer sales in terms of total kVA of rated capacity. As these products are only used in single phase power networks and the capital decisions regarding having such networks are driven by issues on a wholly greater scale than the cost of transformers there is considered to be no risk of a loophole developing wherein a lack of energy performance

requirements for single phase transformers would lead to a switch from three-phase to single-phase transformers due to lower prices for unregulated tranformers. An analysis was presented that examined the expected impact on lifecycle costs from using single phase transformers as a function of their load and no load losses. This found that regulating load losses was unlikely to lead to lower life cycle costs for these products but that there were likely to be economic benefits from regulating no load losses. However, this analysis was handicapped by a lack of data on actual single phase transformer costs (assumptions had to be made to relate the assumed costs to those of three-phase transformers). These estimates took account of the expected impact of known differences and specifically low impedance requirements (e.g. the 2.2% impedance limit that is required in Ireland) but may not have captured other isues related to lack of scale in production. In addition, the analyses assume EU average electricity costs as projected in the Commission's PRIMES40+ scenario but these will not reflect the local tariffs where these products are actually used (e.g. in Ireland and the UK). It may thus be appropriate for actual price data and additional analyses to be gathered before finalising a regulatory determination on this topic, but this was not possible within the constraints applying to this study. Lastly, the study team note that any potential regulatory requirements that might address no load losses for single phase transformers should be differentiated by the impedance levels the product is designed to attain.
Finally it should be noted that these single phase transformers were only reported to be used by one utility in Ireland and some in the UK and that both countries have different technical requirements in short circuit impedance. Therefore, in accordance with the European principle of subsidiarity(Article 5), putting minimum energy of these transformers can also be considered at local level. The current regulation does not exclude this. Due to the small amount of transformers manufacturers and clients there was also no benefits identified to regulate this at European level based on life cycle cost.

Regulatory concessions for pole-mounted transformers and transformers with special combinations of winding voltages

Table I.6 of Annex I in Regulation 548/2014 provides concessions for transformers which are not operated on the ground, but are mounted on poles. Pole-mounted transformers have weight limitations and, in principle, cannot achieve the same levels of efficiency as ground-mounted ones. The review of these concessions is intended to verify if regulatory concessions made for pole-mounted transformers and transformers with special combinations of winding voltages are still appropriate. The review found that the current wording was too broad and that at a minimum the exemption should be limited to 'single pole transformers for one-to one replacement in existing installations', which is a change for which there was a consensus at the stakeholder meeting. Note, some manufacturers do not support having any specific concessions for pole-mounted transformers because they claim that improved technology already allows these to be meet the Tier 2 requirements.

Overall the study team recommended to withdraw the exemptions specified for pole-mounted transformers in Table 1.6 of the regulation and to replace these with the potential brown field transformer exemptions that are discussed in the report. This same formulation could also be applied to transformers with unusual windings.

Treatment of other exemptions

With regard to the other exemptions specified in the regulation it is also recommended to add proposed technical characteristics for maximum specific core losses to most of the current exemptions. This is especially the case for the existing exemption for 'large power transformers which are like for like replacements in the same physical location/installation for existing large power transformers, where this replacement cannot be achieved without entailing disproportionate costs associated to their transportation and/or installation'.

Criteria for the repair of transformers

Regulation 548/2014 currently does not specify minimum energy efficiency requirements for the repair of transformers. Transformers can be repaired under a myriad of different situations and their service life can be extended significantly. In some cases, repaired transformers may be equivalent to new products, but are not currently covered by the regulation. Cases of the market for repaired transformers being unintentionally driven by energy conservation regulations (applicable to new models) have been reported in the USA and other jurisdictions. The task within this study was to investigate whether the existing regulation should be extended to cover the repair of transformers in (the extreme) cases where these transformers result in products which could be considered new.

It was found that CE legislation already limits the possibilities of repaired transformers that have a CE mark, especially when they change characteristics because the full CE marking procedure might have to be redone including new technical documentation, EU DoC, serial number, etc. However, for old transformers that did not yet have a CE mark there are no such limitations. Furthermore, according to information supplied by DSOs repair of medium power transformers is not a common practice because the installation costs are so high that they don't take the risk. Distribution transformers can vary from 15 – 1000kVA and are generally only worth repairing if the problem is something as simple as a broken bushing on a relatively new transformer, which can be easily replaced. Nonetheless there are parts of the market where transformer repair does occur.

From the Blue Guide on the implementation of EU products rules 2016 (Notice-2016/C 272/01) the study team concluded that change of ownership, or so called second hand transformers, could constitute a loophole in the regulations because these products only have to comply with the requirements when they entered the market for the first time. A potential solution is to explicitly consider all repaired, retofitted or resold transformers as new products freshly brought on the market unless they do not undergo a change ownership and they are still within their foreseen product lifetime (<20 years). Implementing this would require ammending Regulation (EU) No 548/2014 and the Blue Guide on the implementation of EU products rules 2016 (Notice- 2016/C 272/01).

Regulation of non-energy, environmental impacts of transformers

The MEErP assessment confirmed that the impact of the use phase on Global Warming Potential remains the dominant environmental impact of transformers. It was also concluded that there is no reason to revise the Tier 2 regulation based on the impacts associated with the adoption of the (new) MEErP.

The impact of unwanted power harmonics on grid power quality also reinforces the rationale for maintaining Tier 2 requirements, as being the best means of reducing these.

Resource efficiency and recycling favours the use of high copper (Cu) content solutions as this metal has a very high recycling rate. It is also recommended to include detailed Bill-of-Material information within transformer catalogues and not only on the transformer name plates, as at present.

It is recommended that noise limits and the use of certain insulation materials be addressed via site level installation requirements, rather than within an amendment to Regulation 548/2014.

The impact of the REACH Directive’s requirements on the phase-out of the use of Cr(VI) during production processes was also assessed and found to be managable. The purpose is to reduce workplace health impact from Cr(VI) in manufacturing. European manufacturers might have some economic disadvantage and there is a risk that this impact is exported with production to factories outside the EEA. It can be considered as a requirement that transformer materials should be produced in a manner that respects the REACH Regulation (1907/2009).

Potential Tier 3 requirements and other issues

The study also assesses the appropropriateness of introducing a Tier 3 level with stricter requirements, indicatively to be considered coming into effect sometime between 2023 and 2025. For liquid transformers, in applications without severe space/weight constraints, there is still a potential to make energy performance improvements beyond Tier 2. Nonetheless, it seems appropriate to revisit this topic once it becomes clear how Tier 2 is being implemented and whether or not there is any dilution in its impacts and uptake due to potential exemptions. Therefore it is recommended to investigate this topic properly after the status of Tier 2 requirements has been clarified. The same investigation could also address additional key topics that were not possible to examine within this study including:

- Whether or not dry type medium power transformers versus liquid power transformers should have very different loss requirements under Tier 2 as at present and the related issue of whether the Tier 2 requirements for dry-type transformers should be re-specified in technology neutral terms that reflect the intended functionality e.g. fire resistant and compact applications.

- Derivation of technology neutral requirements that could apply equally to electronic transformers as well as conventional transformers.

- Derivation of energy performance requirements for low voltage transformers and electronic transformers operating below 1.1 kVA.

These latter areas also have implications for the potential derivation of technology neutral energy performance measurement standards and reflect the need to address the emergence of electronic transformer solutions as well as the importance of managing losses in LV transformers.

Lastly, although Regulation 548/2014 applies to small transformers of <1.1 kVA no requirements are imposed except those related to documentation and rating plate information. It is proposed that a less onerous rating plate information requirement be considered due to the size constraints which apply to these products.

0. Introduction

This study is produced by VITO and its partners Waide Strategic Efficiency and TNO in response to the call for tender from the European Commission DG GROWTH on a "PREPARATORY STUDY FOR THE REVIEW OF COMMISSION REGULATION 548/2014 ON ECODESIGN REQUIREMENTS FOR SMALL, MEDIUM AND LARGE POWER TRANSFORMERS"

This preparatory study is meant to inform this review and, if required, provide the necessary elements for a revision of Regulation 548/2014.

This study is designed to build on the evidence provided by the preparatory study on distribution and power transformers (LOT 2) completed in January 2011. It also follows, as closely as possible, the lifecycle analysis methodology described in the MEErP deliverables, last updated in December 2013. In addition, it draws on other relevant inputs such as the Commission's Impact Assessment for Regulation 548/2014[1].

The specific objectives of the study are all related to Article 7 of Regulation 548/2014 for which it is required to review:

- the possibility to set out minimum values of the Peak Efficiency Index for all medium power transformers, including those with a rated power below 3 150 kVA
- the possibility to separate the losses associated with the core of the transformer from those associated with other components performing voltage regulation functions, whenever this is the case
- the appropriateness of establishing minimum performance requirements for single-phase power transformers, as well as for small power transformers
- whether concessions made for pole-mounted transformers and for special combinations of winding voltages for medium power transformers are still appropriate
- the possibility of covering environmental impacts other than energy in the use phase.

In addition, the study investigates if, in the light of technological progress, the minimum requirements set out for Tier 2 in 2021 are still appropriate based on a market assessment of the evolution in cost and performance for conventional grain-oriented magnetic steel and equally for amorphous steel.

Therefore, the overall objectives of the study are summarised as follows:

- verify if requirements for Tier 2 are still cost-effective over the lifecycle of the product
- provide evidence to inform consideration of minimum energy performance requirements for single-phase transformers
- verify if regulatory concessions made for pole-mounted transformers and transformers with special combinations of winding voltages are still appropriate

[1] In April 2013 The EC conducted an Impact Assessment(IA) on 'Implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to Ecodesign Requirements for Power, Distribution and Small Transformers' that was based on the former Lot 2 preparatory study on distribution and power transformers completed in January 2011. See https://transformers.vito.be/documents

- analyse if existing requirements for medium power transformers based on absolute levels of losses should be converted to relative values based on the Peak Efficiency Index
- analyse if widely accepted criteria addressing the repair of transformers can be developed
- analyse if other, non-energy, environmental impacts of transformers should be regulated.

In order to achieve this the study follows the structure and content of the tasks that were outlined in the technical specifications of the Tender document, as set out below:

- Task 1: Verification of existing minimum requirements for Tier 2
- Task 2: Consideration of minimum requirements for single-phase transformers
- Task 3: Verification of existing exemptions and regulatory concessions, with subtasks:
    - Task 3.1 - Verification of exemptions in Regulation 548/2014
    - Task 3.2 – Analysis of criteria for the repair of transformers in Regulation 548/2014
    - Task 3.3 – Verification of concessions for transformers with unusual combinations of winding voltages
    - Task 3.4 – Verification of concessions for pole-mounted transformers
- Task 4: Analysis of other environmental impacts
- Task 5: Conclusions and recommendations
- Task 6: Reporting and workshop.

1 Task 1 on the verification of existing minimum requirements for Tier 2 and challenges to be addressed

Aim and tender request:
The main goal of this task is verify if the minimum energy efficiency requirements in Regulation 548/2014 for the Tier 2 level, applicable in 2021, are still technologically justified and cost-effective. This entails, for the relevant base-cases, using the most recent MEErP EcoReport tool (2013) to refresh the calculations made in the preparatory study concluded in 2011 with freshly collected data.

Tier 1 minimum efficiency requirements for medium and large power transformers came into effect in the EU in July 2015. Despite this short period of application, it is pertinent to establish what effect these requirements are having in the European transformer market. Thus, the actions being taken by manufacturers and users of transformers in meeting these requirements need to be checked. It is also relevant to learn if there have been shortages of any kind in the supply chain for the manufacturing of transformers.

In the light of technological progress, an assessment is made to verify whether the minimum requirements for Tier 2 are still in line with minimum lifecycle costs, and are therefore cost-effective, as well as technologically feasible. In particular, the evolution and availability of amorphous steel is investigated to inform the assessment of whether these requirements for Tier 2 level are still justified, or a different level of ambition is required.

Where possible, a new estimate of the efficiency levels of the installed base of transformers in the EU, broken down according to the different categories described in Regulation 548/2014, is supplied.

An assessment is also conducted of whether it is more convenient to switch the expression of minimum requirements in Tier 2 from absolute levels of losses to relative ones, expressed through the Peak Efficiency Index. This is done taking into account the views of stakeholders, including manufacturers, electricity companies, and the relevant standardisation community (i.e., Cenelec Technical Committee 20).

The study also assesses the appropropriateness of introducing a Tier 3 level with stricter requirements, indicatively to be considered coming into effect sometime between 2023 and 2025. This last subtask is obviously contingent upon the findings made in the context of the previous subtasks. The questions of whether or not a proposal to alter the level of ambition of requirements in Tier 2 and potentially introduce additional Tier 3 requirements were discussed at the 2nd stakeholder workshop (held on 29/3/2017).

1.1 What are the relevant Tier1&2 Base Cases and are they still economically justified?

1.1.1 Notice on European anti-trust rules and competition law

Note that in the context of this study VITO is committed and required to comply with European anti-trust rules[2] and competition law and further asked participating stakeholders to do so.

European anti-trust policy[3] is developed from two central rules set out in the Treaty on the Functioning of the European Union:

- first, Article 101 of the Treaty prohibits agreements between two or more independent market operators which restrict competition. This provision covers both horizontal agreements (between actual or potential competitors operating at the same level of the supply chain) and vertical agreements (between firms operating at different levels, i.e. agreement between a manufacturer and its distributor). Only limited exceptions are provided for in the general prohibition. The most flagrant example of illegal conduct infringing Article 101 is the creation of a cartel between competitors, which may involve price-fixing and/or market sharing
- second, Article 102 of the Treaty prohibits firms that hold a dominant position on a given market to abuse that position, for example by charging unfair prices, by limiting production, or by refusing to innovate to the prejudice of consumers.

As a consequence of this, competitors should not discuss future prices (including terms of sale) of their products but were invited to verify if the price levels considered within the study are realistic.

This present investigation is only intended to reflect the current and future situation in the transformer market (EU) and to gather sufficient information to assess if Tier 2 requirements of EU regulation 548/2014 are still technologically justified. In order to comply with anti-trust rules some data in this study will be anonymised and aggregated whereever deemed necessary.

1.1.2 Base cases from the impact assessment

In April 2013 the EC conducted an Impact Assessment(IA) on 'Implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to Ecodesign Requirements for Power, Distribution and Small Transformers' that was based on the former Lot 2 preparatory study on distribution and power transformers completed in January 2011[4].

Based on the European market analysis seven Base Cases (BC) with their typical rating and loading parameters were defined:

- BC 1: Distribution Transformer (400kVA) (24/0,4kV)

[2] http://ec.europa.eu/competition/antitrust/legislation/legislation.html
[3] http://ec.europa.eu/competition/antitrust/overview_en.html
[4] https://transformers.vito.be/documents

- BC 2: Industry Transformer: Oil-immersed (1MV) (24/0,4kV)
- BC 3: Industry Transformer: Dry-type (1.25MVA) (24/0,4kV)
- BC 4: Power Transformer (100MVA, primary voltage 132kV, secondary voltage 33kV)(132/33kV)
- BC 5: DER Transformer: Oil-immersed (2MVA) (24/0,4kV)
- BC 6: DER transformer: Dry-type (2MVA) (24/0,4kV)
- BC 7: Separation/Isolation Transformer (16kVA) (24/0,4kV).

The cost of Tier 2 transformers was derived from the preparatory study in Lot 2 and in the cases for which specific assessments were missing it was estimated in the 2013 impact assessment (IA) by interpolation between the available improvement options. In practice this meant that Tier 2 data in the IA for BC 1, 2 and 5 were partially based on amorphous distribution transformers (AMDT), in part because Tier 2 Grain Oriented Silicon Steel (GOES) transformer data was not available during the Lot 2 (2011) work. The 2013 impact assessment also updated the forecast electricity cost that had been applied in each base case in the 2011 Lot 2 study.

All BC data related to Tier 1&2 that were reported in the 2013 impact assessment(IA) are summarised in Table 1-1, Table 1-2 and Table 1-3. **The Life Cycle Cost (LCC) of all Tier 2 BCs compared to Tier 1 was lower and as a consequence Tier 2 was also considered economically justified.** However, in order to allow the industry and market time to adapt to more efficient transformers, the subsequent Ecodesign regulation 548/2014 were set with two tiers phased in over time, Tier 1 (2015) and Tier 2 (2021). The regulation also imposes other constraints such as are discussed in section 1.5.

All the operational parameters included in Table 1-2, Table 1-3 and Table 1-4 are explained in the Lot 2 study (2011) and are assumed, with the exception of economic parameters, not to have altered between 2013 (when the impact assessment study was conducted) and 2017 (e.g. assumptions regarding the Load Factor and other operational parameters are assumed to be invariant). By contrast, the capital expenditure (CAPEX) of transformers, as explained in the Lot 2 study(2011), is highly dependent on transformer commodity prices, and therefore the purpose of the following section is to review and update the assumptions made in this regard. The operational expenditure (OPEX) mainly depends on the electricity cost and discount rate, which are also volatile, and hence is also analysed and discussed in the subsequent sections.

Table 1-1 Tier 1&2 Base Cases for three-phase liquid-immersed medium power transformers as used in the 2013 Impact Assessment

Base Case		**BC1 DT liquid Tier1**	**BC1 DT liquid Tier2**	**BC2 ind liquid Tier1**	**BC2 ind liquid Tier2**	**BC5 DER liquid Tier1**	**BC5 liquid Tier2**
transformer rating (Sr)	kVA	400	400	1000	1000	2000	2000
No load losses (P0)	W	430	387	770	693	1450	1305
no load class		Ao	Ao-10%	Ao	Ao-10%	Ao	Ao-10%
Load losses (Pk)	W	4600	3250	10500	7600	18000	15000
load class		Ck	Ak	Ck	Ak	Bk	Ak
Auxiliary losses (Paux)	W	0	0	0	0	0	0
PEI	%	99,297%	99,439%	99,431%	99,541%	99,489%	99,558%
Load Factor (k) (=Pavg/S)	ratio	0,15	0,15	0,3	0,3	0,25	0,25
Load form factor (Kf)(=Prms/Pavg)	ratio	1,073	1,073	1,096	1,096	1,5	1,5
availability factor (AF)	ratio	1	1	1	1	1	1
Power factor (PF)	ratio	0,9	0,9	0,9	0,9	0,9	0,9
Equivalent load factor (keq)	ratio	0,18	0,18	0,37	0,37	0,42	0,42
load factor@PEI (kPEI)	ratio	0,306	0,345	0,271	0,302	0,284	0,295
no load and aux. losses per year	kWh/y	3766,8	3390,1	6745,2	6070,7	12702,0	11431,8
load losses per transformer per year	kWh/y	1288,7	910,5	12276,4	8885,8	27375,0	22812,5
losses per year	kWh/y	5055,5	4300,6	19021,6	14956,5	40077,0	34244,3
transformer life time	y	40,00	40,00	25,00	25,00	25,00	25,00
interest rate	%	4%	4%	4%	4%	4%	4%
inflation rate	%	2%	2%	2%	2%	2%	2%
kWh price no load and aux. Losses	€	0,0847	0,0847	0,1291	0,1291	0,15	0,15
kWh price load losses	€	0,0847	0,0847	0,1291	0,1291	0,15	0,15
CAPEX - transformer	€	7 824,09	8 977,51	13 567,31	17 277,30	27 126,40	31 736,75
losses per year	kWh/y	5055,5	4300,6	19021,6	14956,5	40077,0	34244,3
discount rate	%	2%	2%	2%	2%	2%	2%
electricity escalation rate	%	0%	0%	0%	0%	0%	0%
PWF	ratio	27,36	27,36	19,52	19,52	19,52	19,52
No load loss capitalization factor (A)	€/W	20,30	20,30	22,08	22,08	25,65	25,65
Load loss capitalization factor (B)	€/W	0,65	0,65	2,95	2,95	4,45	4,45
TCO A/B ratio	ratio	31,27	0,03	0,13	0,13	0,17	0,17
OPEX electricity	€/y	428,20	364,26	2 455,69	1 930,88	6 011,55	5 136,65
LCC electricity	€ /life	11 713,69	9 964,60	47 943,60	37 697,47	117 366,23	100 285,07
LCC total (excl. scrap@EOL)	€ /life	19 537,78	18 942,11	61 510,91	54 974,77	144 492,63	132 021,82

Source: derived from IA (2013) & Lot 2 (2011)

Table 1-2 Tier 1&2 Base Cases for three–phase dry-type medium power transformers as derived from the 2013 Impact Assessment and Lot 2 study

Base Case		BC3 ind dry Tier1	BC3 dry Tier2	BC6 dry Tier1	BC6 dry Tier2
transformer rating (Sr)	kVA	1250	1250	2000	2000
No load losses (P0)	W	1800	1620	2600	2340
no load class		Ao	Ao-10%	Ao	Ao-10%
Load losses (Pk)	W	11000	11000	16000	16000
load class		Ak	Ak	Ak	Ak
Auxiliary losses (Paux)	W	0	0	0	0
PEI	%	99,288%	99,325%	99,355%	99,388%
Load Factor (k) (=Pavg/S)	ratio	0,3	0,3	0,25	0,25
Load form factor (Kf)(=Prms/Pavg)	ratio	1,096	1,096	1,073	1,073
availability factor (AF)	ratio	1	1	1	1
Power factor (PF)	ratio	0,9	0,9	0,9	0,9
Equivalent load factor (keq)	ratio	0,37	0,37	0,30	0,30
load factor@PEI (kPEI)	ratio	0,405	0,384	0,403	0,382
no load and aux. losses per year	kWh/y	15768,0	14191,2	22776,0	20498,4
load losses per transformer per year	kWh/y	12861,0	12861,0	12451,4	12451,4
losses per year	kWh/y	28629,0	27052,2	35227,4	32949,8
transformer life time	y	30,00	30,00	25,00	25,00
interest rate	%	4%	4%	4%	4%
inflation rate	%	2%	2%	2%	2%
kWh price no load and aux. Losses	€	0,1291	0,1291	0,15	0,15
kWh price load losses	€	0,1291	0,1291	0,15	0,15
CAPEX - transformer	€	37 012,31	38 641,39	36 930,72	38 967,44
losses per year	kWh/y	28629,0	27052,2	35227,4	32949,8
discount rate	%	2%	2%	2%	2%
electricity escalation rate	%	0%	0%	0%	0%
PWF	ratio	22,40	22,40	19,52	19,52
No load loss capitalization factor (A)	€/W	25,33	25,33	25,65	25,65
Load loss capitalization factor (B)	€/W	3,38	3,38	2,28	2,28
TCO A/B ratio	ratio	0,13	0,13	0,09	0,09
OPEX electricity	€/y	3 696,01	3 492,44	5 284,11	4 942,47
LCC electricity	€ /life	82 777,44	78 218,31	103 164,12	96 494,13
LCC total (excl. scrap@EOL)	€ /life	119 789,76	116 859,70	140 094,84	135 461,56

Source: derived from IA (2013) & Lot 2 (2011)

Table 1-3 Base Cases for large and small power transformers as derived from the 2013 Impact Assessment and Lot 2 study

Base Case		BC4 power Tier1	BC4 power Tier2	BC7 small	BC7 small BAT 2011
transformer rating (Sr)	kVA	100000	100000	16	16
No load losses (P0)	W	32900	28700	110	110
no load class					
Load losses (Pk)	W	526000	460000	750	400
load class					
Auxiliary losses (Paux)	W	0	0	0	0
PEI	%	99,737%	99,770%	96,410%	97,378%
Load Factor (k) (=Pavg/S)	ratio	0,2	0,2	0,4	0,4
Load form factor (Kf)(=Prms/Pavg)	ratio	1,08	1,08	1,5	1,5
availability factor (AF)	ratio	1	1	0,2	0,2
Power factor (PF)	ratio	0,9	0,9	0,9	0,9
Equivalent load factor (keq)	ratio	0,24	0,24	0,67	0,67
load factor@PEI (kPEI)	ratio	0,250	0,250	0,383	0,524
no load and aux. losses per year	kWh/y	288204,0	251412,0	192,7	192,7
load losses per transformer per year	kWh/y	265407,0	232105,0	2920,0	1557,3
losses per year	kWh/y	553611,0	483517,0	3112,7	1750,1
transformer life time	y	30,00	30,00	10,00	10,00
interest rate	%	4%	4%	4%	4%
inflation rate	%	2%	2%	2%	2%
kWh price no load and aux. Losses	€	0,05	0,05	0,1291	0,1291
kWh price load losses	€	0,05	0,05	0,1291	0,1291
CAPEX - transformer	€	743 886,45	743 886,45	1 153,00	1 546,31
losses per year	kWh/y	553611,0	483517,0	3112,7	1750,1
discount rate	%	2%	2%	2%	2%
electricity escalation rate	%	0%	0%	0%	0%
PWF	ratio	22,40	22,40	8,98	8,98
No load loss capitalization factor (A)	€/W	9,81	9,81	2,03	2,03
Load loss capitalization factor (B)	€/W	0,57	0,57	4,51	4,51
TCO A/B ratio	ratio	0,06	0,06	0,44	0,44
OPEX electricity	€/y	27 680,55	24 175,85	401,85	225,93
LCC electricity	€ /life	619 946,18	541 453,31	3 609,67	2 029,45
LCC total (excl. scrap@EOL)	€ /life	1 363 832,63	1 285 339,76	4 762,67	3 575,76

Source: derived from IA (2013) & Lot 2 (2011)

1.1.3 Current transformer commodity prices

1.1.3.1 Conductor material prices

As mentioned in the Lot 2 study and IA the main conductor materials used in transformers are copper and aluminium. For the same conductivity copper is more compact & expensive whereas aluminium is lighter on itself in weight, has a lower purchase cost but takes a greater volume. Note that the relative lighter weight per conductivity of aluminium does not necesearly result in a lighter transformer due to cooling requirements as explained in 1.6.2. Currently aluminium is mostly used for medium power transformers in Europe due to its lower product purchase cost. The prices used in the IA and the updated prices derived from the current review are included in Table 1-4. **In general the prices of these conductors have remained stable** with an exception being that the cost of aluminium was lower at the time of the IA (2012) but is currently (2016) similar to the values reported in the Lot 2 (2010) study.

Table 1-4 Past and recent conductor material prices

Material	2002-2006 average 5 year material price in €/kg	2002-2006 average 5 year marked up material price in €/kg (=144%)	Lot 2 avg/2010 in €/kg (Agoria &T&D EU)	Lot 2 avg/2010 analytic in €/kg	Impact Assessm. 6/2012	Agoria &T&D EU 11/2016	Review study no mark up
Liquid immersed transformers							
copper wire, formvar, rond 10-20	**4,36**	**6,30**	5,81		5,93	5,49	5,49
copper wire, enameled, round 7-10 flattened	4,42	6,37					
copper wire, enameled, rectangular sizes	4,73	6,82		**6,99**			
aluminum wire, formvar, round 9-17	2,58	3,72					
aluminum wire, formvar, round 7-10	2,62	3,77					
copper strip, tichness range 0,020-0,045	4,54	6,55					
copper strip, tichness range 0,030-0,060	4,41	6,35					
aluminum strip, tichness range 0,020-0,045	2,87	4,14					
aluminum strip, tichness range 0,045-0,080	**2,82**	**4,07**	2,63		1,51	2,47	2,47
copper vs aluminium	154%	155%	221%		393%	222%	

Notes:
'Agoria' price index available from:
http://www.agoria.be/WWW.wsc/rep/prg/ApplContent?ENewsID=105987&TopicID=10203&TopicList=10203

Shifting from aluminium to copper windings in medium power liquid transformers after Tier 2 (>2021) would most likely not have a large impact on the future (>2021) copper price itself because the estimated forecast of copper sales after Tier 2 comes into effect will remain moderate compared to total copper conductor sales. The Lot 2 study forecast some 173 891 of liquid distribution transformers unit sales in 2020. Under a maximum copper utilisation scenario that assumes an estimated average of 450 kg Cu per transformer, the total annual demand would be a maximum of 81 Kton/year, which is negligible compared with the 2252 Kton/year (2013)[5] of EU sales for all copper conductors (e.g. including power cables). Also in Europe **neither copper nor aluminium are recognised as Critical Raw Materials**[6].

1.1.3.2 Magnetic core and tank steel material prices

The main materials used in transformer cores are Grain Oriented Steel (GOES) and amorphous steel (AM), see Lot 2(2011). As explained in Lot 2 (2011), GOES is sold in various grades (M075-23L, M130-27S , ..), which are classified according to their losses and which are in turn related to the sheet thickness (see Table 1-5). Throughout this study conventional GOES is referred to as CGO and high-permeability GOES is referred to as HGO, which aligns with the acronyms used in the US AISI standard (for further details regarding GOES consult Lot 2 Study). Obviously, low-loss GOES with thinner sheets requires more processing (e.g. laser scribing (L)) and is more expensive. Also so-called mechanically scribed steel with lower losses is more expensive.
It should be noted that **a price surge in low loss (M075-23L) GOES, or so called GOES+, occurred in 2015** after a period of price erosion[7] in 2012-2014, see Figure 1-1. This price surge can be explained by the Commission's implementation of Regulation (EU) 2015/1953 which imposed an anti-dumping duty on imports of GOES at a moment that was coincident with the entry into force of the Tier 1 (2015) requirements. From data received from T&D Europe it seems that since that time prices have been declining back to their 2010 "normal" level (i.e. as reported in the

[5] Source: Lot 8 on Power Cables
[6] https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/critical_en
[7] Obviously this confirms steel dumping that Anti-dumping Regulation (EU) 2015/1953 deals with.

Lot 2 study), see Figure 1-1. Hence, **it seems likely that the price of low-loss GOES in the future can be expected to be similar to those reported in the Lot 2 2010 study** after the normalisation of supply and demand. According to some European manufacturers price competition is currently (as of 4/2017) so high that large quantities of the best low-loss steel are commonly available (M075-23L) for the Minimum Import Price (MIP) from the anti-dumping Regulation, i.e. 2 043 euro/kg (Table 1-5).

Table 1-5 Past and more recent transformer steel prices

Type acronym	AISI	EN 10107	Thickness	Max. specific loss (W/kg)		Typical specific loss (W/kg)		2002-2006 average €/kg	2015 MIP €/kg	Lot 2 avg/2010 in €/kg (Agoria &T&D	Lot 2 avg/2010 analytic in €/kg	Agoria &T&D EU 11/2016
			(mm)	50 Hz		50 Hz		€/kg	€/kg	%	€/kg	%
				1,5T	1,7T	1,5T	1,7T					
CGO	M2		0,18	0,68	-	-	-	1,96				
CGO	M3	M120-23S	0,23	0,77	1,20	0,73	1,15	1,79	1,54	1,00	2,58	1,13
CGO	M4	M130-27S	0,27	0,85	1,30	0,83	1,24	1,72	1,54			
CGO	M5	M140-30S	0,30	0,92	1,40	0,87	1,26	1,55	1,54	0,76		0,69
CGO	M6	M150-35S	0,35	1,05	1,50	0,99	1,42			1,32		1,64
HGO-DR		M075-23 L	0,23		0,75	0,55	0,74		2,04			
HGO		M100-27P	0,27		1,00	0,71	0,98		1,87			
HGO-DR		M090-23P*	0,23	0,65	0,90		0,86					
HGO		M100-23P	0,23		1,00		0,96					
HGO-DR		M095-27P*	0,27	0,71	0,95		0,92					
HGO		M103-27P	0,27		1,03		0,97					
HGO-DR		M100-30P*	0,30		1,00		0,97					
HGO		M105-30P	0,30		1,05		1,02		1,54			

Notes:
EU MIP are European anti-dumping duty on imports of certain grain-oriented flat-rolled products of silicon-electrical steel of 29 October 2015 (Regulation (EU) 2015/1953.
'Agoria' price index available from:
http://www.agoria.be/WWW.wsc/rep/prg/ApplContent?ENewsID=105987&TopicID=10203&TopicList=10203
'T&D price index available from:
http://www.tdeurope.eu/en/raw-material/transformers-indices/

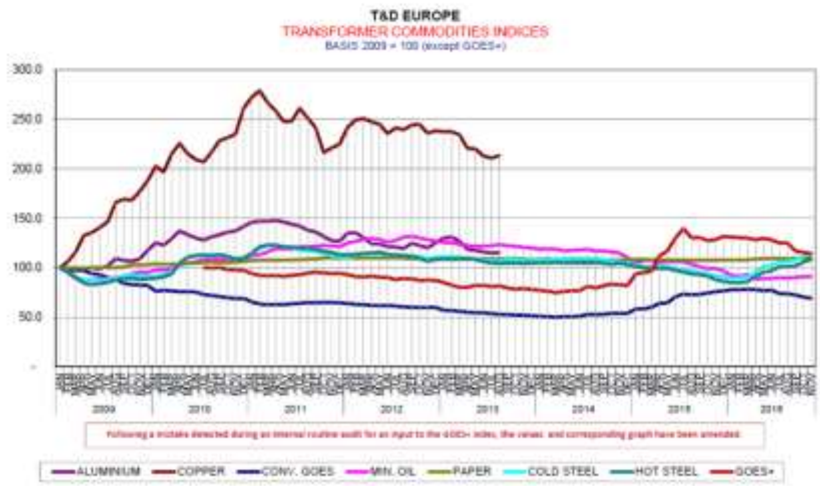

Figure 1-1 2009-2016 evolution of transformer Commodities Indices from T&D Europe

Note, however, that **according to our knowledge GOES M2 steel of 0.18mm thickness is currently only available in Japan[8]. In Europe one manufacturer**

[8] http://www.aksteel.com/markets_products/electrical.aspx#oriented

has announced they will be producing this[9] **in view of the pending Tier 2 requirements** but it is not yet available in their catalogues. For Tier 1 it can be assumed that manufacturers use commonly available M100-27P (0.27 mm) or lower loss steel (see Table 1-5). When introducing Tier 2 (in 2021) a temporary GOES+ surge price could occur again due to production capacity and market competition limits for Tier 2 compliant steel (M075-23L or better). Nevertheless **intellectual property (IP) rights should not be a barrier to compliance with Tier 2 requirements** because amorphous steel has already been available for a long time on the market[10] and patents have expired[11] while low-loss GOES has also been available for a long time[10] and no patents apply to this either.

It was also noted in the stakeholder workshop that laser scribing for domain refined low-loss GOES steel (e.g. M075-23L) has now become broadly available at a reasonable cost.

However, the use of a lower thickness (<0,23mm) GOES is still under development. It has not been yet decided if 0,20 mm, or 0,18 mm, or both will be introduced within the next revision of the IEC60404-8-7 standard. Several GOES producers have already started to develop thinner gauge high-permeability HGO of 0,20 mm, or HGO of 0,18 mm; however, for the time being, the material is only available on the market in small quantities. On the one hand the reason for this is that steel mill manufacturing costs are higher, simply due to lower productivity at cold rolling mills and continuous processing lines. On the other hand, due to permanent process optimisation, the specific total loss Ps is also continuously being lowered. In particular, the High Permeability grade HGO-L 0.23 is now sufficiently available to fulfil the demands of the transformer market. Aside from the economic optimisation issues of the transformer industry, the new thin gauges will not present problematic technical issues for coil slitting with regards to distribution transformers, but addressing these is expected to take more time for the larger power transformers due to lamination handling difficulties for stacking.

Utilities report there has been little uptake of Tier 2 compliant transformers or above thus far, however **in the industrial sector there is some uptake**[12]**.** The explanation is that industry has sufficiently large technical rooms to house the higher efficiency transformers, pays a higher electricity price for their losses and sometimes has a stronger environmental commitment in comparison to utilities and hence is less sensitive to CAPEX considerations.

1.1.1.1. Other important transformer material prices

Other important material prices within transformers are those for mineral oil and insulation paper, see Figure 1-1. Compared with the values reported in the IA 2014 the paper price has remained stable while the mineral oil price has substantially decreased, see Table 1-6. Note also that Nomex[13], which is a **high temperature**

[9] https://www.thyssenkrupp-steel.com/en/customer-magazine/transformer.html

[10] 'The scope for energy saving in the EU through the use of energy-efficient electricity distribution transformers', THERMIE B PROJECT Nº STR-1678-98-BE, First Published December 1999

[11] The maximum term of a European patent is 20 years from its filing date : https://www.epo.org/service-support/faq/procedure-law.html as a consequence they did expire

[12] http://www.wilsonpowersolutions.co.uk/products/wilson-e2-amorphous-transformer/

[13] Nomex is a trade name of Dupont and is a synthetic aramid polymer, it has a high chemical and temperature resistance compared to mineral paper

inorganic insulation used in dry-type transformers, costs substantially more than mineral paper, but could also become important in designing more compact liquid-filled transformers. Apart from Nomex (a Dupont product) other manufacturers[14] also offer high temperature insulation. As a lower-cost alternative to inorganic insulation hybrid insulation is also available and combines inorganic material with organic cellulose paper[15]. Note that alternatives to mineral oil are also available on the market, such as synthetic or natural esters (e.g. MIDEL). They are also more suitable for higher temperature applications; however, the cost of MIDEL is higher[16], e.g. 6.24 euro/l for the synthetic ester-based transformer fluid compared to 1.36 euro/l for mineral oil (2/2017).

Table 1-6 Past and recent transformer liquid and insulation prices compared to Lot 2

Material	2002-2006 average 5 year material price in €/kg	2002-2006 average 5 year marked up material price in €/kg (=144%)	Lot 2 avg/2010 in €/kg (Agoria &T&D EU)	Agoria &T&D EU 11/2016	Iternet 2/2017	Review study no mark up
Liquid immersed transformers						
kraft insulation paper with diamo	2,79	4,02	105%	110%	2,52	2,52
mineral oil (per kg)	3,09	4,36	106%	91%	1,39	1,39
tank steel	0,74	1,08	0,74	0,76		0,76
Dry-type transformers						
Nomex insulation	**30,64**	44,16				
Cequin insulation	18,70	26,95				
impregnation (per liter)	3,71	5,22				
winding combs	31,36	44,11				

Sources:
'Internet' prices, source www.edenoil.co.uk
'Agoria' price index data sourced from: http://www.agoria.be/WWW.wsc/rep/prg/ApplContent?ENewsID=105987&TopicID=10203&TopicList=10203
'T&D price index data sourced from:
http://www.tdeurope.eu/en/raw-material/transformers-indices/

1.1.4 Scrap material value and total end of life cost

As explained in the Lot 2 study transformers still have value at their End-of-Life (EoL) due to the value of their scrap metals. Consequently, this is a driver for transformer recycling and/or repair. Also in relation to this issue E-distribuzione mentioned[17] that in Italy[18] it is important to manufacture distribution transformers with aluminium windings to avoid problems related to copper theft, related environmental ground pollution and interruptions in customers' energy supply.

The current metal scrap values, or so-called secondary commodity prices, are indicated in Table 1-7. Copper, in particular, has a high scrap value. Please note that

[14] E.g.: http://www.weidmann-electrical.com/en/inorganic-paper-paper.html , http://solutions.3m.com/wps/portal/3M/en_US/ElectricalOEM/Home/Products/FlexibleInsulation/ , http://en.metastar.cn/
[15] http://protectiontechnologies.dupont.com/Nomex-910-transformer-insulation
[16] http://www.edenoil.co.uk/component/virtuemart/70/6/transformer-insulating-liquid/tranformer-midel-7131-205-detail?Itemid=0
[17] Source: in a written reply to the 'Questionnaire for Installers on Transformers constraints and limitations' in the course of this study
[18] http://e-distribuzione.it/it-IT

according to this information **copper mostly maintains its value when scrapped (i.e. €4,2/kg as scrap compared with €5,49/kg when new) whereas aluminium loses most of its value (€0,085/kg scrap compared to €2,47/kg when new**). These are market scrap values used at the point of delivery, which is most commonly available[19], even for particular clients. Hence, investing in a copper based transformer might be more economic from a life cycle cost (LCC) perspective when its EoL value is taken into account.

Note that the metal value of a transformer is not the same as the total end of life cost because apart from the scrap metal value there is also the dismantling cost for disconnecting, transport and disassembly, including the cost of mineral oil removal (if any). These are mainly fixed costs and they can therefore be left outside a relative comparison of Tier 1 versus Tier 2 on Life Cycle Cost, which was also done in Lot 2. Nevertheless, there still might be some differences in mineral oil volume although mineral oil also has some positive end-of-life value, see 1.1.1.1., therefore neglecting this aspect is a conservative approach. Furthermore, section 1.6.2 discusses copper conductors compared to aluminium and it can be concluded that the volume including mineral oil of the transformer will decrease when using copper instead of aluminium. It was also said in section 1.6.2 that as a result the total weight of the transformer could remain similar in either case.

In practice recyclers can provide a full dismantling service[20] and often the scrap EoL value compensates the dismantling cost, however knowing that there is valuable copper inside can make a positive difference.

As a conclusion, for a conservative estimate on LCC impact, only the marginal net present EoL value of copper compared to aluminium can be taken into account.

Table 1-7 Current (2/2/2017) scrap value[21] of transformers

Scrap value (2/2/2017)	
Cast Iron (€/kg)	0,175
Steel plate (€/kg)	0,096
Copper (€/kg)	4,200
Aluminium (€/kg)	0,085

1.1.5 Green Field and Brown Field transformer design

In this study so-called green field and brown field reference transformer designs are considered. 'Green field reference designs' are transformers designed for green field projects, i.e. a new project where the size and weight of the transformer is not a specifically constrained requirement due to not being constrained by limitations associated with the dimensions and load baring capacity of existing enclosures. Green Field designs are therefore the most cost-effective designs. Aside from green field designs brown field reference designs are also considered within the study, i.e. transformers for a replacement project that has specific limitations of size/weight resulting from the need to install the transformer in an existing enclosure. In the original Lot 2 Study (2011) this brownfield lock-in effect was not analysed in detail because it was assumed that substations were built with some extra margin with

[19] For example day trade price: http://oudijzer-prijs.com/dag-prijs/
[20] E.g. http://www.allrecup.be/?page_id=280
[21] http://www.tijd.be/grondstoffen/secundaire_grondstoffen/

regards to dimensions & weight in order to easily upgrade the substation to a higher rating in the event of increasing loads[22]. Despite this, some utilities have expressed fears concerning the potential impact of Tier 2 requirements on brownfield sites. Some of them might have been under pressure to reduce to a minimum the public space they required for a substation, and were also historically unaware of this prospective Tier 1 lock-in effect. In the case of industrial LV/MV transformers this problem has not been reported as being an issue. Potentially the industrial sector were more forward looking or simply allowed for some margin to provide extra capacity, which may be easier for them because they are themselves the owners of the substation floor area.

Transformer type	Rated Power	Stock			Replacement sales	Total sales		
		1990	2005	2020		1990	2005	2020
	in kVA	10^3 units	10^3 units	10^3 units	% p.a.	units p.a.	units p.a.	units p.a.
Smaller Industrial Transformers	16	750	750	750	10	75 000	75 000	75 000
Distribution transformer	250	2 714	3 600	4 459	2.5	119 438	140 400	173 891
DER transformers	2 000	0.25	20	89	4.0	94	2 900	12 967
Industry oil transformer	630	603	800	991	4.0	35 590	43 200	53 505
Industry dry transformer	800	128	170	211	3.3	6 708	8 047	9 966
Power transformer	100 000	49	64.35	80	3.3	2 539	3 046	3 772
Phase	100 000	0.49	0.65	0.81	3.3	26	31	38

Table 1-8 Summary of transformer market data according to the estimate of Lot 2 (2001)

In order to quantify the relative importance we can consult the market data of Task 2 from the Lot 2 Study[23](2011), see Table 1-8. It is estimated that some 2,5%/(1,4%+2,5%) or 64 % of all 'distribution' transformer sales are 'replacement' distribution transformers sales meaning that they are retrofits of existing transformers. Some of these distribution transformer replacement sales will be for utlity brownfield transformer applications with space/weight lock-in effects. There are of course also non-distribution MV/LV transformers, e.g. the so called industry & DER transformers, and on average these have higher rated capacities (1000-2000 kVA) compared to distribution transformers (400 kVA). The forecast total sales per year for 2020 were 76438 units for industry and DER transformers (with an average capacity of 1250 kVA) versus 173891 units for distribution transformers (with an average capacity of 400 kVA). **This means that an estimated 27% of the total kVA of LV/MV transformers (comprising distribution, industry & DER types) could be**

[22] This website clearly mentions that the load can be increased in cases with a lack of capacity/ https://trafoserviceonline.netze-bw.de/Fundamentals

[23] See Table 2-1 from new installed Sales versus replacement sales in the Final Final Lot 2 Report(2011)

brownfield distribution transformers[24] **of which an unknown proportion may be subject to space/weight constraints**[25]. Thus, 27% is an **upper boundary** on the proportion of LV/MV transformer sales (in terms of kVA) which could be subject to site space and weight constraints that might oblige using high Cu content design solutions in order to comply with Tier 2 requirements. Almost certainly though, the actual proportion of total kVA sales where this might apply is much lower again.

Note too, that an important solution for compact brownfield transformers is to use copper as the conductor, see section 1.6.2. Because these distribution transformers are installed in public spaces they might be vulnerable to theft due to the value of their scrap material and in that case there might be extra cost for theft protection systems.

Of course it remains difficult to forecast 2020 new and replacement sales as (see Table 1-8), but simple one-to-one replacement sales for existing substations are likely to remain a constant requirement due to aging infrastructure and should be accurate. New sales for new substations is related to infrastructure growth and deep renovation whose furure trends are more uncertain.

1.1.6 Impact of current transformer commodity prices on Tier 2

As mentioned in the Lot 2 study the commodity prices of the active parts of the transformer can have a large impact on the transformer price.

Therefore the potential impact on Tier 2 can be analysed based on the available Bill-of-Material (BOM) data. BOM data is only partially available and in a scattered manner because manufacturers do not want to disclose their latest design details, material content and manufacturing practices for reasons of commercial competitiveness. For the BC1 the best BOM data available according to our knowledge is included in Table 1-9.

Initially (Lot 2, 2011) it was estimated that the commodity prices of the active parts of the transformer were 30 % of the total transformer price. However, during the stakeholder workshop it was also brought to the study team's attention that **the reference prices for the BC1 transformer Tier 1 model (i.e. 7824 euro) are far above the current market prices** and evidence was provided to support this[26]. The current (2016) 630 kVA A0Ck transformer price is only 6300 euro and a premium AMDT better than Tier 2 (A0-60%/Ak) costs only 8190 euro. As a consequence a price correction was made so that a price of 5000 euro[27] for Tier 1 400 kVA transformers and of 7000 euro for a Tier 2+ (A0-60%/Ak) transformer is now deemed to be more realistic. As a consequence also, **48 % value of the active parts and oil in the total transformer price is considered today more realistic**. The Tier 2 brown field application may be supposed for this simple conservative cross-check to be a copper-based transformer with the lowest loss GOES available (Tier 2 Brown F in Table 1-9) and its price is estimated based on its active parts and oil (48 %). Note also that many competing technology options exist to manufacture brown field transformers as explained in section 1.5 and therefore the future price might also go down.

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[24] Scaled to the same kVA: (0.64 x 173891 x 400)/(173891 x 400 + 76438 x 1250)

[25] While all transformer procurement specifications mention site weight and space constraints (as is true of any large equipment) the study team has not seen any information regarding the typical proportion of brownfield transformer sites that have such severe space and weight constraints that they would need to switch to high Cu transformers in order to fit in Tier 2 compliant products of the same rated capacity.

[26] https://www.energy.siemens.com/hq/de/stromuebertragung/transformatoren/assets/pdf/siemens-transformatoren-onepager-fitformer.pdf
Note that in informal contacts aftherthe workshop this lower price was also confirmed.

[27] After informal consultation with some stakeholders, a linear extrapolation of the price 400/650x6300 euro = 4000 euro would be over optimisthc and therefore 5000 euro is a conservative and safe update.

All prices for BC1 in Table 1-9 have been corrected accordingly and as a conclusion **more representative BC1 (400 kVA) reference prices (4/2017) are: Tier 1 (5000 €), Tier 2 green field (5490 €), Tier 2 brown field (8481 €), and Tier 2+(A0-50%/Ak) green field (6500 €).**

Table 1-9 BC1 Tier 1 & 2 transformer BOM data and estimated impact on product price

	CLASP Tier 1	CLASP Tier 2+	current Tier 1	Tier 2 +/-5% brown F	Tier 2 +/-5% green F	Tier 2 Brown F	current Tier 2+ green F	Tier 1 IA	Tier 2 IA
	Tier 1 CLASP	Tier 2 CLASP	Tier 1 ABB-spec	Rauscher spec compact	Rauscher spec economic	VITO analytic model Tier2	Tier 2+ Siemens AMDT	price data IA 2012	price data IA 2012
Power rating:	400 kVA	400 kVA	400 kVA	400 kVA	400 kVA	400 kVA	400 kVA		
Number of legs:	3-legged	5-legged	3-legged	3-legged	3-legged	3-legged	5-legged		
Primary (kV)	11	11	20	<36	<36	11			
Secondary (Volts)	400	400	400	400	400	400			
T rise (deg C):	65	65	75	75	75	NA			
Ambient (deg C):	20	20	20	20	20	20			
Core:	Stacked	Wound	Stacked	Stacked	Stacked	Stacked			
Core Type:	Mitered	AMDT	Mitered	Mitered	Mitered	Mitered	AMDT		
Core Mat'l:	HO	SA1	M100	M075	M075	M075			
Weight of Core (kg):	**683**	**865**	**790**	**638**	**714**	**638**			
Max Magnetic Flux (Bmax):	1,46	1,34				1,35			
Core cross-sectional area (cm2):	258	322				280			
HV Conductor Mat'l:	**CU**	**CU**	**Al**	**Cu**	**Al**	**Cu**			
Weight of HV winding (kg):	**183**	**336**	**85**	**215**	**125**	**234**			
HV current density (A/mm2):	2,71	1,52							
LV Conductor Mat'l:	**CU**	**AL**	**Al**	**Cu**	**Al**	**Cu**			
Weight of LV winding (kg):	**303**	**123**	**85**	**215**	**125**	**234**			
LV current density (A/mm2):	1,23	0,89							
Core Losses (W):	**411**	219	430	*415*	*415*	388	215	430	387
Coil Losses (W):	**4513**	*3324*	4600	3060	3060	3262	3250	4600	3250
Selling Price (IA):	**€ 7.711**	**€ 9.372**						**€ 7.824**	**€ 8.978**
Selling Price updated 44% rule:	**€ 7.711**	**€ 9.372**	**€ 7.824**	**€ 10.222**	**€ 8.161**	**€ 10.541**			
oil weight(kg)			**357**	**280**	**380**	**294**			
other weight(kg)			**473**	**202**	**336**	**294**			
total weight(kg)			**1790**	**1550**	**1680**	**1693**			
current price Review									
Copper(€/kg)			€ 5,49	€ 5,49	€ 5,49	€ 5,49			
Alu(€/kg)			€ 2,47	€ 2,47	€ 2,47	€ 2,47			
Si steel price(€/kg)			€ 1,87	€ 2,04	€ 2,04	€ 2,04			
oil price(€/kg)			€ 1,39	€ 1,39	€ 1,39	€ 1,39			
value active parts			€ 1.897	€ 3.662	€ 2.074	€ 3.871			
value oil			€ 495	€ 395	€ 552	€ 407			
value active parts + oil			€ 2.392	€ 4.057	€ 2.626	€ 4.278			
extra compared to ABB Tier 1:			€ -	€ 1.665	€ 234	€ 1.886			
Copper scrap value (€/kg)			€ 4,20	€ 4,20	€ 4,20	€ 4,20			
transforer marginal Cu scrap value			€ -	**€ 1.806**	€ -	**€ 1.966**			
			€ 5.000						
Share of active ports +oil in price:			48%	48%	48%	48%			
Selling price updated:			**€ 5.000**	**€ 8.481**	**€ 5.490**	**€ 8.944**	**€ 6.500**		
price increase Tier 2/Tier 1:			**100%**	**170%**	**110%**	**179%**	**130%**	**100%**	**115%**

Notes on data sourcing:

- ABB BOM data available from http://new.abb.com/docs/librariesprovider95/energy-efficiency-library/ecodesign_dtr-30-06-2015.pdf?sfvrsn=9
- Rauscher spec transformer data available from http://www.raustoc.ch/Media/KD-00047_Verteiltrafo-freiatmend_de.aspx
- Data in red was missing and has been extrapolated or estimated from similar types
- CLASP and VITO analytic model data is sourced from the Lot 2 study (2011). The VITO analytic model data and CLASP data is only used as a cross check or to extrapolate missing data in other reference designs.
- IA is the data used in the Impact Assessment study.
- Prices have been marked up relative to the bill of material of the active parts and oil (=48%).

1.1.7 Impact from interest, inflation and electriciy prices

1.1.7.1 Values used in the Transformer Impact study (2014) and values currently used for industry in Ecodesign (2016) studies in accordance with the MEErP

The transformer IA (2014) study already used different electricity prices per base case depending on the forecast electricity price over its life time and depending on the application for life cycle cost (LCC) calculations, see Table 1-1, Table 1-2 and Table 1-3. A discount rate (interest-inflation) of 2% was assumed, e.g. corresponding to 4% interest rate and a 2% inflation rate. The new MEErP methodology (2011) also introduced a so-called escalation rate[28], which is the rate of increase in the price of electricity. The transformer IA (2014) study circumvented this technically by topping up electricity prices but did not yet use an 'electricity escalation rate', which means that Table 1-1, Table 1-2 and Table 1-3 have implicitly assumed a 0% escalation rate for the electricity cost applied, yet used forecast electricity prices.

The IA study(2014) forecast an electricity price of 0,0849 euro/kWh which closely fits the latest Eurostat[29] S2/2016 price of 0,0839 euro/kWh (excluding VAT and levies) for industrial consumers, which seems to already be the case today and hence has been reached faster than expected. This electricity price includes transmission and distribution system costs as well as profit margins and a green levy tax depending on the country in question, but excludes VAT.

The IA (2014) used an assumed electricity price of 0,05 euro/kWh for power transformers, which should be representative of the wholesale electricity price excluding any green levy tax and any transmission and distribution costs.

Currently (i.e. 2016) other Ecodesign studies and their impact calculation use 0,117 euro/kWh (excluding VAT only) and a 4% escalation rate with a 4% interest rate.

A summary of the corresponding OPEX cost scenarios (IA2014+, IA2014-, IA2016, Eurelectric2017) can be found in Table 1-10.

scenario	IA2014+	IA2014-	IA2016	Eurelectric2017	PRIMES2040+	PRIMES2040-
	industry distribution	power	all	all	industry distribution	power
€/kWh(excl. VAT)	0,0847	0,05	0,117	0,05	0,098	0,073
discount rate [%]	4,0%	4,0%	4,0%	4,0%	4,0%	4,0%
escalation rate [%]	2,0%	2,0%	4,0%	0,0%	0,0%	0,0%

Table 1-10 Overview of various OPEX scenarios for electricity prices, discount rate and escalation rate to estimate Life Cycle Cost

[28] Dermot Kehily, 2011, 'SCSI Guide to Life Cycle Costing': http://www.sci-network.eu/guide/life-cyclewhole-life-costing/, see also standard 'ISO 15686-5:2008'

[29] Electricity prices for industrial consumers - bi-annual data (from 2007 onwards): http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=nrg_pc_205&lang=en

1.1.7.2 Alternative scenarios for discount rate and companies WACC

Inflation and interest rates change frequently over time and depend on the Central European Bank policy that is regularly reviewed[30]. Looking, for example, to the prevailing market conditions in 2016 inflation in the Eurozone was 1,1 %[31] and the MFI interest rates on new euro-denominated loans to the euro area for non-financial corporations for loans of longer than ten years with an initial rate fixation was 1,84 %[32]. These are usually risk free loan conditions. Uilities and industry however might take into account their own risk premium and use their Weighted Average Cost of Capital (WACC) as a discount rate. The rationale is that companies raise money from a number of sources (debts, stocks,etc.) each with their own expectation on return. The more complex the company's capital structure, the more laborious it is to calculate the WACC. Eurelectric[33] has put forward the suggestion that applying a 4% discount rate with a 0% escalation rate would be more representative.

Also the European Commission has recently developed a better regulation toolbox[34], of which Chapter 8 tool #58 discusses discount rate assumptions. The recommended social discount rate herein is 4%. This 4% rate is intended to be applied in real terms and is therefore applied to costs and benefits expressed in constant prices. It can, however, be adjusted for inflation such that if one were dealing with nominal prices, and inflation were to be, say, 3% per annum then a 7% nominal social discount rate would be used.

As a conclusion, it is also useful to simulate economic impacts with discount rates of 4% within a sensitivity analysis.

1.1.7.3 Future electricity prices and which share is relevant for the life cycle cost of power and distribution transformers

Distribution and power transformers have a long lifetime (25-40 years) hence when modelling the life cycle cost the forward looking electricity price assumptions are important; however, electricity prices fluctuate and there are many uncertainities. The most accepted source currently available for such projections is the 'EU Reference Scenario 2016 Energy, transport and GHG emissions Trends to 2050'[36] elaborated by the European Commission. This study explains how today's electricity price is composed of several components, see Figure 1-2. Not all components can be taken into account, especially fixed costs that cannot be avoided by energy savings, because there will be a rebound effect in the cost per kWh when the costs have to be distributed across fewer kWh sales. In this model the grid and sales costs increase over time due to the increasing share of RES, and particularly variable distributed RES. Hence it is reasonable to take part of the grid cost into account due to the cost avoidance effect that more efficient transformers will produce. More specifically, the fewer the losses incurred in transformers, the lower the need for storage and the more useful transport capacity is available. Note in Table 1-11 that the forecast grid and sales cost is set to rise from 0,026 euro/kWh in 2020 to 0,049 euro/kWh in 2040 due to investments which are necessary to integrate RES, or a ratio of 0,026/0,049 = 0,53. Hence, the rough estimate of a 0,5 relative share of distribution cost for

[30] https://www.ecb.europa.eu/stats/policy_and_exchange_rates/key_ecb_interest_rates/html/index.en.html
[31] http://ec.europa.eu/eurostat/statistics-explained/index.php/Inflation_in_the_euro_area
[32] https://www.ecb.europa.eu/stats/financial_markets_and_interest_rates/bank_interest_rates/mfi_interest_rates/html/index.en.html
[33] http://www.eurelectric.org/media/314743/eurelectrc_resp_ecodesign_tier2_250317_final2_public-2017-030-0205-01-e.pdf
[34] http://ec.europa.eu/smart-regulation/guidelines/docs/br_toolbox_en.pdf

transformers in total distribution and sales costs reported in Table 1-11 might be the best educated guess[35] (PRIMES2040+). As a conclusion for transformers, this study will only look at: annual capital cost, variable costs, fuel costs, tax on fuels and ETS payments, and grid costs (partly or not). In the subsequent analyses (Table 1-11) the grid cost is only partially (PRIMES2040+), or not at all (PRIMES2040-), taken into account. The rationale for taking it partially into account is that lower transformer losses results in cost savings due to avoided CAPEX for grid capacity (PRIMES2040+) but this would not direclty be valid for generation step-up transformers and might be less important for HV TSO power transformers (PRIMES2040-). Nevertheless, for generation step-up transformers the higher efficiency transformers will result in lower generation CAPEX but this is already covered by 'Annual capital cost' in Table 1-11 and therefore can be neglected (PRIMES2040-).

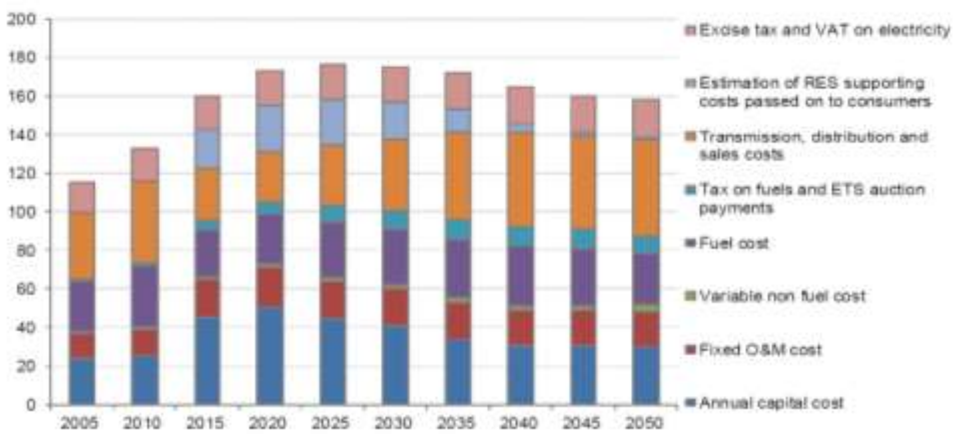

Figure 1-2 Decomposition of electricity generation costs and prices (€ per MWh) historical and forecast values (source: PRIMES[36])

Decomposition of average electricity price(€/kWh)						share +scenario	**scenario PRIMES2040+**	share -scenario	**scenario PRIMES2040-**
year	2010	2020	2030	2040	2050	2040	2040	2040	2040
Annual capital cost	0,035	0,051	0,041	0,03	0,03	1	0,03	1	0,03
Fixed costs	0,014	0,021	0,02	0,019	0,018	0	0	0	0
Variable costs	0,002	0,002	0,002	0,002	0,003	1	0,002	1	0,002
Fuel costs	0,035	0,026	0,029	0,031	0,027	1	0,031	1	0,031
Tax on fuels and ETS payments	0,001	0,006	0,01	0,01	0,009	1	0,01	1	0,01
Grid costs	0,029	0,026	0,037	0,049	0,05	0,5	0,0245	0	0
Excise tax and VAT on Electricy	0,017	0,018	0,019	0,019	0,019	0	0	0	0
Average price of electricity (VAT incl.)	0,133	0,15	0,158	0,162	0,159				
Transformer electricity cost (VAT ex.)							**0,098**		**0,073**

Table 1-11 PRIMES projected 2040 electricity prices useful to transformer LCC calculations

These complex electricity cost scenarios assume a continued uptake of renewables which also explains the high 'annual capital cost'. Therefore a more simple comparison

[35] Because 0,53 of future costs are related to investments needed to host more RES.
[36] EU Reference Scenario 2016 Energy, transport and GHG emissions Trends to 2050, Main results (2016), available at: https://ec.europa.eu/energy/sites/ener/files/documents/20160712_Summary_Ref_scenario_MAIN_RESULTS%20%282%29-web.pdf

of capital expenses for renewables versus energy savings in transformers makes senses and is done in a subsequent section 1.1.9.

1.1.7.4 Impact from the load factor

The Lot 2 Study already mentioned that there can be a significant spreading in transformer loading expressed via the equivalent load factor value, keq. This equivalent load factor depends on the application and therefore it is useful to have a closer look at the impact this aspect is likely to have.

BC1 (Distribution Transformer) used an equivalent load factor (keq) of only 0,18 while BC2 (Industry) uses a value of 0,37. The optimum load factor for the minimum or borderline transformer that still fits Tier 2 varies according to the rating and is between 0,30 and 0,35. This means that for BC1 the minimum transformer that fits Tier 2 has an optimum (KPEI) that differs from its real loading. Despite noting that the BC1 assumed a keq of only 0,18 we take note that Eurelectric in their recent paper alluded to an expected increased uptake of electric vehicles, heat pumps, etc. that might increase the load factor and they also assumed a keq of 0,40 in their analysis[33]. Indeed the load factor will most likely increase with the adoption of electric vehicles, for example, if cars are typically charged at night a charging period of 10h/24h equates to a load factor of about 0,4. Also a load factor of 0,4 might be more representative for brownfield transformers when the loading has increased over time.

Note that for smaller MV/LV distribution transformers (e.g. <100 kVA), such as are used in rural areas, the conclusions regarding low load factors for single phase LV/MV transformers discussed in Task 2 are also valid to three phase transformers. This phenomenon of lower load factors for smaller transformers is related to the so-called diversity factor (see IEC 60439), which is the ratio of the estimated total load of a group of consumers under their normal working conditions to the sum of their nominal ratings. The larger the group of consumers, the lower the factor, and hence the higher the average load factor will be. As an example, a house is typically connected with 10 kVA[37] (230 VAC-40A single phase) but will consume on average only 0,4 kW or 3500 kWh/y which is 0,4kVA/10kVA or 4%. Hence for a single house a transformer would have a low equivalent load factor (e.g. a keq=0,05) but when you have multiple houses and loads you can increase the loading according to the diversity factor method (in IEC 60439). This explains why smaller MV/LV distribution transformers typically have lower load factors than larger units. Often these smaller MV/LV distribution transformers are pole-mounted because the costs are less and their limited weight allows for it.

In conclusion:

- **For normal distribution transformers (BC1) a sensitivity analysis in section 1.1.8 assumes a keq =0,40 instead of 0,18. It is also relevant for brownfield transformers.**
- Task 2 will look at smaller LV/MV distribution transformers, where potentially the considerations for transformers with a rating below 100 kVA can also be applied to three phase transformers. Smaller MV/LV distribution transformers (100 kVA can have loading factors below those assumed in BC1.

[37] To enable an electrical cooking otherwhise 6kVA can be sufficient but gas cooking

1.1.8 Update and sensitivity on the forecast Life Cycle Costs of Tier 2

The sensitivity analysis will also look at a Tier 2 PEI compliant scenario, hereafter referred as 'T2 kPEI=0,25'. The background for that is explained in section 1.3. It is a scenario wherein the Peak Efficiency Index (PEI) is maintained at an identical level to the Tier 2 requirement, but with a different load factor of Peak Efficiency Index (kPEI), i.e. another combination of load and no load losses more adapted to low loads. For this scenario the CAPEX is assumed to be the same but we have received no evidence from manufacturers to confirm this assumption. Following consultation on this issue T&D Europe[38] did not support the PEI approach to review the Tier 2 efficiency requirements because they believe it would result in a need to extend the number of products in their catalogues and therefore make all transformers more expensive because some of the economies of scale in manufacture would be lost.

The following scenarios are considered (Table 1-12, Table 1-13, Table 1-14, Table 1-15):

- IA 2014 is the scenario with cost data from the 2014 impact assessment;
- PRIMES2040+ is the scenario with the updated transformer CAPEX price (see 1.1.6) and electricity OPEX cost parameters (see 1.1.7);
- PRIMES2040- is a cost sensitivity compared to PRIMES2040+ with the low range electricity cost from PRIMES neglecting all transmission, distribution and sales costs (see 1.1.7.3);
- PRIMES2040+HL is a cost sensitivity scenario with increased load factor (see 1.1.7.4);
- PRIMES2040+ low WACC is a cost sensitivity scenario with lower discount rate or WACC until brown field applications have economic LCC;
- PRIMES2040+25 y is a cost sensitivity scenario with the transformer economic life time reduced to 25 y;
- Eurelectric, which is a combined sensitivity analysis scenario with low electricity prices and a higher load factor in line with Eurelectric's proposed assumptions during the stakeholder consultation process;
- IA 2016 is a scenario based on MEErP typical values (electricity cost, discount rate, escalation rate) used for 2016 impact assessment on industrial products.

Tables 1-11 to 1-14 below show the calculated LCC and also the marginal CAPEX for Tier 1 versus Tier 2, the value of losses versus Tier 1 and Benefit/loss ratios for Tier 1 versus Tier 2.

Note that hereafter a case by case comparison is made wherein 'Brown F' means a brownfield transformer with severe space/weight constraints using copper windings. The aggregation of brownfield with greenfield transformers based on their estimated share from section 1.1.5 in a single base case is discussed in a later concluding section 1.9.

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38 http://www.tdeurope.eu/en/home/

Scenario		IA2014	IA2014	PRIMES2040+	PRIMES2040+	PRIMES2040+	PRIMES2040+	PRIMES2040+
Base Case		**BC1 DT liquid Tier1**	**BC1 DT liquid Tier2**	**BC1 DT liquid Tier1**	**BC1 DT liquid Tier2**	**BC1 DT Tier2 brown F**	**BC1 DT liquid BAT**	**BC1 DT liquid T2 kPEI=0,25**
transformer rating (Sr)	kVA	400	400	400	400	400	400	400
no load class		Ao	Ao-10%	Ao	Ao-10%	Ao-10%	Ao-50%	Ao-36%
load class		Ck	Ak	Ck	Ak	Ak	Ak	Ck
PEI	%	99,297%	99,439%	99,297%	99,439%	99,439%	99,582%	99,438%
Load Factor (k) (=Pavg/S)	**ratio**	**0,15**	**0,15**	**0,15**	**0,15**	**0,15**	**0,15**	**0,15**
Load form factor (Kf)(=Prms/Pavg)	ratio	1,073	1,073	1,073	1,073	1,073	1,073	1,073
availability factor (AF)	ratio	1	1	1	1	1	1	1
Power factor (PF)	ratio	0,9	0,9	0,9	0,9	0,9	0,9	0,9
Equivalent load factor (keq)	**ratio**	**0,18**	**0,18**	**0,18**	**0,18**	**0,18**	**0,18**	**0,18**
load factor@PEI (kPEI)	ratio	0,306	0,345	0,306	0,345	0,345	0,257	0,245
no load and aux. losses per year	kWh/y	3766,8	3390,1	3766,8	3390,1	3390,1	1883,4	2409,0
load losses per transformer per year	kWh/y	1288,7	910,5	1288,7	910,5	910,5	910,5	1288,7
losses per year	kWh/y	5055,5	4300,6	5055,5	4300,6	4300,6	2793,9	3697,7
transformer life time	y	40,00	40,00	40,00	40,00	40,00	40,00	40,00
kWh price no load and aux. Losses	**€**	**0,0847**	**0,0847**	**0,098**	**0,098**	**0,098**	**0,098**	**0,098**
kWh price load losses	**€**	**0,0847**	**0,0847**	**0,098**	**0,098**	**0,098**	**0,098**	**0,098**
CAPEX - transformer	€	**7.824,09**	**8.977,51**	**5.000,00**	**5.490,00**	**8.481,00**	**6.500,00**	**5.490,00**
losses per year	kWh/y	5055,5	4300,6	5055,5	4300,6	4300,6	2793,9	3697,7
discount rate	%	**2%**	**2%**	**4%**	**4%**	**4%**	**4%**	**4%**
electricity escalation rate	%	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**
PWF	ratio	27,36	27,36	19,79	19,79	19,79	19,79	19,79
No load loss capitalization factor (A)	€/W	20,30	20,30	16,99	16,99	16,99	16,99	16,99
Load loss capitalization factor (B)	€/W	0,65	0,65	0,54	0,54	0,54	0,54	0,54
TCO B/A ratio	ratio	0,03	0,03	0,03	0,03	0,03	0,03	0,03
OPEX electricity	€/y	428,20	364,26	495,44	421,46	421,46	273,80	362,38
LCC electricity	€ /life	11.713,69	9.964,60	9.806,15	8.341,90	8.341,90	5.419,32	7.172,44
LCC total (excl. scrap@EOL)	**€ /life**	**19.537,78**	**18.942,11**	**14.806,15**	**13.831,90**	**16.822,90**	**11.919,32**	**12.662,44**
marginal scrap value Cu @ EOL	€	0,00	0,00	0,00	0,00	1.806,00	0,00	0,00
NPV scrap value (incl. discount rate)	€	0,00	0,00	0,00	0,00	376,17	0,00	0,00
LCC total (incl. scrap@NPV)	€	19.537,78	18.942,11	14.806,15	13.831,90	16.446,73	11.919,32	12.662,44
extra transformer cost T1 vs T2 (incl. NPV marginal Cu scrap)	**€**		**1.153,42**		**490,00**	**3.104,83**	**1.500,00**	**490,00**
value of losses saved vs T1	**€ /life**		**1.749,09**		**1.464,26**	**1.464,26**	**4.386,83**	**2.633,71**
marginal CAPEX for saving	**€/Wp**		**0,83**		**-1,68**	**0,47**		
RES value of CAPEX	**€/Wp**		**3,00**		**0,00**	**0,00**		
CAPEX increase T1 vs T2	**%**		**115%**		**110%**	**170%**	**130%**	**110%**
Benefit/Loss over life T1 vs T2	**€**		**595,67**		**974,26**	**-1640,57**	**2.886,83**	**2.143,71**

Table 1-12 Updated LCC calculation comparing previous Impact Assessment (2014) with the current updated baseline scenario PRIMES2040+ for BC1

Scenario		PRIMES2040-	PRIMES2040-	PRIMES2040-	PRIMES2040-	PRIMES2040+	PRIMES2040+ HL(high load)	PRIMES2040+ HL(high load)	PRIMES2040+ HL(high load)	PRIMES2040+ HL(high load)	PRIMES2040+ HL(high load)
Base Case		**BC1 DT liquid Tier1**	**BC1 DT liquid Tier2**	**BC1 DT Tier2 brown F**	**BC1 DT liquid BAT**	**BC1 DT liquid T2 kPEI=0,25**	**BC1 DT liquid Tier1**	**BC1 DT liquid Tier2**	**BC1 DT Tier2 brown F**	**BC1 DT liquid BAT**	**BC1 DT liquid T2 kPEI=0,25**
transformer rating (Sr)	kVA	400	400	400	400	400	400	400	400	400	400
no load class		Ao	Ao-10%	Ao-10%	Ao-50%	Ao-36%	Ao	Ao-10%	Ao-10%	Ao-50%	Ao-36%
load class		Ck	Ak	Ak	Ak	Ck	Ck	Ak	Ak	Ak	Ck
PEI	%	99,297%	99,439%	99,439%	99,582%	99,438%	99,297%	99,439%	99,439%	99,582%	99,438%
Load Factor (k) (=Pavg/S)	**ratio**	**0,15**	**0,15**	**0,15**	**0,15**	**0,15**	**0,33**	**0,33**	**0,33**	**0,33**	**0,33**
Load form factor (Kf)(=Prms/Pavg)	ratio	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073
availability factor (AF)	ratio	1	1	1	1	1	1	1	1	1	1
Power factor (PF)	ratio	0,9	0,9	0,9	0,9	0,9	0,9	0,9	0,9	0,9	0,9
Equivalent load factor (keq)	**ratio**	**0,18**	**0,18**	**0,18**	**0,18**	**0,18**	**0,39**	**0,39**	**0,39**	**0,39**	**0,39**
load factor@PEI (kPEI)	ratio	0,306	0,345	0,345	0,257	0,245	0,306	0,345	0,345	0,257	0,245
no load and aux. losses per year	kWh/y	3766,8	3390,1	3390,1	1883,4	2409,0	3766,8	3390,1	3390,1	1883,4	2409,0
load losses per transformer per year	kWh/y	1288,7	910,5	910,5	910,5	1288,7	6237,4	4406,9	4406,9	4406,9	6237,4
losses per year	kWh/y	5055,5	4300,6	4300,6	2793,9	3697,7	10004,2	7797,0	7797,0	6290,3	8646,4
transformer life time	y	40,00	40,00	40,00	40,00	40,00	40,00	40,00	40,00	40,00	40,00
kWh price no load and aux. Losses	**€**	**0,073**	**0,073**	**0,073**	**0,073**	**0,073**	**0,098**	**0,098**	**0,098**	**0,098**	**0,098**
kWh price load losses	**€**	**0,073**	**0,073**	**0,073**	**0,073**	**0,073**	**0,098**	**0,098**	**0,098**	**0,098**	**0,098**
CAPEX - transformer	€	**5.000,00**	**5.490,00**	**8.481,00**	**6.500,00**	**5.490,00**	**5.000,00**	**5.490,00**	**8.481,00**	**6.500,00**	**5.490,00**
losses per year	kWh/y	5055,5	4300,6	4300,6	2793,9	3697,7	10004,2	7797,0	7797,0	6290,3	8646,4
discount rate	%	**4%**	**4%**	**4%**	**4%**	**4%**	**4%**	**4%**	**4%**	**4%**	**4%**
electricity escalation rate	%	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**
PWF	ratio	19,79	19,79	19,79	19,79	19,79	19,79	19,79	19,79	19,79	19,79
No load loss capitalization factor (A)	€/W	12,66	12,66	12,66	12,66	12,66	16,99	16,99	16,99	16,99	16,99
Load loss capitalization factor (B)	€/W	0,40	0,40	0,40	0,40	0,40	2,63	2,63	2,63	2,63	2,63
TCO B/A ratio	ratio	0,03	0,03	0,03	0,03	0,03	0,15	0,15	0,15	0,15	0,15
OPEX electricity	€/y	369,05	313,95	313,95	203,96	269,93	980,41	764,10	764,10	616,45	847,35
LCC electricity	€ /life	7.304,58	6.213,86	6.213,86	4.036,84	5.342,74	19.405,08	15.123,75	15.123,75	12.201,18	16.771,37
LCC total (excl. scrap@EOL)	**€ /life**	**12.304,58**	**11.703,86**	**14.694,86**	**10.536,84**	**10.832,74**	**24.405,08**	**20.613,75**	**23.604,75**	**18.701,18**	**22.261,37**
marginal scrap value Cu @ EOL	€	0,00	0,00	1.806,00	0,00	0,00	0,00	0,00	1.806,00	0,00	0,00
NPV scrap value (incl. discount rate)	€	0,00	0,00	376,17	0,00	0,00	0,00	0,00	376,17	0,00	0,00
LCC total (incl. scrap@NPV)	€	12.304,58	11.703,86	14.318,69	10.536,84	10.832,74	24.405,08	20.613,75	23.228,58	18.701,18	22.261,37
extra transformer cost T1 vs T2 (incl. NPV marginal Cu scrap)	**€**		**490,00**	**3.104,83**	**1.500,00**	**490,00**		**490,00**	**3.104,83**	**1.500,00**	**490,00**
value of losses saved vs T1	**€ /life**		**1.090,72**	**1.090,72**	**3.267,74**	**1.961,85**		**4.281,33**	**4.281,33**	**7.203,91**	**2.633,71**
marginal CAPEX for saving	**€/Wp**		**-1,68**	**0,47**				**-1,68**	**0,47**		
RES value of CAPEX	**€/Wp**		**0,00**	**0,00**				**0,00**	**0,00**		
CAPEX increase T1 vs T2	**%**		**110%**	**170%**	**130%**	**110%**		**110%**	**170%**	**130%**	**110%**
Benefit/Loss over life T1 vs T2	**€**		**600,72**	**-2014,11**	**1.767,74**	**1.471,85**		**3.791,33**	**1.176,50**	**5.703,91**	**2.143,71**

Table 1-13 LCC sensitivity to electricity price (PRIMES2040-) and high load factor assumption (PRIMES2040+HL)

Scenario		PRIMES2040+ low WACC	PRIMES2040+ low WACC	PRIMES2040+ low WACC	PRIMES2040+ low WACC	PRIMES2040+ low WACC	PRIMES2040+ 25 y	PRIMES2040+ 25 y	PRIMES2040+ 25 y	PRIMES2040+ 25 y	PRIMES2040+ 25 y
Base Case		**BC1 DT liquid Tier1**	**BC1 DT liquid Tier2**	**BC1 DT Tier2 brown F**	**BC1 DT liquid BAT**	**BC1 DT liquid T2 kPEI=0,25**	**BC1 DT liquid Tier1**	**BC1 DT liquid Tier2**	**BC1 DT Tier2 brown F**	**BC1 DT liquid BAT**	**BC1 DT liquid T2 kPEI=0,25**
transformer rating (Sr)	kVA	400	400	400	400	400	400	400	400	400	400
no load class		Ao	Ao-10%	Ao-10%	Ao-50%	Ao-36%	Ao	Ao-10%	Ao-10%	Ao-50%	Ao-36%
load class		Ck	Ak	Ak	Ak	Ck	Ck	Ak	Ak	Ak	Ck
PEI	%	99,297%	99,439%	99,439%	99,582%	99,438%	99,297%	99,439%	99,439%	99,582%	99,438%
Load Factor (k) (=Pavg/S)	**ratio**	**0,15**	**0,15**	**0,15**	**0,15**	**0,15**	**0,15**	**0,15**	**0,15**	**0,15**	**0,15**
Load form factor (Kf)(=Prms/Pavg)	ratio	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073
availability factor (AF)	ratio	1	1	1	1	1	1	1	1	1	1
Power factor (PF)	ratio	0,9	0,9	0,9	0,9	0,9	0,9	0,9	0,9	0,9	0,9
Equivalent load factor (keq)	**ratio**	**0,18**	**0,18**	**0,18**	**0,18**	**0,18**	**0,18**	**0,18**	**0,18**	**0,18**	**0,18**
load factor@PEI (kPEI)	ratio	0,306	0,345	0,345	0,257	0,245	0,306	0,345	0,345	0,257	0,245
no load and aux. losses per year	kWh/y	3766,8	3390,1	3390,1	1883,4	2409,0	3766,8	3390,1	3390,1	1883,4	2409,0
load losses per transformer per year	kWh/y	1288,7	910,5	910,5	910,5	1288,7	1288,7	910,5	910,5	910,5	1288,7
losses per year	kWh/y	5055,5	4300,6	4300,6	2793,9	3697,7	5055,5	4300,6	4300,6	2793,9	3697,7
transformer life time	**y**	40,00	40,00	40,00	40,00	40,00	**25,00**	**25,00**	**25,00**	**25,00**	**25,00**
kWh price no load and aux. Losses	**€**	**0,098**	**0,098**	**0,098**	**0,098**	**0,098**	**0,098**	**0,098**	**0,098**	**0,098**	**0,098**
kWh price load losses	**€**	**0,098**	**0,098**	**0,098**	**0,098**	**0,098**	**0,098**	**0,098**	**0,098**	**0,098**	**0,098**
CAPEX - transformer	€	**5.000,00**	**5.490,00**	**8.481,00**	**6.500,00**	**5.490,00**	**5.000,00**	**5.490,00**	**8.481,00**	**6.500,00**	**5.490,00**
losses per year	kWh/y	5055,5	4300,6	4300,6	2793,9	3697,7	5055,5	4300,6	4300,6	2793,9	3697,7
discount rate	%	**1,1%**	**1,1%**	**1,1%**	**1,1%**	**1,1%**	**4%**	**4%**	**4%**	**4%**	**4%**
electricity escalation rate	%	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**
PWF	ratio	32,22	32,22	32,22	32,22	32,22	15,62	15,62	15,62	15,62	15,62
No load loss capitalization factor (A)	€/W	27,66	27,66	27,66	27,66	27,66	13,41	13,41	13,41	13,41	13,41
Load loss capitalization factor (B)	€/W	0,88	0,88	0,88	0,88	0,88	0,43	0,43	0,43	0,43	0,43
TCO B/A ratio	ratio	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03	0,03
OPEX electricity	€/y	495,44	421,46	421,46	273,80	362,38	495,44	421,46	421,46	273,80	362,38
LCC electricity	€ /life	15.962,86	13.579,28	13.579,28	8.821,80	11.675,59	7.739,82	6.584,11	6.584,11	4.277,37	5.661,08
LCC total (excl. scrap@EOL)	€ /life	**20.962,86**	**19.069,28**	**22.060,28**	**15.321,80**	**17.165,59**	**12.739,82**	**12.074,11**	**15.065,11**	**10.777,37**	**11.151,08**
marginal scrap value Cu @ EOL	€	0,00	0,00	1.806,00	0,00	0,00	0,00	0,00	1.806,00	0,00	0,00
NPV scrap value (incl. discount rate)	€	0,00	0,00	1.165,93	0,00	0,00	0,00	0,00	677,46	0,00	0,00
LCC total (incl. scrap@NPV)	€	20.962,86	19.069,28	20.894,36	15.321,80	17.165,59	12.739,82	12.074,11	14.387,65	10.777,37	11.151,08
extra transformer cost T1 vs T2 (incl. NPV marginal Cu scrap)	**€**		**490,00**	**2.315,07**	**1.500,00**	**490,00**		**490,00**	**2.803,54**	**1.500,00**	**490,00**
value of losses saved vs T1	**€ /life**		**2.383,58**	**2.383,58**	**7.141,06**	**4.287,27**		**1.155,71**	**1.155,71**	**3.462,45**	**2.078,74**
marginal CAPEX for saving	**€/Wp**		**-1,68**	**0,47**				**-1,68**	**0,47**		
RES value of CAPEX	**€/Wp**		**0,00**	**0,00**				**0,00**	**0,00**		
CAPEX increase T1 vs T2	**%**		**110%**	**170%**	**130%**	**110%**		**110%**	**170%**	**130%**	**110%**
Benefit/Loss over life T1 vs T2	€		**1.893,58**	**68,51**	**5.641,06**	**3.797,27**		**665,71**	**-1647,83**	**1.962,45**	**1.588,74**

Table 1-14 LCC sensitivity to lower WACC (PRIMES2040+ low WACC) and transformer life time (PRIMES2040 25y) assumptions

Scenario		Eurelectric	Eurelectric	Eurelectric	Eurelectric	Eurelectric	Ecodesign IA 2016	Ecodesign IA 2016	Ecodesign IA 2016	Ecodesign IA 2016	Ecodesign IA 2016
Base Case		**BC1 DT liquid Tier1**	**BC1 DT liquid Tier2**	**BC1 DT Tier2 brown F**	**BC1 DT liquid BAT**	**BC1 DT liquid T2 kPEI=0,25**	**BC1 DT liquid Tier1**	**BC1 DT liquid Tier2**	**BC1 DT Tier2 brown F**	**BC1 DT liquid BAT**	**BC1 DT liquid T2 kPEI=0,25**
transformer rating (Sr)	kVA	400	400	400	400	400	400	400	400	400	400
no load class		Ao	Ao-10%	Ao-10%	Ao-50%	Ao-36%	Ao	Ao-10%	Ao-10%	Ao-50%	Ao-36%
load class		Ck	Ak	Ak	Ak	Ck	Ck	Ak	Ak	Ak	Ck
PEI	%	99,297%	99,439%	99,439%	99,582%	99,438%	99,297%	99,439%	99,439%	99,582%	99,438%
Load Factor (k) (=Pavg/S)	**ratio**	**0,33**	**0,33**	**0,33**	**0,33**	**0,33**	**0,15**	**0,15**	**0,15**	**0,15**	**0,15**
Load form factor (Kf)(=Prms/Pavg)	ratio	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073	1,073
availability factor (AF)	ratio	1	1	1	1	1	1	1	1	1	1
Power factor (PF)	ratio	0,9	0,9	0,9	0,9	0,9	0,9	0,9	0,9	0,9	0,9
Equivalent load factor (keq)	**ratio**	**0,39**	**0,39**	**0,39**	**0,39**	**0,39**	**0,18**	**0,18**	**0,18**	**0,18**	**0,18**
load factor@PEI (kPEI)	ratio	0,306	0,345	0,345	0,257	0,245	0,306	0,345	0,345	0,257	0,245
no load and aux. losses per year	kWh/y	3766,8	3390,1	3390,1	1883,4	2409,0	3766,8	3390,1	3390,1	1883,4	2409,0
load losses per transformer per year	kWh/y	6237,4	4406,9	4406,9	4406,9	6237,4	1288,7	910,5	910,5	910,5	1288,7
losses per year	kWh/y	10004,2	7797,0	7797,0	6290,3	8646,4	5055,5	4300,6	4300,6	2793,9	3697,7
transformer life time	**y**	40,00	40,00	40,00	40,00	40,00	40,00	40,00	40,00	40,00	40,00
kWh price no load and aux. Losses	**€**	**0,05**	**0,05**	**0,05**	**0,05**	**0,05**	**0,117**	**0,117**	**0,117**	**0,117**	**0,117**
kWh price load losses	**€**	**0,05**	**0,05**	**0,05**	**0,05**	**0,05**	**0,117**	**0,117**	**0,117**	**0,117**	**0,117**
CAPEX - transformer	€	**5.000,00**	**5.490,00**	**8.481,00**	**6.500,00**	**5.490,00**	**5.000,00**	**5.490,00**	**8.481,00**	**6.500,00**	**5.490,00**
losses per year	kWh/y	10004,2	7797,0	7797,0	6290,3	8646,4	5055,5	4300,6	4300,6	2793,9	3697,7
discount rate	%	**4%**	**4%**	**4%**	**4%**	**4%**	**4%**	**4%**	**4%**	**4%**	**4%**
electricity escalation rate	%	**0%**	**0%**	**0%**	**0%**	**0%**	**4%**	**4%**	**4%**	**4%**	**4%**
PWF	ratio	19,79	19,79	19,79	19,79	19,79	40,00	40,00	40,00	40,00	40,00
No load loss capitalization factor (A)	€/W	8,67	8,67	8,67	8,67	8,67	41,00	41,00	41,00	41,00	41,00
Load loss capitalization factor (B)	€/W	1,34	1,34	1,34	1,34	1,34	1,31	1,31	1,31	1,31	1,31
TCO B/A ratio	ratio	0,15	0,15	0,15	0,15	0,15	0,03	0,03	0,03	0,03	0,03
OPEX electricity	€/y	500,21	389,85	389,85	314,51	432,32	591,50	503,17	503,17	326,89	432,63
LCC electricity	€ /life	9.900,55	7.716,20	7.716,20	6.225,09	8.556,82	23.659,84	20.126,95	20.126,95	13.075,50	17.305,33
LCC total (excl. scrap@EOL)	€ /life	**14.900,55**	**13.206,20**	**16.197,20**	**12.725,09**	**14.046,82**	**28.659,84**	**25.616,95**	**28.607,95**	**19.575,50**	**22.795,33**
marginal scrap value Cu @ EOL	€	0,00	0,00	1.806,00	0,00	0,00	0,00	0,00	1.806,00	0,00	0,00
NPV scrap value (incl. discount rate)	€	0,00	0,00	376,17	0,00	0,00	0,00	0,00	376,17	0,00	0,00
LCC total (incl. scrap@NPV)	€	14.900,55	13.206,20	15.821,03	12.725,09	14.046,82	28.659,84	25.616,95	28.231,78	19.575,50	22.795,33
extra transformer cost T1 vs T2 (incl. NPV marginal Cu scrap)	**€**		**490,00**	**3.104,83**	**1.500,00**	**490,00**		**490,00**	**3.104,83**	**1.500,00**	**490,00**
value of losses saved vs T1	**€ /life**		**2.184,35**	**2.184,35**	**3.675,46**	**1.343,73**		**3.532,89**	**3.532,89**	**10.584,34**	**6.354,50**
marginal CAPEX for saving	**€/Wp**		**-1,68**	**0,47**				**-1,68**	**0,47**		
RES value of CAPEX	**€/Wp**		**0,00**	**0,00**				**0,00**	**0,00**		
CAPEX increase T1 vs T2	**%**		**110%**	**170%**	**130%**	**110%**		**110%**	**170%**	**130%**	**110%**
Benefit/Loss over life T1 vs T2	€		**1.694,35**	**-920,48**	**2.175,46**	**853,73**		**3.042,89**	**428,06**	**9.084,34**	**5.864,50**

Table 1-15 LCC sensitivity to low electricity prices, higher loading (Eurelectric) and MEErP 2016 industry conform electricity prices, discount and escalation rate (IA 2016)

From these Tables the following conclusions can be taken:

- Negative business cases having lower LCC for Tier 1 compared with Tier 2 arise only for copper based brownfield (Brown F) transformers in some but definitively not all scenarios.
- The negative business case for brownfield sites is also seen in the reference scenario (PRIMES2040+), meaning that with the default parameters Tier 2 is not justified for them. However the sensitivity shows that it is not the case in scenarios with a lower WACC (PRIMES2040+low WACC) or higher load factor (PRIMES2040+HL) nor is it in the Ecodesign default MEErP energy OPEX (IA 2016) scenario. This means that:
    - The root of the problem is the higher transformer price due to the extra use of copper for brownfield transformers versus aluminium (see 1.1.6). A lower copper price would be most helpful but there is no evidence for that.
    - The main cause is related to searching for a high capital yield (WACC = 4%) versus the long life time of the transformer. The Present Worth Factor [39](PWF) is only 19,79 for any 40 year life time product and discount rate or WACC of 4%. If one would be satisfied with a lower WACC of 1,1 % then Tier 2 is cost effective compared to Tier 1, see 'PRIMES2040+low WACC' in Table 1-14. Also using the default MEErP parameters used for other industrial products (IA 2016) ends up with a positive business case. Using the default MEErP parameters (IA 2016) is useful to compare all products and their energy saving options on a similar basis to search for the 'most economic' in the envelope of options available to achieve the EU energy saving targets as a whole. This is of course different from claiming that Tier 2 could be a missed opportunity to search for a high WACC while only paying for the wholesale[40] electricity price component on long life time products, see also section 1.1.7.3 on electricity price. The latter is the 'Eurelectric scenario' (Eurelectric) and herein Tier 2 doesn't present a profitable business case for brown field applications with lock-in (severely space constrained) effect, see Table 1-15.
    - Another important cause is the low loading of BC1 (keq=0,18). If one were to assume a higher load then Tier 2 would be economically justified, see 'PRIMES2040+HL' in Table 1-13. Note that in section 1.1.7.4 this was identified as a realistic scenario for brownfield transformers. In practice it would simply mean that for some cases with a brownfield lock-in effect one should choose a lower rated retrofit transformer that ends up with a higher load factor.
- For BC1 the Tier 2 PEI compliant transformer 'T2 kPEI=0,25' provided more energy savings than the current borderline Tier 2 transformer. It still underperformed in energy saving and economic terms compared with the Tier 2 BAT transformer. This is a hypothetical case because manufacturers did not provide us with data for a Tier 2 PEI compliant transformer 'T2 kPEI=0,25', as they believe such an approach is uneconomic when applied to a broad range of products due to a reduced economy of scale for manufacture;
- The BAT transformer that is above the Tier 2 borderline out-performs all other greenfield options, hence there are grounds for considering Tier 3 requirements

[39] See MEErP methodology report
[40] https://www.belpex.be/market-results/the-market-today/dashboard/

disregarding the cases subject to brownfield lock in effects for which the BAT that relied on AMDT was not seen as a solution.

1.1.9 CAPEX for energy savings compared to CAPEX for RES

The life cycle cost of Tier 2 transformers is installed in green field sites is less than for Tier 2 models installed in brown field sites (see Table 1-9). Including the scrap-value improves the cost effectiveness of the Tier 2 brown field site case such that the life cycle costs are marginally below those of Tier 1 transformers in green field sites (and thus also below those of Tier 1 transformers in brown field sites)

However, it should be recognised that life cycle costs expressed across the average electricity mix are not the only valid comparator because there are also a variety of (often binding) policy measures in place that are designed to promote green (decarbonised) power. Thus it is also appropriate to consider how cost effective it is to deliver green power objectives by comparison with attaining an equivalent outcome (in terms of climate change impacts and energy security) from reducing transformer losses.

The previous base case analyses include estimates of the marginal CAPEX (in €) per peak watt (Wp) avoided from attaining Tier 2 loss levels (Table 1-9). Also shown are the estimated marginal CAPEX from supplying a peak watt of renewable energy (RES)[41]. **The marginal CAPEX due to moving from Tier 1 to Tier 2 loss reductions for green field transformers is just €0.83/Wp, which compares very favourably to a mean estimated value of €3.00/Wp from additional RES**. **The marginal CAPEX due to moving from Tier 1 to Tier 2 loss levels for brown field transformers is just €1.85/Wp,** which while higher than for green field sites, is still just 62% of the equivalent CAPEX for additional RES. Thus, while the life cycle cost of Tier 2 brown field transformers is not as low as for green field transformers, it is still just cost effective when using an average electricity mix and the marginal CAPEX is still very attractive compared with additional RES.

1.2 What is the environmental impact according to the new MEErP versus the previous MEEuP methodology of the base cases?

1.2.1 What is new in the MEErP compared to the MEEuP?

The Lot 2 study of 2011 used Ecoreport spreadsheets with environmental unit indicators produced in line with the MEEuP methodology (2005), this spreadsheet tool was amended in 2013 with the adoption of the MEErP methodology (2013)[42].

Both methods contain around 100 materials and processes with 13 environmental indicators per unit of material (e.g. in kg) or process (e.g. in kWh/ GJ). The new MEErP updated these indicators, e.g. with electrical energy impacts assessed

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[41] This is calculated from assuming a 50:50 mix of solar PV and wind power, where the cost of PV includes the cost of the inverter as well as the solar panel and the wind power is partially backed-up with hydro pumped storage. The inverter and storage need to be included so that the peak watt values are of equivalent reliability between the RES and avoided transformer loss cases. Not including these aspects would lower the cost of an equivalent Wp to €2 but this is no-longer of equivalent reliability.

[42] http://ec.europa.eu/growth/industry/sustainability/ecodesign_en (note: all documents including the Ecodesign spreadsheet and the MEErP methodology can be downloaded from this website)

according to the EU's 2013 electricity production mix. In 2011 the Lot 2 study (section 4.1.2.2) also extended the environmental unit indicators specifically applicable to transformers by adding 'mineral oil', 'wood' and 'ceramics'. These materials are still not included in the update but provision is made to add 'Extra Materials' in a separate category without the need for tweaking existing materials as was done in the Lot 2 study. The Bill-Of-Material input in the MEErP (2013) is identical to that used in the MEEuP (2005), see Annex B with BC1 transformer input.

The 2013 MEErP also extended the Ecoreport spreadsheet tool to include means for analysing material efficiency; this mainly affects End-of-Life (EoL) recycling. It enables the inclusion of separate assumptions (expressed as a percentage) on 'Reuse (repair)', 'Material recycling', 'Heat recovery', 'incineration' and 'Landfill' per product group (Ferro, non-Ferro, etc.). A comparison of EoL input for the BC1 transformer is given in Annex B. For some plastics (PET, HDPE, PVC) it also contains data and a conceptual calculation to give credits to the amount of recycled material used in production. Therefore the method calculates also a 'Recyclability Benefit Rate' (RBR) describing the "potential output" for future recycling. This is, however, mainly relevant for plastics (e.g. a non-coloured versus coloured) but irrelevant for metals and hence the transformers in this review. A key finding related to RBR was also that specific methods regarding material efficiency for ecodesign are rarely used in industry, and that those methods which exist are still in the phase of scientific development. Hence for the review of the transformer regulation it is not recommended to consider these aspects of recycling.

The new MEErP also includes a calculation of Critical Raw Material (CRM) index (e.g. Germanium), but this is not relevant for transformers because such materials are not part of their BOM.

The results still report the 13 Environmental Unit Indicators (Figure 1-3). The production phase (brown) is often compensated by the recycling in the End-of-Life phase (green). These results were obtained using default recycling assumptions irrespective of the type of product addressed in the MEErP, but they are conservative for transformers and in reality the degree of recycling is likely to be greater. Particulate Matter environmental impact is largely related to distribution (shown in blue) but obviously this can be reduced by selecting railway transport.

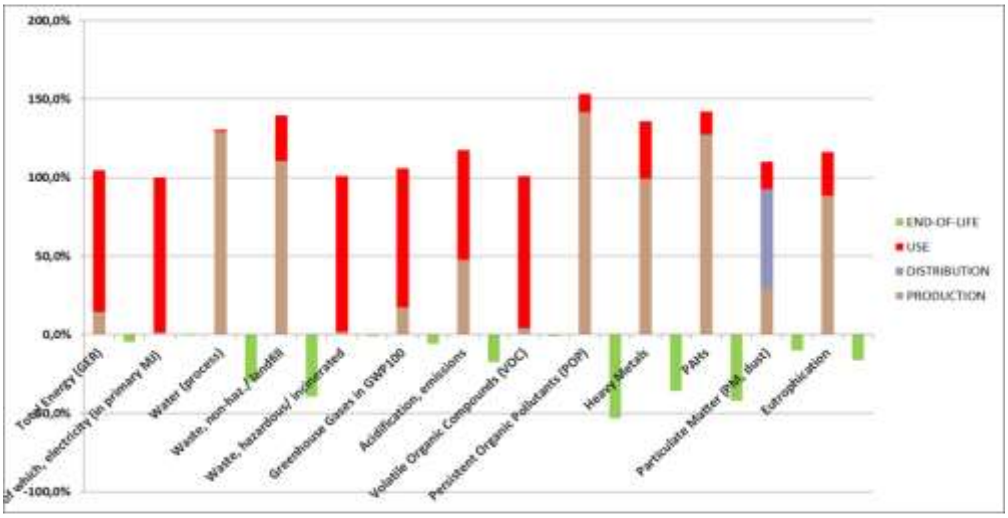

Figure 1-3 Processed graphical results from MEErP Ecoreport tool (2014) for BC1 - Distribution transformer A0+Ak or BAT transformer

1.2.2 What information related to the Tier 2 review does the MEErP still not provide?

It should be noted that the new MEErP Ecoreport tool spreadsheet does not provide:

- refined LCA details that model the differences between low loss steel, as needed to attain Tier 2 performance levels, versus the less efficient steel which is sufficient to attain Tier 1 (see section 1.5). It only contains a few unit indicators for a few types of steel per kg, and, for example, does not discriminate between 0.18 mm and 0.23 mm silicon steel. Hence a Tier 2 design with low loss steel will not create a different output compared to a Tier 1 design. Such data is hard to find and would require an in-depth LCA study to analyse the detailed manufacturing processes, which are beyond the time and budget frame of this study
- refined LCA data to compare different transformer liquids, such as synthetic or natural esters with mineral oil
- an environmental unit indicator for electricity use (kWh) differentiated according to the year of production. The value used is representative of the current electricity mix but does not account for changes over the time frame corresponding to a typical transformers lifespan (20-40 years)
- different approaches for recycling of Aluminium versus Copper, because it only allows the use of a single unified value for all non-ferro metals. The copper price scrap value and theft reports however suggest that there are different recycling practices and drivers, see section 1.1.6. Hence comparing both in a Tier 2 design is difficult as they cannot be discriminated.

1.2.3 Conclusions of the new MEErP related to Tier 2

From this cross-check it can be concluded that the impact of the use phase on the Global Warming Potential remains dominant, see Annex A. **Hence there is no reason to revise the Tier 2 regulation based on the impacts associated with the adoption of the (new) MEErP.**

LCA data in the new MEErP does not contain sufficient details to support proposing new requirements other than energy, for which it would be justified to consider additional requirements in the context of the review of Regulation 548/2014. As a conclusion, **for this purpose other data sources should be consulted in Task 4**.

The MEErP does not account for long term changes (i.e. over 40 years) in environmental impacts from transformer losses. To assess this, one could in principle compare the marginal (LCA) environmental impact from Tier 2 savings on losses to an LCA for renewable energy sources (RES) production, the same way as is done for CAPEX in section 1.1.9. Sufficient and reliable LCA data for a Tier 1 to Tier 2 transformer comparison is not available and therefore it will not be elaborated further in this limited study. Nevertheless we think that the LCA for this comparison will most likely follow the CAPEX comparison in section 1.1.9, meaning that the proposed Tier 2 savings are more beneficial from an environmental policy perspective compared to increased installation of RES and storage.

1.3 How does the Peak Efficiency Index (PEI) approach compare to the minimum load and no load losses approach?

1.3.1 Understanding the equations and relations behind PEI

In contrast to the analysis presented in the Lot 2 study (2011), which focused on maximum no load and load losses, the regulatory requirements introduced for large power transformers requirements in Regulation 548/2014 are based on the Peak Efficiency Index (PEI). The 'Peak Efficiency Index' (PEI) is defined in Regulation 548/2014 as 'the maximum value of the ratio of the transmitted apparent power of a transformer minus the electrical losses to the transmitted apparent power of the transformer'. In principle this could also be applied to medium power transformers and in the following text we analyse the possibilities and impact of potentially extending the use of this index to such medium power transformers.

In Annex II of Regulation 548/2014 the methodology for calculating the Peak Efficiency Index (PEI) is given based on the ratio of the transmitted apparent power of a transformer minus the electrical losses to the transmitted apparent power of the transformer.

PEI = 1 – 2 x (P0 + Pc0)/Sr/sqrt((P0 + Pc0)/Pk) (f.1)

Where,

- P0 is the no load losses measure at rated voltage and rated frequency, on the rated tap
- Pc0 is the electrical power required by the cooling system for no load operation
- Pk is the measured load loss at rated current and rated frequency on the rated tap corrected to the reference temperature
- Sr is the rated power of the transformer or autotransformer on which Pk is based.

The following text provides an explanation how this formula was obtained and it also helps comprehension of the meaning and use of it. For simplicity Pc0 will be neglected or it can be assumed to be part of P0, it is also zero for ONAN transformers.

In principle the loading, and hence the losses, of transformers vary over time, but with the subsequent formula time invariant calculations that correspond to these time variant losses can be done through the use of an equivalent load factor (keq) (defined below) and load form factor (Kf).

Total transformer losses (Ptot) are a combination of load and no load losses:

$Ptot = P0 + k_{eq}^2 \times Pk = P0 + k^2 \times Kf^2 \times Pk$ (f.2)

Where (see the Lot 2 study),

- Ptot are the total transformer losses;
- Pavg is the average power loading of the transformer over a period of time (=∫ P(t)dt/T);
- Prms is the root-mean-square (rms) value of the power loading of the transformer over a period of time (=∫ P²(t)dt/T);
- Load form factor (Kf): the ratio of the root mean squared (rms) power to the average power (=Prms/Pavg). This is a correction factor on the load factor to be applied when the transformer is not loaded constantly over time;

- k is (=Pavg/S): the ratio of the energy generated by a unit during a given period of time to the energy it would have generated if it had been running at its maximum capacity for the operation duration within that period of time (IEC 60050). The load factor of a transformer is defined as the ratio of the average load (Pavg) to the rated power (S) of the transformer. Note that herein Pavg is in kVA and that Pavg needs to be corrected for the power factor where applicable, e.g. Pavg(kVA)=Pavg (kW) x PF. For simplicity the power factor is left out of the subsequent analysis (PF=1) but can be added afterwards;
- k_{eq} (=kxKf): is the equivalent load factor (see Lot 2) which is the load factor for a flat or constant load profile that corresponds with the real time variable load profile.

The Efficiency Index (EI) of a transformer depends on its loading (k_{eq}) and is defined as:

$$EI = 100. (S- P0 + k_{eq}^2 \times Pk)/S\ [\%] = 100. (1- (P0 + k_{eq}^2 \times Pk)/S) \qquad (f.3)$$

Where (see the Lot 2 study):

- Efficiency Index (EI) as ratio of the transmitted apparent power of a transformer minus electrical losses to the transmitted apparent power of the transformer (see EN 50588-1:2016).

Note, however, that this effiiciency index calculation (EI) is a simplification that neglects a small positive temperature effect at part load (k<1) on conduction losses and also a secondary effect (+/-) on the current and associated load losses from the interaction between load (cos phi<1) and the transformer impedance.

As a consequence of this **the real transformer efficiency (EI) for a given combination of load (Pk) and no load losses (P0) depends on the loading** and **the peak or maximum efficiency always occurs at the point where no load losses are equal to load losses** (see Lot 2). The impact of this equation is illustrated in Figure 1-4, wherein 'Tier 1 αopt=0,306' represents the Tier 1 requirements for 400 kVA liquid transformer with P0=430W and Pk=4600W and 'Tier 2 αopt=0,345' Tier 2 with P0=387W and Pk=3250W. In this figure BAT-AMT is the Best Available Technology of Lot 2 based on an amorphous transformer.

The previous equation allows a so-called optimum equivalent load factor or load factor of Peak Efficiency Index (k_{PEI}) to be calculated for each combination of P0 and Pk, because at the optimum $k_{PEI}^2 \times Pk = P0$:

$$k_{PEI} = sqrt(P0/Pk) \qquad (f.4)$$

Where:

- k_{PEI} is the load factor for a given combination of P0 and Pk that has the highest efficiency or 'load factor at which Peak Efficiency Index occurs' (see EN 50588-1:2016).

This optimum load factor (k_{PEI}) occurs at the Peak Efficiency Index (PEI) and therefore:

$$PEI = (k_{PEI} \times S-(Pk \times k_{PEI}^2 + Po))/(k_{PEI} \times S)$$

Substituting αopt with sqrt(P0/Pk) in the previous formula results in the formula from the equation (f.1).

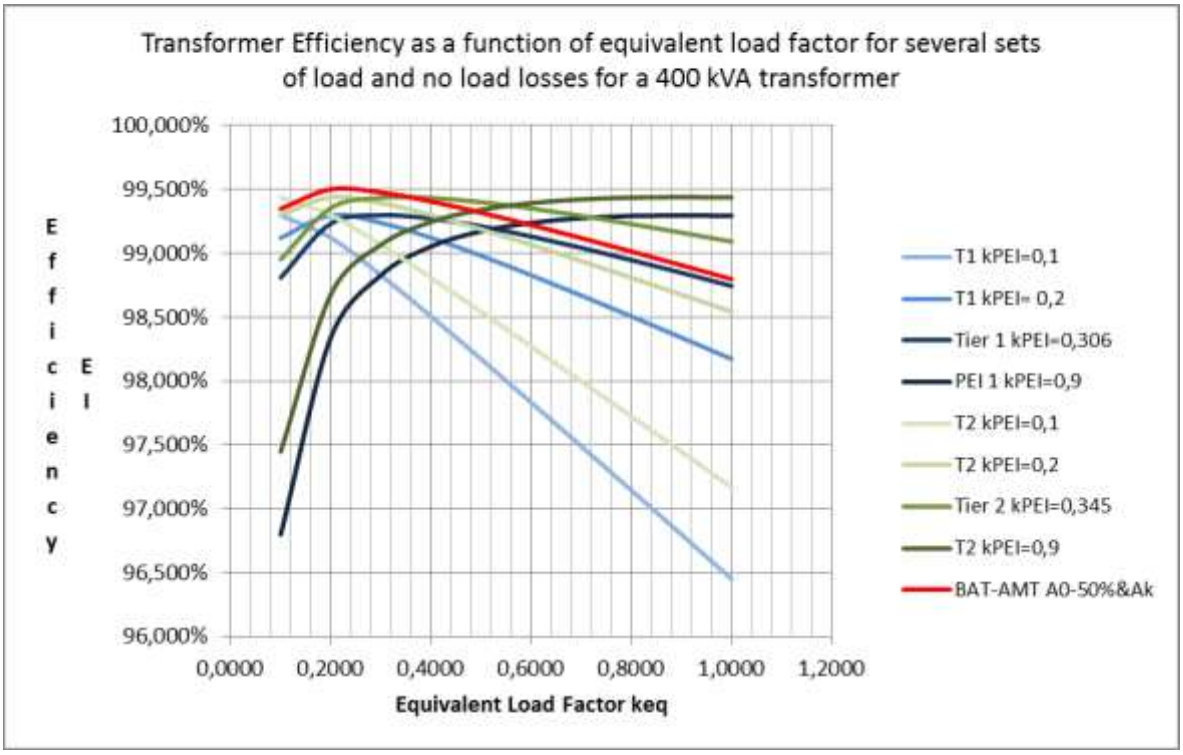

Figure 1-4 Efficiency versus loading for various designs

Hence, **for each combination of Pk & P0 the load factor of Peak Efficiency Index (k_{PEI}) can be calculated** that corresponds to the load factor that produces the PEI. For example, a 400 kVA liquid filled transformer Tier 1 (P0=430W, Pk=4600W) will have an optimum loading at load factor 0.306 and Tier 2 (P0=387W, Pk=3250W) at load factor 0.345.

As a consequence with this formula for a given PEI several combinations of P0 & Pk can be calculated, each of them having a different optimum equivalent load factor (αopt), as is done in Figure 1-4. In this figure all curves 'T1 αopt=0.1', 'T1 αopt= 0.2', 'Tier 1 αopt=0.306' and 'T1 kPEI=0.9' have the same PEI of 99.297% but only 'Tier 1 kPEI = 0.306' is compliant with Tier 1 of Regulation 548/2014. The others are non-compliant but have the same PEI**.** Consequently, **if the PEI was used instead of a combination of load (Pk) and no load losses (P0) many other combinations would be possible that are none compliant today.**

Also it should be noted **for every combination of PEI & kPEI there is a corresponding combination of Pk & P0** that can be calculated, and that results in a single curve, as shown in Figure 1-4.

1.3.2 How does the equivalent load factor and PEI relate to the no load (A) and load (B) loss capitalization factors for calculating Total Cost of Ownership?

Ideally during any transformer procurement process the **expected equivalent load factor (keq)** should be estimated and **should be set to match with the optimum load factor (kPEI)** to warrant the real efficiency matches with the PEI.
Therefore the tender could in principle add the optimum load factor as a second criterion to the minimum PEI and tender for the lowest cost capital expenditure

(CAPEX) for a transformer meeting these specifications. It is however also possible to tender for the lowest total cost of ownership (TCO) by also taking the operational expenditure (OPEX) into account. In this case the OPEX is related to the electricity cost, present worth factor (PWF) and load factor, as follows:

$$OPEX = A \times P0 + B \times Pk$$

and

$$A = C0 \times PWF$$
$$B = keq^2 \times Ck \times PWF$$

Where:

- A is the no load loss capitalisation factor [€/W]
- B is the load loss capitalisation factor [€/W]
- C0 is the present electricity cost for no load losses [€/W]
- Ck is the present electricity cost for load losses [€/W]
- PWF is the present worth factor with $PWF = (1 - 1/(1+ r)^N)/r$
- N is the transformer economic life time in years
- r is the discount rate [%].

Therefore the B/A ratio is related to the load losses by:

$$B/A = keq^2 \times Ck/C0$$

When there is no difference between the electricity cost for load and no load losses (Ck/C0):

$$B/A = keq^2 = kPEI^2$$

As a consequence, the ratio between capitalisation factors for load and no load losses (B/A) is directly related to the equivalent load factor (keq). Hence having a minimum ratio between load and no load losses is an alternative requirement for having a minimum equivalent load factor.

The TCO and loss capitalisation data for the base cases considered in this study is shown in Table 1-1, Table 1-2 and Table 1-3.

1.3.3 What is the benefit of using PEI?

In principle, the PEI allows the specification of a transformer design whereby the highest operational efficiency equal to the PEI is achieved on the condition that the equivalent load factor (keq) matches the optimum load factor (kPEI), see Figure 1-4. For example, consider the case of a 400 kVA liquid filled transformer at Tier 2 when the equivalent load factor (keq) in real circumstances is equal to the optimum load factor (kPEI) of 0.345. Obviously, Tier 2 (P0=387W, Pk=3250W) compared to Tier 1 (P0=430W, Pk=4600W) mainly lowers the transformer load losses and therefore the optimum load factors increase from 0.306 to a higher loading value of 0.345. The cost sensitivity analysis in section 1.1.8 also examines a Tier 2 PEI borderline compliant scenario, referred as 'T2 kPEI=0,25'. This hypothetical transformer was closer to the loading factor of BC1 (keq=0,18) and therefore resulted in lower losses and lower OPEX compared to the borderline 'T2' compliance (kPEI=0.345). Despite this, the BAT which is Tier 2 compliant and which is not a borderline case, had lower losses and lower LCC compared to this.

In principle, the use of the PEI allows freedom to design a range of borderline compliant transformers with different combinations of Pk & P0 to

match the optimum load factor or load factor at PEI. For this reason some utilities[43] support the PEI approach.

A **simplification of the PEI** approach is to **use two or three lists of load/no load losses for minimum compliant transformers** that have identical PEI to Tier 2. Based on BC1 and the underlying evidence of Lot 2 **there is an argument to review Tier 2 and also allow a second Tier 2 PEI compliant scenario**, referred as 'T2 kPEI=0,25' **which is A0-35%/Ck**. Note that this a hypothetical transformer, for which we have received no evidence indicating such products are available on the market today.

Note, however, that the PEI approach does not necessarily result in the lowest life cycle cost (LCC) for a given efficiency because:

- OPEX (euro/kWh) for load(Pk) and no load (P0) losses can be different.
- CAPEX for lowering load and no load losses can be different, e.g. for the same efficiency lowering load losses can be more expensive due to the relatively higher copper price compared to lowering the load losses.

1.3.4 What is the risk of only specifying PEI requirements?

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, see Figure 1-4. 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.

This loophole could only be avoided by specifying PEI together with a minimum load factor at PEI (kPEI), e.g. PEI & kPEI > 0,19 [44]. For large power transformers a larger kPEI can be used (see 1.3.5**), e.g. kPEI >0,25**. Such a combined specification provides freedom of design but prevents the loophole from underspecifying the optimum load factor as a means of seeking a low cost transformer design. Note that the capitalisation factors are related to kPEI, hence **specifying requirements in terms of a minimum capitalisation factor ratios would be an equivalent policy.**

The manufacturers grouped in T&D Europe[45] **do not support PEI** or several load/no load loss lists of minimum compliance for smaller MV/LV transformers because of:

- **a resulting reduction in standardisation** of components which could produce a **non-negligible increase in production costs for small series products** (potentially of >10%);
- **an increase in transformer prices due to reduced market competition,** as local premises will have advantages over non-local through better-adapted products and stock for the local specifications;

[43] See stakeholder workshop minutes of meeting
[44] 0,19 was the minimum load factor found in the Lot 2 study (2011)
[45] http://www.tdeurope.eu/en/home/

- **a risk for backsliding** in the market **towards specifying kPEI with the lowest known price** (most likely low kPEI due to the importance of copper when reducing load losses);
- An incentive to cheat because the PEI is a complex notion and more difficult to understand by the users.

As a consequence of these concerns, and of those previously expressed, **we do not recommend that energy performance regulations be set for medium power transformers just in terms of the PEI, without also including a minimum kPEI requirement.**

Note too that instead of using a minimum PEI & kPEI the specification of a minimum P0 & Pk could be considered. This offers flexilbility to do better compared to the minimum. **Hence there is no recommendation to extend the application of PEI to smaller power transformers.**

1.3.5 PEI data for large power transformers

Commission Regulation (EU) No 548/2014 requires only that a minimum PEI level be met for large power transformers, hence this opens a loophole as discussed previously in section 1.3.4 by underspecifying a low optimum load factor (= sqrt((P0+Pc0)/Pk)). Therefore it might be useful to consider the specification of a minimum optimum load factor (sqrt((P0+Pc0)/Pk)) as a complementary measure to the PEI, or alternatively, specification of the ratio of no load to load losses ((P0+Pc0)/Pk). Figure 1-5 and Figure 1-6 contain a selection of historic data collected within the Lot 2 study (2010) and CENELEC (2012) collected data on PEI and no load to load losses ratios. At the time of collecting this data, from the installed transformer base, the Commission Regulation (EU) No 548/2014 was not yet in force. It can be observed that optimum load factors varied between 0.25 and 0.7 and that PEI was often below Tier 1 or Tier 2 requirements. **A loophole could exist wherein Tier 2 transformer procurement specifiers shift specifications towards low optimum load factors (<0.25)** to satisfy PEI requirements without having to invest in higher copper content products for load loss reduction. This loophole could be closed by **the addition of a minimum load factor at PEI (kPEI) or ratio of no-load to load losses.** From the stakeholder workshop it was concluded that amongst stakeholders there is no consensus on a minimum kPEI approach and that TSOs grouped within ENTSOE want to maintain the freedom to specify this themselves. Some of the rationale put forward against using a PEI approach for distribution transformers were related to the economic benefits of mass production and are not valid for large power transformers because they are small volume niche products. Hence there is an argument to maintain the current use of PEI within the Tier 2 regulatory requirements for larger power transformers.

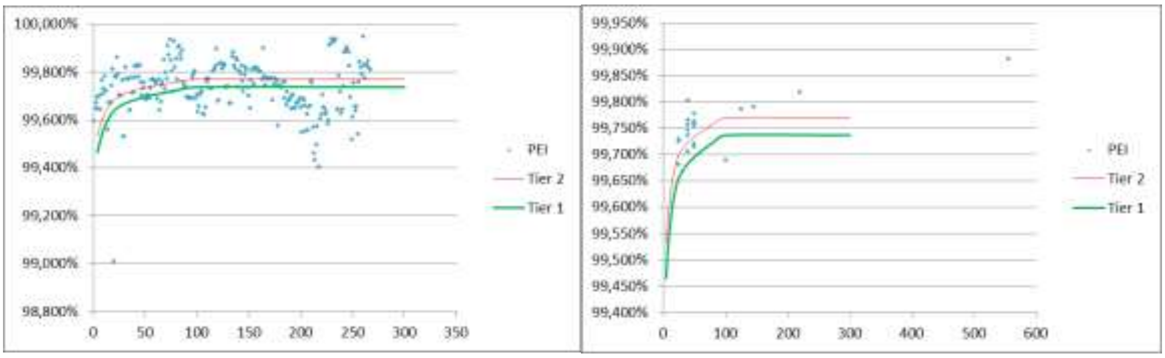

Figure 1-5 Collated Power Efficiency Index(PEI) data of installed large power transformers and Tier1 & 2 minimum requirements (left, based on data collected by CENELEC in 2012 supplied to the study; right, from Lot 2 in 2010)

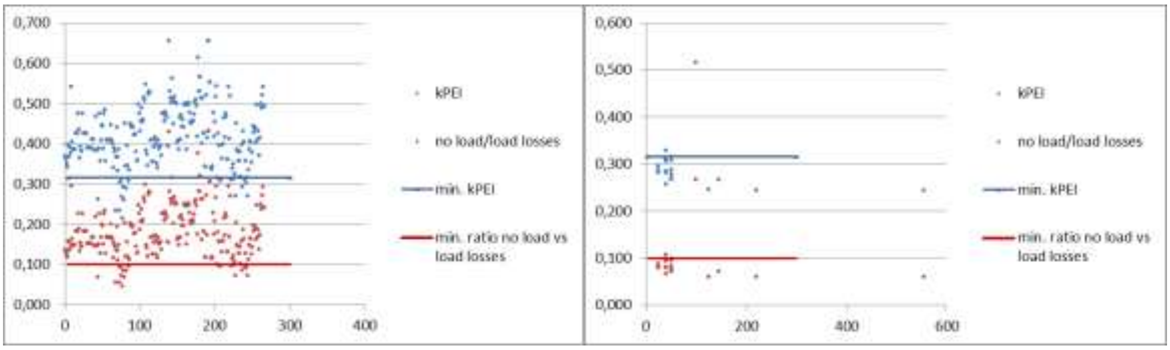

Figure 1-6 Collated optimum load factor (kPEI) or no load vs load losses ratio ((P0+Pc0)/Pk) data of installed large power transformers and Tier1 & 2 minimum requirements (left, based data collected by CENELEC in 2012 supplied to the study; right, in Lot 2 in 2010)

Also when looking at this historical kPEI data in Figure 1-6 ENTSO-E[46] remarked in the stakeholder workshop that for transmission networks distributed generation is increasing the difference between minimum and maximum loads and that average loads may therefore be coming down for large power transformers.

1.4 What is the current status of manufacturers reaching Tier 2 requirements for green field applications?

1.4.1 Green-field transformers - manufacturer survey

Table 1-16 shows the responses[47] received for a T&D Europe[48] transformer manufacturer association survey into the feasibility of Tier 2 transformer requirements for green field applications. **The conclusion is that there are no technical barriers**

[46] https://www.entsoe.eu/

[47] Source: in a written reply to the 'Questionnaire for distribution tranformer manufacturers (MV/LV) for brown field and green field applications' in the course of this study

[48] http://www.tdeurope.eu/en/home/

to manufacture Tier 2 transformers, as was expected in the Lot 2 study. Only in the case of large pole-mounted transformers (315 kVA) and larger dry type medium power transformers (4-16 MVA) did some manufacturers report difficulties in producing them.

Table 1-16 T&D Europe manufacturer survey on Green Field transformer Tier 2 feasibility

Base/Boundary	Application	Insulation Technology	Case Power Rating (kVA)	Case Voltage Rating high side (kV)	Tap changer	FEASIBILITY YES	NO	Voted	RAW MATERIAL Alu	Cu	Both	Total
boundary lower	Distribution	liquid immmersed	250	20...22	DETC	100%	0%	**100%**	14%	29%	57%	100%
base	Distribution	liquid immmersed	400	20...22	DETC	100%	0%	**100%**	29%	29%	43%	100%
boundary upper	Distribution	liquid immmersed	1000	20...22	DETC	100%	0%	**100%**	14%	43%	43%	100%
boundary	Distribution /Industruial	liquid immmersed	3150	20...22	DETC	100%	0%	**100%**	14%	43%	29%	86%
base	industry transformer	dry type	1250	20	DETC	86%	0%	**86%**	29%	29%	29%	86%
boundary upper	industry transformer	dry type	3150	20	DETC	86%	0%	**86%**	29%	29%	29%	86%
boundary lower	industry transformer	dry type	400	20	DETC	86%	0%	**86%**	29%	29%	29%	86%
base	pole mounted	liquid immersed	100	20...22	DETC	86%	0%	**86%**	14%	29%	43%	86%
boundary upper	pole mounted	liquid immersed	315	20...22	DETC	71%	14%	**86%**	29%	14%	29%	71%
boundary lower	pole mounted	liquid immersed	25	25...33	DETC	86%	0%	**86%**	14%	43%	29%	86%
sample	pole mounted/single phase	liquid immersed	50	25...33	DETC	71%	0%	**71%**	14%	29%	29%	71%
base	medium power	liquid immersed	25,000	33	OLTC	86%	0%	**86%**	0%	43%	29%	71%
boundary upper	medium power	liquid immersed	31,500	33	OLTC	86%	0%	**86%**	0%	43%	29%	71%
boundary lower	medium power	liquid immersed	6,300	33	OLTC	86%	0%	**86%**	0%	43%	29%	71%
base	medium power	dry type	4,000	30	DETC	57%	14%	**71%**	14%	14%	29%	57%
boundary upper	medium power	dry type	16,000	30	DETC	29%	29%	**57%**	0%	14%	29%	43%
base	Large Power	liquid immersed	100,000	132	OLTC	71%	0%	**71%**	0%	43%	29%	71%
base	large Power	dry type	25,000	66	OLTC	29%	29%	**57%**	0%	14%	29%	43%

1.4.2 Examples of Tier 2 compliant products

Most Tier 2 compliant transformers[49] already on the market are Amorphous Metal Transformers (AMT). As explained in Lot 2 they are larger and heavier due to the limited maximum magnetic flux density (typically 1,2 Tesla). Their no load losses are well below Tier 2 requirements. Due to their typical rectangular core cross section more care must be given to withstanding conductor forces during short circuits. Therefore the new standard EN 50588-1:2016 also introduced an additional short-circuit test for new transformers with a level of no load loss 'AAA_0'. Note, however, that some manufacturers[50] have clearly solved the issue of short circuit behaviour. Finally AMT Tier 2 is more expensive than GOES Tier 1 solutions due to the amount and cost of material, see section 1.1.3.2. The higher price and greater volume may explain the relatively modest uptake on the European market today of AMT Tier 2 compliant transformers.

Obviously, Tier 2 transformers can also be made from Grain Oriented Electrical Steel (GOES) but today few examples of such products can be found in manufacturers catalogues. One manufacturer has a GOES distribution transformer in their catalogue[51] with no load losses +5 % and no load losses -5% compared to Tier 2, which is therefore PEI compliant but with different kPEI. This load/no load loss combination might also fit better to lower load factors found in distribution today (e.g. BC1 is 0,18) (see discussion in section 1.9).

[49] For example 'Minera HE+' http://www.schneider-electric.com.eg/en/product-range/62108-minera-he-/ or 'Wilson e2' http://www.wilsonpowersolutions.co.uk/products/wilson-e2-amorphous-transformer/ or ABB AMT produced in Poland 'http://www.abb.com/cawp/seitp202/997a6720461a541fc1257c19004a1434.aspx'

[50] http://www.cired.net/publications/cired2009/pdfs/CIRED2009_0090_Paper.pdf

[51] http://www.raustoc.ch/Media/KD-00047_Verteiltrafo-freiatmend_de.aspx

1.5 What are the Tier 2 technical limits from space/weight constraints and challenges for brown field installations?

1.5.1 Introduction

As explained in Lot 2 (2011) **some of the improvement options to reduce transformer losses can increase the size and weight of the transformer**, e.g. increase the amount of copper in order to decrease load losses, or reduce the maximum magnetic flux density in silicon steel to lower the no load losses. Hence **the introduction of the Tier 2 limits could increase the size and weight of equivalent designs compared to Tier 1.** The subsequent sections will investigate the consequence of this with regard to installation requirements.

1.5.2 Installation space/weight constraints for medium power transformers

This section discusses brown field transformer applications, i.e. transformers destined for a replacement project that has specific limitations of size and/or weight resulting from the need to install the transformer in an existing enclosure, see for example Figure 1-7 and Figure 1-8. The rationale behind this investigation is that transformers are often considered to be a 'spare part' for an existing substation. In principle, constraints for space and/or weight depend on the type of substation, or may also apply to transformers used in wind turbines (see Figure 1-8).

Figure 1-7 Metal substation max. 250 kVA (left) and standard concrete prefabricated substation max. 630 kVA (right) with dimensional and weight constraints (Source: Synegrid BE, 2016)

Figure 1-8 Dry type transformer installed in wind turbine tower with dimensional constraints (Source: EDF EN (Energies Nouvelles), 2016)

If a transformer is too big or too heavy additional investments are required, e.g. a change of all the MV equipment and the substation, or parts of it. The cost for a completely new transformer substation installation can be up to 8 times greater than the transformer itself. E.g. in Germany[52] the typical unit cost for a fully installed greenfield 400 kVA transformer substation is 36 950 euro (excl. VAT). Obviously such an investment is beyond the scale considered for the cost-benefits assessment that informed the Tier 2 requirements, see Table 1-1. Therefore this study launched an enquiry of installers with regard to transformer constraints and limitations, see Annex C. The subsequent results for the most common types of distribution transformers are shown in Annex D and an extract for a liquid filled 630 kVA distribution transformer is given in Table 1-17. It can be seen that dimension & weight constraints and also other technical requirements vary depending on the utility and/or country across Europe. In general dimensional requirements result in quite close fits to compact substations. These findings suggest that mainly the weight could become a limiting factor, but height may also become one. The weight is limited because of the flooring, e.g. concrete or metal in prefab substations. The height is often limited due to the ceiling height combined with requirements for cable bending. The width depends on the door width. The feasibility of Tier 2 compliant designs to cope with these requirements is further investigated in sections 1.6, 1.7 and 1.8. In general **it appears that European utilities have often been under pressure to limit the urban space they claim for their substations and therefore have historically elaborated tight specifications without being aware it could create lock-in effects against larger more efficient transformers.**

[52] Price consulted on 15/5/2017: http://www.starkstrom-lobenstein.de/mittelspannung.php

Table 1-17 Different space and weight constraints in Europe depending on the Utility for a liquid filled 630 kVA distribution transformer

		brownfied country specifications								brownfield average	brownfied country specifications (received after manufacturer enquiry launch)		
country		BE	D	NL	F	PL	ES	N	S		SI	IT	IT
sample (s) or representative (r)		r	s REWAG2015	r spec 11/2016	r classical	s	r Iberdrola2014	r	r		r	r areti-1	r e-distributzione
Transformer category(1)		DT	DT	DT	DT-Enedis	DT	DT	DT	DT	DT	DT	DT	DT
Rated power of each winding (kVA)		630/630/630	630	630	630	630	630	630	800	630	630	630/472	630
Rated voltage of each winding (kV)	high side (kV)	15,4	20,8	23	20	21	20	22	22	20,8	21(10,5)	20,8(8,4)	20 or 15 or 10
	Low Side (kV)	0,42	0,4	0,4	0,4	0,42	0,42	0,42	0,42	0,4	0,42	0,42(0,242)	0,42
	Low Side (kV) 2 LV windings	0,242											
Highest voltage for equipment of each	high side (kV)	17,5	24	24	20	24	24	24	24	24	24	24	24
	low side (kV)	3,6	DIN EN 50386	EN 50386 (1kV)		1	1,1	1,1	1,1	1,1	1,1	1,1	1,1
Vector Group(3)		DYN11a11	DYN5	DYN5 or DYN11	DYN11	DYN5	DYN11	Yyn0	Yyn0 or DYN11	Dyn11	Dyn5	Dyn11	Dyn11
Regulation type		DETC		DETC		DETC	DETC	DETC		DETC	DETC	DETC	DETC
Tapping				±2x2.5%			±2x2.5%						
Impedance(6) [%]		4	4	4	4	4 and 4.5	4	4 or 6	5,8	4	4	6,7(0,42) /5,1(0,242)	4 (or 6)
max. length (mm)		**1500**	**1500**	**1500**	**1700**	**1400**	**1650**	**1550**	**1500**	**1538**	**1500**	**1600**	**1800**
max. width (mm)		**850**	**900**	**820**	**920**	**900**	**1140**	**900**	**900**	**916**	**800**	**930**	**1030**
max. heigth (mm)		**1360**	**1800**	**1680**	**1650**	**1700**	**1870**	**2100**	**1400**	**1695**	**NA**	**NA**	**1850**
max. weight (kg)		**2400**	**2500**	**2650**	**2500**	**2000**	**2400**	**NA**	**2300**	**2393**	**2000**	**2500**	**2000**
Sound power level			<50	<52						<51			
Minimum clearance between live parts and ground [mm]		EC60076-3	55	100				IEC 60076-3			130(230)	NA	NA
Minimum free distance required around the transformer [mm]					200						100	200	NA

1.5.3 Space weight constraints for the transportation of large power transformers

1.5.3.1 Introduction

As explained in section 1.5.1 some of the improvement options to reduce transformer losses can increase transformer size and weight. Hence the introduction of Tier 2 requirements could increase size and weight compared to Tier 1 and therefore **it might become more difficult to transport the largest power transformers after Tier 2** requirements come into effect. The subsequent sections provide more information on this isuse. **As a potential consequence of this effect it is possible that the exemption of Regulation 548/2014** for 'large power transformers which are like-for-like replacements in the same physical location/installation for existing large power transformers, where this replacement cannot be achieved without entailing disproportionate costs associated to their transportation and/or installation' **will be invoked more frequently**. However, **for greenfield applications this exemption does not exist and hence the largest power transformers might face transportation or installation problems**. This study therefore launched an installers enquiry to establish the extent to which transportation limits may apply, see Annex C. The results are discussed in the rest of this section.

1.5.3.2 Transportation on roads

For regular road transport in Europe vehicles must comply with certain rules with regards to weights and dimensions for road safety reasons and to avoid damaging roads, bridges and tunnels. This is regulated by Directive (EU) 2015/719 and limited to 40 tonnes (incl. trailer), 2.6 meter width, 4 meter height (incl. trailer) and 12 meter length. Consequently, **regular road transport can only be used for smaller power transformers** such as distribution transformers. For larger and heavier products, special road transports have to be used (Figure 1-9) and limits which apply to these depend on the local circumstances and permits. Specific questions on this topic were included in the installers enquiry of this study in order to verify what the typical special transport limits are in Europe, see Annex C. Some countries provided specific input on transportation limits but it was not possible to identify similarities between them. For example in Norway the limits for special road transport are 10 m long, 3,7 m in width, 4,5 m in height and a maximum weight of 250 tonnes while Italy reported limits of 18,75 m long, 2,55m in width and 4 m height without any weight limits. Therefore given the short time frame for this study and the incomplete information received on this topic **it was concluded that above the limits applicable to regular EU road transport (40 tons; 2,6 m width; 4 m high; 12 m long) any power transformer could encounter transportation limits at some point.** This typically also allows the transport of standard containers (ISO 668), which are smaller of course.

Figure 1-9 Exceptional road transport of a transformer (source: Scheuerle-Nicolas catalogue[53])

1.5.3.3 Transportation on railways

As is the case for road transport, discussd in section 1.5.3.2, railways also have transportation dimension and weight limits (Figure 1-10 and Figure 1-11). They are not harmonised across Europe nor within any given country because they can depend on the local railway infrastructure such as bridges. Questions on this topic were included in the installers enquiry conducted for this study to verify what the typical railway limits are in Europe (see Annex C). Results were only obtained for a small number of countries which are unrepresentative of the EU as a whole and thus it was also considered to be inappropriate to ascribe any European limit above the limits of regular road transport for containers (ISO), e.g. Italy.

[53] Available from https://www.scheuerle.com/

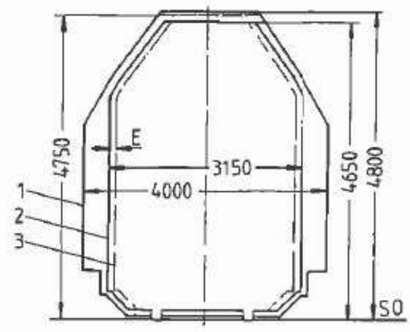

Bild 6.3: Begrenzung beim Schienentransport gemäß der Eisenbahn-Bau- und Betriebsvorschrift

1 Umgrenzung des lichten Raumes (Regellichtraum)
2 Begrenzung II für Fahrzeuge (Lademaß)
3 eingeschränktes Lademaß (E Einschränkung durch Auswanderung in Kurven)
SO Schienenoberkante

Figure 1-10 Dimensional limits for railroad transport in Germany (source: Deutsche Bahn)

Caractéristiques du convoi	1 ère catégorie	2 ième catégorie	3 ième catégorie
Longueur	L ≤ 20 m	20 m < L ≤ 25 m	L > 25 m
Largeur	l ≤ 3 m	3 m < l ≤ 4 m	l > 4 m
Masse	M ≤ 48 t	48 t < M ≤ 72 t	M > 72 t

Figure 1-11 Dimension and weight limits for railway transport in France.

1.6 Technology roadmap for Tier 2 brown field applications

1.6.1 Low loss GOES

Using low-loss silicon steel is one of the most obvious means of reducing no load losses to progress from Tier 1 to Tier 2 levels; see Lot 2 (2011) for a description of this technology and section 1.1.3.2 for information on its price and availability. **Using low loss steel will decrease the cooling needs and therefore decrease the volume and weight of the cooling system and the transformer**, e.g. the cooling finns for air-cooled systems. The price and availability of low-loss GOES might be the main barrier to its wider adoption. **Using low-loss steel also allows the maximum magnetic flux density to be increased and therefore decrease the size and weight of the transformer**. Increasing the magnetic flux will also impact transformer noise which could limit the practical possibilities of using this design option. In view of the pending Tier 2 requirements and the general interest in energy savings research is ongoing to upgrade GOES production plants worldwide to achieve lower loss grades[54], hence it is reasonable to expect they will become more available at a competitive cost.

1.6.2 Copper instead of aluminium conductors

Copper is more compact and aluminium more light weight for the same conductivity (see Lot 2 Study, 2011). **Using a copper conductor combined with more efficient GOES is an obvious choice for brown field applications**. The impact of meeting the Tier 2 requirement via this potential brown field solution is estimated in section 1.1.6. This demonstrated that taking the scrap value of the BC 1 transformer into account, Tier 2 is still an economic choice from the Total Cost of Ownership perspective. Also in the 2nd stakeholder workshop (see minutes) it was concluded that the weight only increases very slightly for high efficiency Tier 2 transformers using copper compared to Tier 1 solutions using aluminium. In many cases Cu designs are shown to be lighter than Al. For a 1600 kVA oil immersed transformer the weight increases by 2-3% when moving to Tier 2. Furthermore using Cu helps to reduce the volume of oil required. This design trend regarding the relative low weight increase of copper versus aluminium transformers is also confirmed by the product data included in Table 1-9. Today power transformers only use copper as a conductor hence for them it is no longer a relevant improment option.

1.6.3 High temperature inorganic insulation and esters instead of cellulose paper insulation and mineral oil cooling liquid

Higher temperature operation means less cooling and therefore transformers can be made more compact. A positive impact of compactness is that the decrease of conductor volume and core steel volume also decreases the losses. A negative impact is that conductor resistance increases with temperature. Hence designing a more efficient and compact transformer is a complex design trade-off that requires advanced thermal modelling.

Liquid-immersed power transformers using high-temperature insulation materials are defined in standard IEC 60076 Power Transformers Part 14. These transformers therefore rely on high temperature inorganic insulation and esters instead of cellulose paper insulation and mineral oil cooling liquid. As a lower cost alternative to inorganic insulation, hybrid insulation is also available, which combines inorganic material with organic cellulose paper[55]. The alternatives to the use of mineral oil at higher temperature are typically synthetic or natural esters (e.g. MIDEL[56], ENVIROTEMP FR3[57], ..).

In 2013[58] **some manufacturers made a comparison** between a cast resin, a conventional liquid-immersed and a liquid-immersed transformer with high temperature insulation **which indicated that the latter is a valuable option for brownfield applications** with space/weight constraints.

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[54] Stefano Fortunati et al. (6/2016), 'New Frontiers for Grain Oriented Electrical Steels: Products and Technologies', available at: https://www.researchgate.net/publication/305496881_New_Frontiers_for_Grain_Oriented_Electrical_Steels_Products_and_Technologies

[55] http://protectiontechnologies.dupont.com/Nomex-910-transformer-insulation

[56] http://www.midel.com/

[57] http://www.envirotempfluids.com/

[58] Radoslaw SZEWCZYK et.al, 'COMPARISON OF VARIOUS TECHNOLOGIES USED FOR DISTRIBUTION TRANSFORMERS FROM AN ECO STANDPOINT' CIRED 22nd International Conference on Electricity Distributionn Stockholm, 10-13 June 2013

As a conclusion, in practice for space constrained brownfield applications **it is possible to select a transformer with a reduced capacity rating and operate it under a higher load factor**. It will also be more economic due to the lower rating (S). As explained in section 1.6.3 **this could be done in conjunction with IEC 60076 part 14** compliant transformers that operate at higher temperatures (@120 °C).

Table 1-18 A manufacturer comparison between a cast resin, a conventional liquid-immersed and a liquid-immersed transformer with high temperature insulation (source: CIRED 2013[58])

		Cast resin	Conventional liquid-immersed	SLIM® liquid-immersed
No load loss	W	3900	2500	2500
Load loss @ 75°C	W	-	20500	-
Load loss @ 120°C	W	20500	-	20500
Impedance	%	8	6	6
Sound level	dB(A)	74	74	70
Length	mm	2800 (in IP23 housing)	2185	2315
Width	mm	1400 (in IP23 housing)	1010	770
Height	mm	2900 (in IP23 housing)	2075	2110
Footprint	m^2	3.9	2.2	1.8
Volume	m^3	11.4	4.6	3.8
Fluid weight	kg	--	1185 (mineral oil)	990 (silicone fluid)
Total weight	kg	8075 (in IP23 housing)	5700	5375
Top oil rise	K	-	60	80
Average winding rise	K	100	65	120

1.6.4 Forced cooling

Medium power transformers used today are air cooled (e.g. ONAN, KNAN) but they **can also benefit from forced cooling (e.g. OFAF) to lower the temperature and the conductor losses and use more compact cooling finns with ventilators**. The technology is well know and commonly used in large power transformers.

Note the Cooling Class Designations (applied from 2000 onwards) for transformers are:

First Letter: Internal cooling medium in contact with the windings

O: Mineral oil or synthetic insulating liquid with fire point < 300°C

K: Insulating liquid with fire point > 300°C

L: Insulating liquid with no measurable fire point

Second Letter: Circulation mechanism for internal cooling medium

N: Natural convection flow through cooling equipment and windings

F: Forced circulation through cooling equipment (cooling pumps), natural convection flow in windings (non-direct flow)

D: Forced circulation through cooling equipment, directed from the cooling equipment into at least the main windings

Third Letter: External cooling medium

A: Air

W: Water

Fourth Letter: Mechanism for external cooling medium

N: Natural convection

F: Forced convection

1.6.5 Non-conductive clamps and bolts

There are also losses in metallic clamps and bolts used in distribution transformers and therefore using glass fibre reinforced plastic clamps and bolts can also reduce losses[59].

1.6.6 Hexagonal or 3D core form transformers

Section 5.1.3.3 of the Lot 2 (2011) study reported that hexagonal core form transformers with GOES are now produced under license in India[60]. They have some benefits because they need less core material per capacity rating (S), however, there is a need to anneal the core after bending which can result in a conflict with our estimates regarding the maintainance of loss properties in domain refined silicon steel. Hence it is unlikely to become BAT.

More recently in 2015 a Chinese company Haihong[61] succeeded in **designing a hexagonal or so-called 3D triangle shaped amorphous transformer** and invested in innovative mass production machinery to manufacture it. This reduces the amount of amorphous material needed, which has weight benefits and also has a circular core cross section which improves the short circuit behaviour. They also claim reductions in transformer noise. **It is a promising development for more compact and light weight amorphous transformers**.

1.6.7 On site assembly

An obvious solution for large power transformers to reduce transportation weight is to do part of the assembly on site, mainly through attachment of the bushing and oil filling. This is common practice for large power transformers. It is also possible for dry type transformers to assemble the core with conductor on site.

1.6.8 Gas insulated transformers

In Japan Gas Insulated (GIS) transformers based on SF6 gas cooling have been on the market for decades[62,63]. SF6 itself is a gas with a high Global Warming Potential (GWP) and it falls under Regulation (EU) No 517/2014 of the European Parliament and of the Council of 16 April 2014 on fluorinated greenhouse gases. Despite this, it has been used to build compact substations. The benefits are complete fire resistance and that high voltage switch gear can be incorporated into the transformer housing.

1.7 Current status of Tier 2 brown field solutions for medium power transformers and manufacturer enquiry

A questionnaire for distribution transformer manufacturers was launched on the project website, see Annex E. This questionnaire checks the results obtained from the enquiry on installers requirements; see Annex D for a selection of the ratings and types considered (250 kVA liquid, 400 kVA liquid, 630 kVA liquid, 100 kVA pole-mounted, 160 kVA pole-mounted).

[59] http://www.transformers-magazine.com/component/k2/2430-transformer-2020-new-vision-of-a-future-power-transformer-premiered-in-vienna.html
[60] http://raychemrpg.com/transformers/deltaformer.html
[61] http://ecotrafo.com.cn/pad.html
[62] http://www.meppi.com/Products/Transformers/Pages/SF6Gas.aspx
[63] http://www.toshiba-tds.com/tandd/products/trans/en/gitrans.htm

T&D Europe presented their findings in the 2nd stakeholder workshop (held on 29/3/2017). It was concluded that **Tier 2 is always attainable for brownfied applications** and their study was **based on the existing technology without considering potential new developments**, see also Table 1-19.

As noted in the 2nd stakeholder workshop we should not forget that in 2011 manufacturers and other stakeholders thought Tier 1 was impossible but now we have attained it without any problem. In the future, attaining Tier 2 will also be possible with existing production technology, but in some cases through the use of new technology. The future is with new technology and there will be smaller Tier 2 compliant transformers as this is pioneered.

			Feasible : TIER 1 or TIER 2 or Impossible				LV winding nature COPPER OR ALU			MV winding nature COPPER OR ALU			Magnetic Steel used (<0,9 W/kg@1,7T/50Hz)			OIL TYPE			INSULATION TYPE			OPERATING TEMPERATURE >75°		
Ref Sheets	Rated Power	Country	Tier 2	Tier 1	No study	Impossible	COPPER	ALU	Not filled	COPPER	ALU	Not filled	YES	NO	Not filled	STANDARD	SPECIAL	NOT FILLED	STANDARD	SPECIAL	NOT FILLED	YES	NO	NOT FILLED
TD 1	250KVA	BE	25%	25%	50%		25%		75%	25%		75%	25%		75%	25%		75%	25%		75%		25%	75%
TD 2	250KVA	D	50%		50%		25%		75%	25%		75%	25%		75%	25%		75%	25%		75%		25%	75%
TD 3	250KVA	NL	50%		50%		25%		75%	25%		75%	25%		75%	25%		75%	25%		75%		25%	75%
TD 4	250KVA	F	50%	25%	25%		50%		50%	50%		50%	50%		50%	50%		50%	50%		50%		50%	50%
TD 5	250KVA	PL	25%	25%	50%		25%		75%	25%		75%	25%		75%	25%		75%	25%		75%		25%	75%
TD 6	250KVA	ES	75%	25%			50%	25%	25%	50%	25%	25%	75%		25%	75%		25%	75%		25%	25%	50%	25%
TD 7	250KVA	N	25%	25%	50%		25%		75%	25%		75%	25%		75%	25%		75%	25%		75%		25%	75%
TD 8	250KVA	N	50%		50%		25%		75%	25%		75%	25%		75%	25%		75%	25%		75%		25%	75%
TD 9	250KVA	Average			100%				100%			100%			100%			100%			100%			100%
TD 10	250KVA	Border Line			100%		25%		75%		25%	75%	25%		75%	25%		75%	25%		75%		25%	75%
TD 11	400kVA	BE	25%		75%				100%			100%			100%			100%			100%			100%
TD 12	400kVA	D	25%		75%				100%			100%			100%			100%			100%			100%
TD 13	400kVA	NL	25%		75%				100%			100%			100%			100%			100%			100%
TD 14	400kVA	PL		25%	75%				100%			100%			100%			100%			100%			100%
TD 15	400kVA	ES	50%	25%	25%		25%	25%	50%	25%	25%	50%	50%		50%	50%		50%	50%		50%	25%	25%	50%
TD 16	400kVA	N	25%		75%				100%			100%			100%			100%			100%			100%
TD 17	400kVA	Average			100%				100%			100%			100%			100%			100%			100%
TD 18	400kVA	Border Line	25%		75%		25%		75%	25%		75%	25%		75%	25%		75%			100%			100%
TD 19	630kVA	BE	25%	25%	50%		25%		75%	25%		75%	25%		75%	25%		75%	25%		75%		25%	75%
TD 20	630kVA	D	50%		50%		25%		75%	25%		75%	25%		75%	25%		75%	25%		75%		25%	75%
TD 21	630kVA	NL	50%		50%		25%		75%	25%		75%	25%		75%	25%		75%	25%		75%		25%	75%
TD 22	630kVA	F	75%		25%		50%		50%	50%		50%	50%		50%	50%		50%	50%		50%		50%	50%
TD 23	630kVA	PL	25%	25%	50%		25%		75%	25%		75%	25%		75%	25%		75%	25%		75%		25%	75%
TD 24	630kVA	ES	75%	25%			50%	25%	25%	50%	25%	25%	75%		25%	75%		25%	75%		25%	25%	50%	25%
TD 25	630kVA	N	50%		50%		25%		75%	25%		75%	25%		75%	25%		75%	25%		75%		25%	75%
TD 26	630kVA	S	50%		50%		25%		75%	25%		75%	25%		75%	25%		75%	25%		75%		25%	75%
TD 27	630kVA	Average			100%				100%			100%			100%			100%			100%			100%
TD 28	630kVA	Border Line			75%	25%			100%			100%			100%			100%			100%			100%
TD 29	100kVA	N	50%		50%			25%	75%		25%	75%	25%		75%	25%		75%	25%		75%		25%	75%
TD 30	100kVA	F	25%	25%	25%	25%	25%		75%	25%		75%	25%		75%	25%		75%	25%		75%		25%	75%
TD 31	160kVA	F	25%	25%	25%	25%		25%	75%	25%		75%	25%		75%	25%		75%	25%		75%		25%	75%

Table 1-19 Brown Field analysis from T&D Europe based on space/weight limits from the stakeholder enquiry

1.8 Conclusion on Tier 2 for space/weight and transportation constraints related to technical feasability

For medium power transformers there are sufficient techniques available today to enable space/weight constraints for Tier 2 compliant transformers to be overcome, as described in section 1.6 and confirmed by the responses received from manufacturers (see 1.7). Therefore **for medium power transformers there are no technical**

grounds for the introduction of any new exemption in the regulation due to the satisfaction of Tier 2 requirements.

For large power transformers for anything above 40 tonnes, 2,6 m width, 4 m high and 12 m long depending on the local transportation limits (bridges, tunnels, etc,..) problems could arise for Tier 2 compliant transformers. Larger power transformers already use copper conductors, hence they cannot use this technology to further reduce dimensions (see 1.6.2). Hence the exemption in Regulation 548/2014 that is only applicable to 'like for like replacements' might be insufficient. Therefore, based on the technical evidence made available to the study **it is recommended to introduce an exemption for green-field large power transformers** that are Tier 1 compliant, constructed of state of art technology but incompliant with Tier 2 due to taking into account the space and weight constraints applicable to their transportation or installation.

1.9 Is the Tier 2 cost excessive for some brownfield applications with space/weight constraints?

Article 15 of the EU Ecodesign Directive (2009/125/EC) section 5 (c) requires that there shall be 'no significant negative impact on consumers in particular as regards the affordability and the life cycle cost of the product'.

As pointed out in section 1.1.8 the critical point can occur for liquid filled medium power transformers for brown field applications with space/weight constraints. All other Tier 2 compliant cases, have a positive LCC compared to equivalent Tier 1 products under various OPEX assumptions. This is also the case for the BAT which could become a more ambitious Tier 3 level.

Our analysis showed that the Tier 2 compliant, space-constrained brownfield transformer applications were most 'uneconomic' for utilities when the use of copper conductors is the only technical solution and under the economic scenario assuming a 4% discount rate and low wholesale electricity prices, see 1.1.8. However, for other OPEX assumptions regarding the electricity price and discount rate the effect of Tier 2 compliance on life cycle cost was beneficial and therefore **'uneconomic' under some particular utility conditions does not mean that attainment of Tier 2 performance is not economically beneficial across the EU as a whole.**

When using the same metrics as other industrial Ecodesign product regulations, scenario 'IA2016' in section 1.1.8, it is economic and this is relevant to compare with other Ecodesign products.

Also, on a macroeconomic scale one can also try to compare the benefits of all liquid medium power transformers to brownfield transformers with significant cost impact due to space/weight constraints. Section 1.1.5 contained the 2020 market forecast that discriminates between replacement sales (brownfield), new sales, distribution, industry & DER liquid medium voltage transformers. Under the worst case scenario, i.e. one that assumes that all distribution transformer replacement sales have space/weight constraints; up to 27 % of total transformer kVA sales in the EU could suffer from a negative LCC brownfield impact in 2020. In the reference scenario (PRIMES2040+) (see 1.1.8), the BC1 LCC benefit (+)/loss (-) for greenfield was +974 euro/life versus -1640 euro/life for brownfield with copper based transformers. As a consequence the weighted average worst case benefit estimate is 171 euro over the product lifespan[64]. This indicates that **on a larger economic scale the benefits of transformers without space/weight constraints out weigh those with constraints**. Note, that this worst case scenario is pessimistic because not all country existing brownfield specifications would require copper to have be used to attain Tier 2 performance levels.

Of course, one could also hope that the copper price will decrease significantly by 2020 but that was not considered realistic (see 1.1.3.1). Nevertheless, in all these considerations **one should take into account the particular space/weight constraints and economic conditions of Distribution System Operators (DSOs).** DSOs are classified as 'natural monopolies' and are therefore regulated by national regulatory authorities (NRAs[65]). The **economic and cost rules are set by these NRAs** and vary from EU member state to member state[66]. In principle, the DSO profit policy implemented by NRAs is a mixture of permitted revenue and financial incentives. Depending on the profit policy in place it is possible that DSOs may be incentivised to make their investments with a high WACC and this might conflict with long term energy efficiency investments (see 1.1.8). Also, DSOs are often owned by municipalities and the income from this ownership is a form of taxation that cannot easily be decreased without imposing other taxes. **It will be important for NRAs to cross check that the DSO profit policy is not in conflict with the cost impact of Tier 2 for brown field transformers with space/weight constraints.** This means that NRAs may need to consider a special capital revenue treatment for transformer energy efficiency investments in the case of severe brownfield space/weight constraints for an affected DSO.

1.10 Is Tier 3 an option?

For liquid transformers in applications without space/weight constraints there is still improvement potential over Tier 2 and hence for a **more ambitious Tier 3 for medium power liquid transformers**, see 'BAT' in section 1.1.8. Of course, the first step is to see if Tier 2 itself is current and that Regulation (548/2009) Tier 2 is not postponed and/or weakened in the review process. Therefore it is recommended to investigate this topic at a later stage after Tier 2 requirements are confirmed (>2018).

Dry type medium power transformers and liquid power transformers have very different loss requirements in Tier 2 for the same rating, it is therefore strongly recommended to review this issue in future. The root of the problem is related to approaches to fire/smoke/explosion risks related to functional properties of each particular technology. It should be noted that silicon liquid transformers are believed to offer both high efficiency and improved fire behaviour[67], however there is probably not a consensus on this[68]. It will also be important to establish whether there has been any increase in the uptake of less-efficient dry type transformers after Tier 2

[64] =-1640x0,27+974x0.63

[65] http://www.acer.europa.eu/en/Pages/default.aspx or http://www.ceer.eu/

[66] 28 January 2015, Final Report, 'Study on tariff design for distribution systems', prepared for EC DG ENER, https://ec.europa.eu/energy/sites/ener/files/documents/20150313%20Tariff%20report%20fina_revREF-E.PDF

[67] CG Global SLIM or BIO SLIM transformer presentation: http://www.cgglobal.com/be/files/brochures/Leaflet_CG_Fire_A4.pdf

[68] ABB Resibloc presentation: https://library.e.abb.com/public/d13a07f1c4b979acc1257b9d002fd490/1LDE000003%20revB%20en%20RESIBLOC%20presentation%20INTERNET.pdf

requirements come into effect, because they have less ambitious loss requirements and could become economically more competitive. Apart from dry versus liquid types it is also possible that new types of electronic distribution transformers might enter the market and therefore a more technology neutral approach may be necessary to encompass technologies that are not currently specified in Regulation No 548/2014, such as solid state transformers[69]. So far solid state transformers are more expensive and have lower efficiencies, however, sooner or later they might enter the market because of some other functional benefits, e.g. they can have both DC and AC output wherein DC might be for example useful for Electric Vehicle fast chargers. In conclusion, under a future Tier 3 assessment **technology neutral requirements might be considered,** or one that specifies requirements in terms of a functional classification (e.g. fire resistance, etc..). Note, technology neutral approaches for energy efficiency specifications within standards and labelling schemes is generally recommended. Yet, for the same rating and identical load or no load classes as defined in EN 50588 dry type and liquid transformers have different loss specifications, e.g. the maximum loss for the AA0 class is 675 Watt for dry type tramsformers versus 387 Watt for AA0 liquid transformers at 400 kVA rated capacity. It is, thus, highly recommended to **mandate CENELEC** to **explore functional technology neutral and future proof classifications in their standards**.

So far, **smaller LV/LV transformers do not have loss limits** specified in Regulation No 548/2014. A new draft standard prEN 50645 specifies 'Ecodesign requirements for small power transformers'. It will allow customers to readily compare the Ecodesign values and characteristics of transformers supplied by different manufacturers. This study did not have the objective nor time to investigate such loss limits and it is important to have new data according to prEN 50645 which is not yet available due to its draft status. In the stakeholder meeting it was mentioned that, based on the evolution of electrical vehicles and their associated electrical charging needs, a growth in sales of LV/LV transformers can be expected to occur. Especially when Mode-4 DC charging will be in place (DC charging requires an IT Grid which will require a transformer). However, in general the use of small transformers is so diverse that they are a complex product to analyse and can have thousands of different applications. For example, there is demand for transformers for: isolation, protection, transformation, ... For example in the Lot 2 study (2011) a large part of the LV/LV transformers were allocated to 12V AC halogen lamp supply circuits, but with the growing use of LEDs such transformers are losing market share. To be regulated under the Ecodesign Regulation product sales must exceed 200.000 units per year across the EU and during the stakeholder consultation it became clear that this criterion will be met[70] for smaller LV transformers. In conclusion **it is recommended to consider introducing loss limits for smaller LV/LV transformers within a set of future Tier 3 requirements but a new in-depth study would be necessary to explore this**.

There remains **a risk that in Tier 2 power transformer procurement** specifiers shift specifications **towards low optimum load factors at peak load (kPEI<0.25)** to satisfy PEI requirements without investing in copper for load loss reduction. This loophole could be closed by the addition of a minimum load factor at PEI (kPEI) or ratio of no-load to load losses. From the stakeholder workshop it was concluded that there is no consensus amongst stakeholders on a minimum kPEI approach and that

69 https://www.pes.ee.ethz.ch/uploads/tx_ethpublications/__ECPE_SST_Workshop_2016_SST_Concepts_Challenges_Opportunities_FINAL_JWK_270116.pdf

70 *not said in the stakeholder meeting but received after the meeting and just as an indication: only one manufacturer EREA supplies yearly about 50.000 pieces LV/LV transformer which do represent an installed power base of 50MVA in total.*

the TSOs grouped in ENTSOE want to maintain the freedom to specify this by themselves. It is therefore highly recommended that market surveillance authorities collect load and load losses data and see whether they shift towards low kPEI values or not. It is also recommended to investigate which applications have which kPEI. In this context it might also be relevant to check how kPEI was specified within the tender: indirectly specified through capitalisation factors (see 1.3.1), directly as a tender requirement on kPEI, or unspecified allowing all kPEI to go for minimum cost irrespective of loading. **In the case that market surveillance notes a shift towards low optimum load factors at peak load (kPEI<0.25) then a minimum kPEI requirement should be considered in Tier 3 requirements for power transformers.**

2 Task 2 on Consideration of minimum requirements for single-phase LV/MV transformers

Aim and tender request:
Single-phase transformers were excluded from the scope of Regulation 548/2014 for a number of reasons, primarily due to a lack of available data. These transformers are mainly used by utilities in Ireland and the United Kingdom and their exclusion could be reconsidered, as this represents a missed opportunity for energy efficiency and a potential regulatory loophole. The task here is to investigate whether it is technically and economically justified to extend existing minimum energy efficiency requirements due to come into effect for Tier 2 to also apply to single-phase transformers.

An investigation is also conducted to establish whether the existing harmonised standards, CENELEC EN 50588-1:2015 and EN 50629:2015, adequately cover the measurement and calculation of the energy efficiency of single-phase transformers, or whether further standardisation work is necessary.

Data sources and disclaimer on data validity:
Data on market volumes, typical total load factors, load losses and no load losses was supplied in the kick-off meeting by Antony Walsh (Eurelectric, DSO) and also via a document prepared for CENELEC WG21 and supplied to the EC for use in this study. Data on the performance of amorphous transformers is publically available from ABB[71].
For single phase transformers also data was sourced from CENELEC EN 50588-1:2015. This standard includes maximum no load (A0, AA0, and AAA0) and load losses (Ak, Bk, and Ck) as a function of the rated capacity (S). The 2015 version of the standard said that Tables 2 and 3 of the standard give the maximum level of losses for single phase transformers and for three phase transformers; however, this statement has since been withdrawn by CENELEC. Therefore only Table 12 in EN 50588-1:2015 contains potential information on single phase transformer energy performance limits and this is expressed in the form of the Peak Efficiency Index (PEI), which defines two levels of PEI losses (Level 1 and Level 2). Nevertheless, there seems to be a correlation between Table 12 (PEI) and the maximum losses defined in Tables 2 and 3, indicating that the proposed maximum losses for single phase transformers correlate with and would require AAA0 losses for Level 1 and BK or Ak for Level 2.
Due to a lack of other data sources the study used the maximum loss values from Tables 2 and 3 of EN 50588-1 as potential improvement options and extrapolated price information from that applying to three phase transformers, because very little relevant data was made available for use within the time from of the study. In consequence the conclusions built on this data have a large degree of uncertainty.

A key difficulty in obtaining data was that single phase LV/MV transformers represent a very small volume with only a few DSO clients and very few manufacturers.

[71] https://library.e.abb.com/public/604bd67ca8e54100a3a2065c473709ef/GDT_Sustainability_A4-natural%20ester_upd_29-10-2015.pdf

transformer rating (Sr)	kVA	25	25	25	25	25	25	25	25	25	25	25	25
No load losses (P0)	W	70	70	70	63	63	63	35	35	35	35	35	35
no load class EN 50588 Table 2		Ao	Ao	Ao	AA0	AA0	AA0	AAA0	AAA0	AAA0	AAA0	AAA0	AAA0
Load losses (Pk)	W	900	725	600	900	725	600	900	725	600	900	725	600
load class EN 50588 Table 3		Ck	Bk	Ak	Ck	Bk	Ak	Ck	Bk	Ak	Ck	Bk	Ak
Auxiliary losses (Paux)	W	0	0	0	0	0	0	0	0	0	0	0	0
PEI	%	97,992%	98,198%	98,360%	98,095%	98,290%	98,445%	98,580%	98,726%	98,841%	98,580%	98,726%	98,841%
load factor@PEI (k_{PEI})	ratio	0,279	0,311	0,342	0,265	0,295	0,324	0,197	0,220	0,242	0,197	0,220	0,242
Level Table 12 EN 50588		**no level**	**no level**	**no level**	**no level**	**no level**	**no level**	**Level 1**	**Level 2**	**Level 2**	**Level 1**	**Level 2**	**Level 2**

Table 2-1 Level 1 and Level 2 PEI defined for single phase transformers in EN 50588-1:2015 and potential correlation to maximum load and no load losses defined in Tables 2 and 3 for three phase transformers.

2.1 Stock and sales of single-phase transformers[72]

There are no EU-wide stock and sales statistics for single-phase transformers; however, it is understood from information supplied during the stakeholder consultation process that within the EU these products are essentially exclusively used within the UK and Ireland. In particular, they are used as utility distribution transformers to supply electricity on single phase MV networks. Because the MV networks where these transformers are used are single phase the households linked to these networks can not be supplied with three-phase power unless they install an expensive electronic converter. Despite the large disparity in national population sizes this situation is actually more common in Ireland than the UK. The text below to the end of section 2.1 excluding the last paragraph, is drawn from A. Walsh[73].

In Ireland 40% of the population live in rural areas, mainly in isolated rural dwellings, so that small single phase transformers are predominant – 90% of single phase transformers used in Ireland are 15kVA single phase and 10% are 33kVA single phase.

Ireland:

Urban Areas: 20 000 Ground Mounted Three Phase
Rural Areas 20 000 Pole Mounted Three Phase
210 000 Pole Mounted Single Phase (90% x 15kVA & 10% x 33kVA)
250 000 Transformers

Again, in the Irish case, of the 2,2 million low voltage customers, 0,6 million are rural with a consumption of 3 000 GWh, and the remainder are urban with a consumption of 13000 GWh, so that it is, clear that urban three phase transformers have a significantly greater loading than rural single phase transformers. Hence, the annual consumption per rural household is about 5000 kWh.

In the UK, which is much more urbanised, single phase transformers are much less common, as the settlement pattern tends to result in rural dwellers congregating in villages, with three phase transformer supply.

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[72] Data on market volumes, typical total load factors, load losses and no load losses was supplied in the kick-off meeting by Antony Walsh (Eurelectric, ESB DSO) and also via a document prepared for CENELEC WG21 and supplied to the EC for use in this study. Data on the performance of amorphous transformers is publically available from ABB.

[73] Ibid

At present the UK is reported to install about 5 000 single phase units per annum and Ireland 5500 per annum.

The number of transformers installed is determined by the number of new connections and the replacement rate for transformers. Additionally, in Ireland the replacement rate is largely determined by the conversion of networks from 10kV to 20kV, which requires non-10kV transformers to be changed out.

In the UK the size of single phase transformers used extends from 5kVA to 200kVA, but about 90% of UK single phase transformers are in the 25kVA and 50kVA sizes (about 50% 25kVA, 20% 15kVA, 20% 50kVA), with 5% at 5kVA and 5% at 100kVA – usage of models >100kVA is extremely low.

Detailed network statistics from Ireland are publicly available[74] and are summarised in the following table.

Table 2-2 ESB Network Statistics

Subtransmission		Medium & Low voltage	
220 kV S/Stns & 110kV Networks		**MV Network**	**(km)**
220/110kV Stations	3	20kV Overhead - 3 Phase	14,700
220/110kV transformer Capacity (MVA)	2,250	20kV Overhead - 1 Phase	29,500
110kV Lines	439	10kV Overhead - 3phase	12,800
110kV cables	184	10kV Overhead - 1 Phase	25,800
110kV substations		20kV Cable	600
110/38kV	82	10 KV Cables	8,849
110/MV	28	**MV/LV S/stns**	
110/38kV Transformer capacity (MVA)	6,292	Pole mounted - 3 phase	19,941
110/MV Transformer capacity (MVA)	1,345	Pole mounted - 1 phase	213,784
38kV Network	**(km)**	Ground mounted	19,787
Overhead	5,731	**LV Network**	**(km)**
Cables	951	Overhead - 3ph	4,208
38kV S/Stns		Overhead - 1ph	54,300
No. of Stations	432	LV Cables	12,256
Transformer capacity (MVA)	5,112	LV Minipillars	167,983

Thus, based on these figures some 154 MVA of single phase transformers are installed in the UK annually and 84 MVA in Ireland, making a total of 238 MVA of annual single phase transformer capacity installed annually in the EU as a whole.

2.2 Status and gaps of standards to cover measurement and calculation of the energy

Measurement and rating of losses from single phase transformers is covered in the standard EN 50588-1:2015+A1:2016 (E) *Medium power transformers 50 Hz, with highest voltage for equipment not exceeding 36 kV - Part 1: General requirements*. This is the same standard used to measure and rate losses of distribution transformers. The scope of this standard covers medium power transformers, wherein 'Medium power transformer' means a power transformer with a highest voltage for

74 https://www.esb.ie/esbnetworks/en/downloads/esb_networks_summary_statistics.pdf?v=2014f

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.

This standard addresses losses in single phase transformers, although it may be noted that it does not distinguish the performance of products lower than 25kVA in rated capacity nor of those between 25kVA and 50kVA. Thus the losss classes applicable to 15kVA products are the same as those that apply to 25kVA products and similarly those that apply to 33kVA products are the same as those that apply to 50kVA. This means that the products which are most used in Ireland (15 and 33kVA) are treated indistinguishably from those most used in the UK (25 and 50kVA even though their losses should be less all other aspects being equal.

2.3 Should single-phase transformers be subject to Ecodesign requirements with respect to losses?

2.3.1 Single phase transformer losses

Data on the losses experienced by single phase transformers sold in the UK and IE are shown in Table 2-3. The PEI and kPEI associated with these is also shown. Transformers should be loaded at kPEI to obtain its PEI efficiency. In Ireland the average annual household consumption is 5300 kWh or 605 Watt on average. Typically houses are connected with 6 to 15 kVA, as this power level is needed to operate several appliances simultaneously (hobs, oven, drying, etc..). When connecting a single house to a 15 KVA transformer annual no load losses will be 420 kWh compared with 5300 kWh of end-use consumption. Therefore **the real efficiency of the transformer will be less than 92,66 % and is** completely **different from the PEI (98,48%)** hence only considering PEI results in a performance gap. The reason for such a deviation is that the kPEI is very diffirent from the real loading. For these applications reducing no load loasses is a key to improving their real efficiency.

Table 2-3 Current typical single-phase transformer losses in the UK (shaded white) & Ireland (shaded green), Weighted Average for UK, Actual for Ireland

kVA	PO(W)	Pk(W)	PEI	kPEI
15	48	270	98.48%	0.42
16	48	405	98.26%	0.34
25	68	540	98.47%	0.35
33	58	675	98.80%	0.29
50	112	900	98.73%	0.35
100	228	1557	98.81%	0.38

Source: A. Walsh paper to CENELEC WG21

In addition ABB have published data on the P0 of their single phase transformers and have compared high efficiency AMT models to standard GOES models, see Table 2-4. On average the AMT models have NLL values that are about 64% less than the typical GOES values. They are also between 56% and 69% less than the equivalent average IE/UK values. This indicates that **there is a substantial technical potential to reduce no load losses** for single phase transformers.
To consider whether single-phase transformers should be subject to minimum loss requirements under the Ecodesign Directive the load losses and no load losses are now addressed in turn.

Table 2-4 Single-phase transformer no load losses reported in ABB brochure[75]

kVA	GOES typical P0(Watt)	AMTP0(Watt)
15	55	20
25	65	30
50	105	35
75	155	55
100	200	75
167	235	95

2.3.2 Load losses for single phase transformers

Load losses are proportional to the square of the loading applied to a transformer and hence increase non-linearly with increased loading.

In EI the average Total Load Factor applied to single phase transformers is reported to be just 0,024, which is greater than a factor of ten less the equivalent value applicable to three phase distribution tranformers.

The study was unable to gather information on the average TLFs applicable to single phase transformers in the UK; however, they are likely to be higher than the EI values but still significantly lower than typical values found for three phase transformers.

To consider the implications of this on the potential rational for load loss limits applicable to single phase transformers, theoretical single transformer base case models were developed for a variety of transformer rated capacities (15, 25, 33 and 50kVA), load loss classes (Ck, Bk or Ak) and load factors (k) (0.024, 0.075 and 0.2 but also 0.05, 0.1 and 0.3). **This is a theoretical exercise that assumes that EN 50588-1 data from three phase transformers is also applicable on single phase.** Table 2-5 shows these base case models and associated analytical results for the 25kVA models and Table 2-6 for the 50kVA models that are typical in the UK – these also assume UK average no load losses for these products. **It has not been possible to obtain specific cost data for these single phase** transformers and thus the **CAPEX** costs shown here **are derived** by assuming **that the single-phase transformer** costs for any given load class and no-load class **can be scaled as a function of those that apply to three phase transformers**. In practice single-phase transformers sold in Ireland are required to have a 2.2% short circuit impedance while those sold in the uK are thought to have a 4% impedance. This is in order to implement grid level short circuit protection taking into account the distribution lines. Herein we assume that, the lower the transformer impedance requirement is, the more compact the transformer windings need to be made in order to have a better magnetic coupling between the primary and the secondary. Also, lower short circuit impedance means higher short circuit forces on coils and supports, which also presents a challenge if transformers are to be kept compact. **At the 2.2% impedance level this may therefore require the use of Cu in the primary** (and Al in the secondary). **Accordingly, the estimated transformer costs are increased by 10% for the 4% impedance case and by 40% for the 2.2% impedance case,** in line with the estimated impact of requiring greater Cu content.

Ideally actual cost data for single phase transformers would have been forthcoming for use in the study but no such data was made available[76]. The tables below show how

[75] https://library.e.abb.com/public/604bd67ca8e54100a3a2065c473709ef/GDT_Sustainability_A4-natural%20ester_upd_29-10-2015.pdf

the CAPEX, load losses, OPEX and Life cycle costs vary as a function of the average load factor (k) assumed. If the average load factor (k) of 0.024, which is claimed for Irish single phase transformers, is applied there is no economic advantage from reducing the load losses from the Ck to Bk or Ak classes; however, if the load factor (k) rises to 0.075 then the life cycle cost of the Ck and Bk classes becomes equivalent. If the load factor (k) is increased to 0.1 then the life cycle costs of the Bk class becomes less than the Ck class, but the Ak class has the lowest life cycle cost.

These findings show that the cost effectiveness of reduced load losses is highly sensitive to the load factor (k) and that on average this would need to attain 0.075 for there to be an economic rationale to introduce minimum load losses for 25 and 50 kVA single phase transformers (i.e. for the model types most commonly sold in the UK).

One caveat in this finding is that as the UK dominates the sale of 25 and 50 kVA single phase transformers in the EU the average characteristics of UK products has been assumed; however, the average EU tariff has been assumed; thus, it could be argued that the average UK tariff should also be applied to this analysis as these products are scarcely sold elsewhere in the EU.

Table 2-6 and Table 2-8 shows the equivalent analysis for the single phase transformer with the rated capacities that dominate the Irish market, i.e. for 15 and 33 kVA models respectively with 2.2% impedance.

Table 2-5 Base Cases for single-phase liquid-immersed medium power transformers – 25kVA models for UK-average NLL and 4% impedance– with varying load factor (k) and load classes

Base Case		Liquid Single Phase A0 (Ukave)	Liquid Single Phase A0 (Ukave)	Liquid Single Phase A0 (Ukave)	Liquid Single Phase A0 (Ukave)	Liquid Single Phase A0 (Ukave)	Liquid Single Phase A0 (Ukave)	Liquid Single Phase A0 (Ukave)	Liquid Single Phase A0 (Ukave)	Liquid Single Phase A0 (Ukave)
transformer rating (S)	kVA	25	25	25	25	25	25	25	25	25
No load losses (P0)	W	68	68	68	68	68	68	68	68	68
no load class		Ao	Ao	Ao	Ao	Ao	Ao	Ao	Ao	Ao
Load losses (Pk)	W	900	725	600	900	725	600	900	725	600
load class		Ck	Bk	Ak	Ck	Bk	Ak	Ck	Bk	Ak
Auxiliary losses (Paux)	W	0	0	0	0	0	0	0	0	0
PEI	%	98.021%	98.224%	98.384%	98.021%	98.224%	98.384%	98.021%	98.224%	98.384%
Load Factor (α) (=Pavg/S)	ratio	0.024	0.024	0.024	0.075	0.075	0.075	0.2	0.2	0.2
Load form factor (Kf)(=Prms/Pavg)	ratio	1.073	1.073	1.073	1.073	1.073	1.073	1.073	1.073	1.073
availability factor (AF)	ratio	1	1	1	1	1	1	1	1	1
Power factor (PF)	ratio	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Equivalent load factor (αeq)	ratio	0.03	0.03	0.03	0.09	0.09	0.09	0.24	0.24	0.24
αopt (= sqrt ((Po+Paux)/Pk))	ratio	0.275	0.306	0.337	0.275	0.306	0.337	0.275	0.306	0.337
no load and aux. losses per year	kWh/y	595.7	595.7	595.7	595.7	595.7	595.7	595.7	595.7	595.7
load losses per transformer per year	kWh/y	6.5	5.2	4.3	63.0	50.8	42.0	448.3	361.1	298.8
losses per year	kWh/y	602.1	600.9	600.0	658.7	646.5	637.7	1043.9	956.8	894.5
transformer life time	y	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00
kWh price no load and aux. Losses	€	0.098	0.098	0.098	0.098	0.098	0.098	0.098	0.098	0.098
kWh price load losses	€	0.098	0.098	0.098	0.098	0.098	0.098	0.098	0.098	0.098
CAPEX - transformer	€	335.84	348.24	358.93	335.84	348.24	358.93	335.84	348.24	358.93
losses per year	kWh/y	602.1	600.9	600.0	658.7	646.5	637.7	1043.9	956.8	894.5
discount rate	%	4%	4%	4%	4%	4%	4%	4%	4%	4%
electricity escalation rate	%	0%	0%	0%	0%	0%	0%	0%	0%	0%
PWF	ratio	19.79	19.79	19.79	19.79	19.79	19.79	19.79	19.79	19.79
No load loss capitalization factor (A)	€/W	16.99	16.99	16.99	16.99	16.99	16.99	16.99	16.99	16.99
Load loss capitalization factor (B)	€/W	0.01	0.01	0.01	0.14	0.14	0.14	0.97	0.97	0.97
TCO A/B ratio = α² (only if kWh price load/no load =)	ratio	0.00	0.00	0.00	0.01	0.01	0.01	0.06	0.06	0.06
TCO A/B ratio = α².(€/kWh load)/(€/kWh no load)	ratio	0.00	0.00	0.00	0.01	0.01	0.01	0.06	0.06	0.06
OPEX electricity	€/y	59.01	58.89	58.80	64.55	63.35	62.49	102.31	93.76	87.66
LCC electricity	€ /life	1,167.96	1,165.52	1,163.78	1,277.70	1,253.93	1,236.95	2,024.90	1,855.84	1,735.08
LCC total (excl. scrap@EOL)	€ /life	1,503.80	1,513.77	1,522.71	1,613.54	1,602.17	1,595.88	2,360.74	2,204.08	2,094.01
scrap value @ EOL	€	14.75	14.75	14.75	14.75	14.75	14.75	14.75	14.75	14.75
NPV scrap value (incl. discount rate)	€	3.07	3.07	3.07	3.07	3.07	3.07	3.07	3.07	3.07
LCC total (incl. scrap@NPV)	€	1,500.72	1,510.69	1,519.64	1,610.47	1,599.10	1,592.81	2,357.67	2,201.01	2,090.94

[76] A. Walsh from ESB/Eurelectric remarked that the provisional estimates of single phase transformer costs presented at the 2nd Stakeholder meeting were an underestimate by more than a factor of 2 but no data was supplied to confirm or refute this claim.

Table 2-6 Base Cases for single-phase liquid-immersed medium power transformers – 50kVA models for UK-average NLL and 4% impedance – with varying load factor (k) and load classes

Base Case		**Liquid Single Phase A0 (Ukave)**	**Liquid Single Phase A0 (Ukave)**	**Liquid Single Phase A0 (Ukave)**	**Liquid Single Phase A0 (Ukave)**	**Liquid Single Phase A0 (Ukave)**	**Liquid Single Phase A0 (Ukave)**	**Liquid Single Phase A0 (Ukave)**	**Liquid Single Phase A0 (Ukave)**	**Liquid Single Phase A0 (Ukave)**
transformer rating (S)	kVA	50	50	50	50	50	50	50	50	50
No load losses (P0)	W	112	112	112	112	112	112	112	112	112
no load class		Ao	Ao	Ao	Ao	Ao	Ao	Ao	Ao	Ao
Load losses (Pk)	W	1100	875	750	1100	875	750	1100	875	750
load class		Ck	Bk	Ak	Ck	Bk	Ak	Ck	Bk	Ak
Auxiliary losses (Paux)	W	0	0	0	0	0	0	0	0	0
PEI	%	98.596%	98.748%	98.841%	98.596%	98.748%	98.841%	98.596%	98.748%	98.841%
Load Factor (α) (=Pavg/S)	ratio	0.024	0.024	0.024	0.075	0.075	0.075	0.2	0.2	0.2
Load form factor (Kf)(=Prms/Pavg)	ratio	1.073	1.073	1.073	1.073	1.073	1.073	1.073	1.073	1.073
availability factor (AF)	ratio	1	1	1	1	1	1	1	1	1
Power factor (PF)	ratio	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Equivalent load factor (αeq)	ratio	0.03	0.03	0.03	0.09	0.09	0.09	0.24	0.24	0.24
αopt (= sqrt ((Po+Paux)/Pk))	ratio	0.319	0.358	0.386	0.319	0.358	0.386	0.319	0.358	0.386
no load and aux. losses per year	kWh/y	981.1	981.1	981.1	981.1	981.1	981.1	981.1	981.1	981.1
load losses per transformer per year	kWh/y	7.9	6.3	5.4	77.0	61.3	52.5	547.9	435.8	373.5
losses per year	kWh/y	989.0	987.4	986.5	1058.2	1042.4	1033.6	1529.0	1416.9	1354.7
transformer life time	y	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00
kWh price no load and aux. Losses	€	0.098	0.098	0.098	0.098	0.098	0.098	0.098	0.098	0.098
kWh price load losses	€	0.098	0.098	0.098	0.098	0.098	0.098	0.098	0.098	0.098
CAPEX - transformer	€	671.68	696.49	717.86	671.68	696.49	717.86	671.68	696.49	717.86
losses per year	kWh/y	989.0	987.4	986.5	1058.2	1042.4	1033.6	1529.0	1416.9	1354.7
discount rate	%	4%	4%	4%	4%	4%	4%	4%	4%	4%
electricity escalation rate	%	0%	0%	0%	0%	0%	0%	0%	0%	0%
PWF	ratio	19.79	19.79	19.79	19.79	19.79	19.79	19.79	19.79	19.79
No load loss capitalization factor (A)	€/W	16.99	16.99	16.99	16.99	16.99	16.99	16.99	16.99	16.99
Load loss capitalization factor (B)	€/W	0.01	0.01	0.01	0.14	0.14	0.14	0.97	0.97	0.97
TCO A/B ratio = α² (only if kWh price load/no load =)	ratio	0.00	0.00	0.00	0.01	0.01	0.01	0.06	0.06	0.06
TCO A/B ratio = α².(€/kWh load)/(€/kWh no load)	ratio	0.00	0.00	0.00	0.01	0.01	0.01	0.06	0.06	0.06
OPEX electricity	€/y	96.92	96.76	96.68	103.70	102.16	101.30	149.84	138.86	132.76
LCC electricity	€ /life	1,918.37	1,915.24	1,913.50	2,052.51	2,021.94	2,004.96	2,965.75	2,748.39	2,627.63
LCC total (excl. scrap@EOL)	€ /life	2,590.05	2,611.73	2,631.37	2,724.19	2,718.43	2,722.82	3,637.43	3,444.88	3,345.49
scrap value @ EOL	€	29.50	29.50	29.50	29.50	29.50	29.50	29.50	29.50	29.50
NPV scrap value (incl. discount rate)	€	6.14	6.14	6.14	6.14	6.14	6.14	6.14	6.14	6.14
LCC total (incl. scrap@NPV)	€	2,583.91	2,605.59	2,625.22	2,718.04	2,712.29	2,716.68	3,631.29	3,438.73	3,339.35

Table 2-7 Base Cases for single-phase liquid-immersed medium power transformers – 15kVA models for EI-average NLL and 2.2% impedance – with varying load factor (k) and load classes

Base Case		**Liquid Single Phase AAo (Elave)**	**Liquid Single Phase AAo (Elave)**	**Liquid Single Phase AAo (Elave)**	**Liquid Single Phase AAo (Elave)**	**Liquid Single Phase AAo (Elave)**	**Liquid Single Phase AAo (Elave)**	**Liquid Single Phase AAo (Elave)**	**Liquid Single Phase AAo (Elave)**	**Liquid Single Phase AAo (Elave)**
transformer rating (S)	kVA	15	15	15	15	15	15	15	15	15
No load losses (P0)	W	48	48	48	48	48	48	48	48	48
no load class		AAo	AAo	AAo	AAo	AAo	AAo	AAo	AAo	AAo
Load losses (Pk)	W	900	725	600	900	725	600	900	725	600
load class		Ck	Bk	Ak	Ck	Bk	Ak	Ck	Bk	Ak
Auxiliary losses (Paux)	W	0	0	0	0	0	0	0	0	0
PEI	%	97.229%	97.513%	97.737%	97.229%	97.513%	97.737%	97.229%	97.513%	97.737%
Load Factor (α) (=Pavg/S)	ratio	0.024	0.024	0.024	0.075	0.075	0.075	0.2	0.2	0.2
Load form factor (Kf)(=Prms/Pavg)	ratio	1.073	1.073	1.073	1.073	1.073	1.073	1.073	1.073	1.073
availability factor (AF)	ratio	1	1	1	1	1	1	1	1	1
Power factor (PF)	ratio	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Equivalent load factor (αeq)	ratio	0.03	0.03	0.03	0.09	0.09	0.09	0.24	0.24	0.24
αopt (= sqrt ((Po+Paux)/Pk))	ratio	0.231	0.257	0.283	0.231	0.257	0.283	0.231	0.257	0.283
no load and aux. losses per year	kWh/y	420.5	420.5	420.5	420.5	420.5	420.5	420.5	420.5	420.5
load losses per transformer per year	kWh/y	6.5	5.2	4.3	63.0	50.8	42.0	448.3	361.1	298.8
losses per year	kWh/y	426.9	425.7	424.8	483.5	471.3	462.5	868.7	781.6	719.3
transformer life time	y	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00
kWh price no load and aux. Losses	€	0.098	0.098	0.098	0.098	0.098	0.098	0.098	0.098	0.098
kWh price load losses	€	0.098	0.098	0.098	0.098	0.098	0.098	0.098	0.098	0.098
CAPEX - transformer	€	317.51	331.37	343.05	317.51	331.37	343.05	317.51	331.37	343.05
losses per year	kWh/y	426.9	425.7	424.8	483.5	471.3	462.5	868.7	781.6	719.3
discount rate	%	4%	4%	4%	4%	4%	4%	4%	4%	4%
electricity escalation rate	%	0%	0%	0%	0%	0%	0%	0%	0%	0%
PWF	ratio	19.79	19.79	19.79	19.79	19.79	19.79	19.79	19.79	19.79
No load loss capitalization factor (A)	€/W	16.99	16.99	16.99	16.99	16.99	16.99	16.99	16.99	16.99
Load loss capitalization factor (B)	€/W	0.01	0.01	0.01	0.14	0.14	0.14	0.97	0.97	0.97
TCO A/B ratio = α² (only if kWh price load/no load =)	ratio	0.00	0.00	0.00	0.01	0.01	0.01	0.06	0.06	0.06
TCO A/B ratio = α².(€/kWh load)/(€/kWh no load)	ratio	0.00	0.00	0.00	0.01	0.01	0.01	0.06	0.06	0.06
OPEX electricity	€/y	41.84	41.72	41.63	47.38	46.18	45.33	85.14	76.59	70.49
LCC electricity	€ /life	828.12	825.69	823.95	937.87	914.10	897.11	1,685.07	1,516.01	1,395.25
LCC total (excl. scrap@EOL)	€ /life	1,145.63	1,157.06	1,166.99	1,255.38	1,245.47	1,240.16	2,002.58	1,847.38	1,738.29
scrap value @ EOL	€	8.85	8.85	8.85	8.85	8.85	8.85	8.85	8.85	8.85
NPV scrap value (incl. discount rate)	€	1.84	1.84	1.84	1.84	1.84	1.84	1.84	1.84	1.84
LCC total (incl. scrap@NPV)	€	1,143.78	1,155.21	1,165.15	1,253.53	1,243.62	1,238.32	2,000.73	1,845.53	1,736.45

Table 2-8 Base Cases for single-phase liquid-immersed medium power transformers – 33kVA models for EI-average NLL – with varying load factor (k) and load classes

Base Case		Liquid Single Phase AAo (Elave)	Liquid Single Phase AAo (Elave)	Liquid Single Phase AAo (Elave)	Liquid Single Phase AAo (Elave)	Liquid Single Phase AAo (Elave)	Liquid Single Phase AAo (Elave)	Liquid Single Phase AAo (Elave)	Liquid Single Phase AAo (Elave)	Liquid Single Phase AAo (Elave)
transformer rating (S)	kVA	33	33	33	33	33	33	33	33	33
No load losses (P0)	W	58	58	58	58	58	58	58	58	58
no load class		AAo	AAo	AAo	AAo	AAo	AAo	AAo	AAo	AAo
Load losses (Pk)	W	1100	875	750	1100	875	750	1100	875	750
load class		Ck	Bk	Ak	Ck	Bk	Ak	Ck	Bk	Ak
Auxiliary losses (Paux)	W	0	0	0	0	0	0	0	0	0
PEI	%	98.469%	98.635%	98.736%	98.469%	98.635%	98.736%	98.469%	98.635%	98.736%
Load Factor (α) (=Pavg/S)	ratio	0.024	0.024	0.024	0.05	0.05	0.05	0.075	0.075	0.075
Load form factor (Kf)(=Prms/Pavg)	ratio	1.073	1.073	1.073	1.073	1.073	1.073	1.073	1.073	1.073
availability factor (AF)	ratio	1	1	1	1	1	1	1	1	1
Power factor (PF)	ratio	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Equivalent load factor (αeq)	ratio	0.03	0.03	0.03	0.06	0.06	0.06	0.09	0.09	0.09
αopt (= sqrt ((Po+Paux)/Pk))	ratio	0.230	0.257	0.278	0.230	0.257	0.278	0.230	0.257	0.278
no load and aux. losses per year	kWh/y	508.1	508.1	508.1	508.1	508.1	508.1	508.1	508.1	508.1
load losses per transformer per year	kWh/y	7.9	6.3	5.4	34.2	27.2	23.3	77.0	61.3	52.5
losses per year	kWh/y	516.0	514.4	513.5	542.3	535.3	531.4	585.1	569.4	560.6
transformer life time	y	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00
kWh price no load and aux. Losses	€	0.098	0.098	0.098	0.098	0.098	0.098	0.098	0.098	0.098
kWh price load losses	€	0.098	0.098	0.098	0.098	0.098	0.098	0.098	0.098	0.098
CAPEX - transformer	€	668.62	697.26	721.46	668.62	697.26	721.46	668.62	697.26	721.46
losses per year	kWh/y	516.0	514.4	513.5	542.3	535.3	531.4	585.1	569.4	560.6
discount rate	%	4%	4%	4%	4%	4%	4%	4%	4%	4%
electricity escalation rate	%	0%	0%	0%	0%	0%	0%	0%	0%	0%
PWF	ratio	19.79	19.79	19.79	19.79	19.79	19.79	19.79	19.79	19.79
No load loss capitalization factor (A)	€/W	16.99	16.99	16.99	16.99	16.99	16.99	16.99	16.99	16.99
Load loss capitalization factor (B)	€/W	0.01	0.01	0.01	0.06	0.06	0.06	0.14	0.14	0.14
TCO A/B ratio = α² (only if kWh price load/no load =)	ratio	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01
TCO A/B ratio = α².(€/kWh load)/(€/kWh no load)	ratio	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01
OPEX electricity	€/y	50.56	50.41	50.32	53.15	52.46	52.08	57.34	55.80	54.94
LCC electricity	€ /life	1,000.82	997.69	995.95	1,051.94	1,038.35	1,030.80	1,134.96	1,104.39	1,087.41
LCC total (excl. scrap@EOL)	€ /life	1,669.44	1,694.95	1,717.41	1,720.55	1,735.61	1,752.26	1,803.58	1,801.65	1,808.87
scrap value @ EOL	€	19.47	19.47	19.47	19.47	19.47	19.47	19.47	19.47	19.47
NPV scrap value (incl. discount rate)	€	4.06	4.06	4.06	4.06	4.06	4.06	4.06	4.06	4.06
LCC total (incl. scrap@NPV)	€	1,665.38	1,690.90	1,713.36	1,716.50	1,731.56	1,748.21	1,799.52	1,797.60	1,804.82

Again these findings show that the cost effectiveness of reduced load losses is highly sensitive to **the load factor** and that on average this **would need to attain 0.075 for there to be an economic rationale** to introduce minimum load losses for 15 and 33 kVA single phase transformers (i.e. for the model types most commonly sold in Ireland).

Again a caveat in this finding is that as Ireland dominates the sale of 15 and 33 kVA single phase transformers in the EU the average characteristics of EI products has been assumed; however, the average EU tariff has been assumed; thus, it could be argued that the average EI tariff should also be applied to this analysis as these products are scarcely sold elsewhere in the EU.

The same caveats as previously also apply to the assumptions regarding the product price and hence CAPEX.

2.3.3 No load losses for single phase transformers

No load losses are obviously independent of the loads applied. Thus the relatively low load factors that apply to single phase transformers compared to three phase transformers are not relevant when considering whether there is an economic case to improve no load losses.

As with the load loss consideration base cases have been developed for single phase transformers at 15, 25, 33 and 50 kVA i.e. for the models that dominate the UK and Irish single phase transformer markets. Table 2-9 to Table 2-12. Table 2-9 shows the 25 and 50kVA cases where the load losses are consistent with the Ck class from the EN50588 standard and the no load losses correspond to the Ao, AAo and AAAo cases from the same standard. Table 2-10 is similar except in this case the load losses correspond to the actual UK average values and the UK average no load loss case is also shown. Table 2-11 shows the 15 and 33kVA cases where the load losses are consistent with the Ck class from the EN50588 standard and the no load losses correspond to the Ao, AAo and AAAo cases from the same standard. Table 2-12 is similar except in this case the load losses correspond to the actual EI average values and the EI average no load loss case is also shown. Investigation of the trends in the least life cycle cost show that the lowest life cycle costs always correspond to the models with the lowest no load loss EN 50588 class i.e. to the AAAo no load loss class. This is the case regardless of the rated capacity considered (15, 25, 33, or 50kVA). These findings indicate that it should be cost effective to impose Ecodesign limits on the no load losses of single phase transformers up to at least the threshold associated with the AAAo class indicated in the EN50588 standard; however, as discussed in the introduction to section 2 and in the text above, this is predicated on EU average tariffs and on the assumption that the CAPEX of single phase transformers is scalable by rated capacity from 3-phase CAPEX as a function of losses and taking into account impedance requirement effect assumptions on cost

Table 2-9 Base Cases for single-phase liquid-immersed medium power transformers – 25kVA and 50kVA models at 4% impedance – with varying NLLs for the Ck load loss class

Base Case		**Liquid Single Phase A0**	**Liquid Single Phase AA0**	**Liquid Single Phase AAA0**	**Liquid Single Phase A0**	**Liquid Single Phase AA0**	**Liquid Single Phase AAA0**
transformer rating (S)	kVA	25	25	25	50	50	50
No load losses (P0)	W	70	63	35	90	81	45
no load class		Ao	AAo	AAAo	Ao	AAo	AAAo
Load losses (Pk)	W	900	900	900	1100	1100	1100
load class		Ck	Ck	Ck	Ck	Ck	Ck
Auxiliary losses (Paux)	W	0	0	0	0	0	0
PEI	%	97.992%	98.095%	98.580%	98.741%	98.806%	99.110%
Load Factor (α) (=Pavg/S)	ratio	0.1	0.1	0.1	0.1	0.1	0.1
Load form factor (Kf)(=Prms/Pavg)	ratio	1.073	1.073	1.073	1.073	1.073	1.073
availability factor (AF)	ratio	1	1	1	1	1	1
Power factor (PF)	ratio	0.9	0.9	0.9	0.9	0.9	0.9
Equivalent load factor (αeq)	ratio	0.12	0.12	0.12	0.12	0.12	0.12
αopt (= sqrt ((Po+Paux)/Pk))	ratio	0.279	0.265	0.197	0.286	0.271	0.202
no load and aux. losses per year	kWh/y	613.2	551.9	306.6	788.4	709.6	394.2
load losses per transformer per year	kWh/y	112.1	112.1	112.1	137.0	137.0	137.0
losses per year	kWh/y	725.3	663.9	418.7	925.4	846.5	531.2
transformer life time	y	40.00	40.00	40.00	40.00	40.00	40.00
kWh price no load and aux. Losses	€	0.098	0.098	0.098	0.098	0.098	0.098
kWh price load losses	€	0.098	0.098	0.098	0.098	0.098	0.098
CAPEX - transformer	€	335.84	358.83	476.08	671.68	717.66	952.16
losses per year	kWh/y	725.3	663.9	418.7	925.4	846.5	531.2
discount rate	%	4%	4%	4%	4%	4%	4%
electricity escalation rate	%	0%	0%	0%	0%	0%	0%
PWF	ratio	19.79	19.79	19.79	19.79	19.79	19.79
No load loss capitalization factor (A)	€/W	16.99	16.99	16.99	16.99	16.99	16.99
Load loss capitalization factor (B)	€/W	0.24	0.24	0.24	0.24	0.24	0.24
TCO A/B ratio = α² (only if kWh price load/no load =)	ratio	0.01	0.01	0.01	0.01	0.01	0.01
TCO A/B ratio = α².(€/kWh load)/(€/kWh no load)	ratio	0.01	0.01	0.01	0.01	0.01	0.01
OPEX electricity	€/y	71.08	65.07	41.03	90.69	82.96	52.05
LCC electricity	€ /life	1,406.79	1,287.84	812.08	1,794.92	1,642.00	1,030.30
LCC total (excl. scrap@EOL)	€ /life	1,742.63	1,646.68	1,288.16	2,466.60	2,359.66	1,982.46
scrap value @ EOL	€	14.75	14.75	14.75	29.50	29.50	29.50
NPV scrap value (incl. discount rate)	€	3.07	3.07	3.07	6.14	6.14	6.14
LCC total (incl. scrap@NPV)	€	1,739.55	1,643.60	1,285.09	2,460.46	2,353.52	1,976.32

Table 2-10 Base Cases for single-phase liquid-immersed medium power transformers – 25kVA and 50kVA models at 4% impedance – with varying NLLs for the average UK load loss class

Base Case		**Liquid Single Phase A0**	**Liquid Single Phase UK ave**	**Liquid Single Phase AA0**	**Liquid Single Phase AAA0**	**Liquid Single Phase UK ave**	**Liquid Single Phase A0**	**Liquid Single Phase AA0**	**Liquid Single Phase AAA0**
transformer rating (S)	kVA	25	25	25	25	50	50	50	50
No load losses (P0)	W	70	68	63	35	112	90	81	45
no load class		Ao	Ao	AAo	AAAo	<Ao	Ao	AAo	AAAo
Load losses (Pk)	W	540	540	540	540	900	900	900	900
load class		Ck	Ck	Ck	Ck	Ck	Ck	Ck	Ck
Auxiliary losses (Paux)	W	0	0	0	0	0	0	0	0
PEI	%	98.445%	98.467%	98.524%	98.900%	98.730%	98.862%	98.920%	99.195%
Load Factor (α) (=Pavg/S)	ratio	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Load form factor (Kf)(=Prms/Pavg)	ratio	1.073	1.073	1.073	1.073	1.073	1.073	1.073	1.073
availability factor (AF)	ratio	1	1	1	1	1	1	1	1
Power factor (PF)	ratio	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Equivalent load factor (αeq)	ratio	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12
αopt (= sqrt ((Po+Paux)/Pk))	ratio	0.360	0.355	0.342	0.255	0.353	0.316	0.300	0.224
no load and aux. losses per year	kWh/y	613.2	595.7	551.9	306.6	981.1	788.4	709.6	394.2
load losses per transformer per year	kWh/y	67.2	67.2	67.2	67.2	112.1	112.1	112.1	112.1
losses per year	kWh/y	680.4	662.9	619.1	373.8	1093.2	900.5	821.6	506.3
transformer life time	y	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00
kWh price no load and aux. Losses	€	0.098	0.098	0.098	0.098	0.098	0.098	0.098	0.098
kWh price load losses	€	0.098	0.098	0.098	0.098	0.098	0.098	0.098	0.098
CAPEX - transformer	€	335.84	342.41	358.83	476.08	559.27	671.68	717.66	952.16
losses per year	kWh/y	680.4	662.9	619.1	373.8	1093.2	900.5	821.6	506.3
discount rate	%	4%	4%	4%	4%	4%	4%	4%	4%
electricity escalation rate	%	0%	0%	0%	0%	0%	0%	0%	0%
PWF	ratio	19.79	19.79	19.79	19.79	19.79	19.79	19.79	19.79
No load loss capitalization factor (A)	€/W	16.99	16.99	16.99	16.99	16.99	16.99	16.99	16.99
Load loss capitalization factor (B)	€/W	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24
TCO A/B ratio = α² (only if kWh price load/no load =)	ratio	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
TCO A/B ratio = α².(€/kWh load)/(€/kWh no load)	ratio	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
OPEX electricity	€/y	66.68	64.97	60.67	36.64	107.13	88.25	80.52	49.61
LCC electricity	€ /life	1,319.84	1,285.86	1,200.90	725.13	2,120.44	1,746.62	1,593.69	981.99
LCC total (excl. scrap@EOL)	€ /life	1,655.68	1,628.26	1,559.73	1,201.21	2,679.71	2,418.30	2,311.36	1,934.16
scrap value @ EOL	€	14.75	14.75	14.75	14.75	29.50	29.50	29.50	29.50
NPV scrap value (incl. discount rate)	€	3.07	3.07	3.07	3.07	6.14	6.14	6.14	6.14
LCC total (incl. scrap@NPV)	€	1,652.61	1,625.19	1,556.66	1,198.14	2,673.57	2,412.15	2,305.21	1,928.01

Table 2-11 Base Cases for single-phase liquid-immersed medium power transformers – 15kVA and 33kVA models at 2.2% impedance – with varying NLLs for the Ck load loss class

Base Case		**Liquid Single Phase A0**	**Liquid Single Phase AA0**	**Liquid Single Phase AAA0**	**Liquid Single Phase A0**	**Liquid Single Phase AA0**	**Liquid Single Phase AAA0**
transformer rating (S)	kVA	15	15	15	33	33	33
No load losses (P0)	W	70	63	35	76.4	68.76	38.2
no load class		Ao	AAo	AAAo	Ao	AAo	AAAo
Load losses (Pk)	W	900	900	900	964	964	964
load class		Ck	Ck	Ck	Ck	Ck	Ck
Auxiliary losses (Paux)	W	0	0	0	0	0	0
PEI	%	96.653%	96.825%	97.634%	98.355%	98.440%	98.837%
Load Factor (α) (=Pavg/S)	ratio	0.1	0.1	0.1	0.1	0.1	0.1
Load form factor (Kf)(=Prms/Pavg)	ratio	1.073	1.073	1.073	1.073	1.073	1.073
availability factor (AF)	ratio	1	1	1	1	1	1
Power factor (PF)	ratio	0.9	0.9	0.9	0.9	0.9	0.9
Equivalent load factor (αeq)	ratio	0.12	0.12	0.12	0.12	0.12	0.12
αopt (= sqrt ((Po+Paux)/Pk))	ratio	0.279	0.265	0.197	0.282	0.267	0.199
no load and aux. losses per year	kWh/y	613.2	551.9	306.6	669.3	602.3	334.6
load losses per transformer per year	kWh/y	112.1	112.1	112.1	120.0	120.0	120.0
losses per year	kWh/y	725.3	663.9	418.7	789.3	722.4	454.7
transformer life time	y	40.00	40.00	40.00	40.00	40.00	40.00
kWh price no load and aux. Losses	€	0.098	0.098	0.098	0.098	0.098	0.098
kWh price load losses	€	0.098	0.098	0.098	0.098	0.098	0.098
CAPEX - transformer	€	256.46	274.02	363.55	564.21	602.84	799.82
losses per year	kWh/y	725.3	663.9	418.7	789.3	722.4	454.7
discount rate	%	4%	4%	4%	4%	4%	4%
electricity escalation rate	%	0%	0%	0%	0%	0%	0%
PWF	ratio	19.79	19.79	19.79	19.79	19.79	19.79
No load loss capitalization factor (A)	€/W	16.99	16.99	16.99	16.99	16.99	16.99
Load loss capitalization factor (B)	€/W	0.24	0.24	0.24	0.24	0.24	0.24
TCO A/B ratio = α² (only if kWh price load/no load =)	ratio	0.01	0.01	0.01	0.01	0.01	0.01
TCO A/B ratio = α².(€/kWh load)/(€/kWh no load)	ratio	0.01	0.01	0.01	0.01	0.01	0.01
OPEX electricity	€/y	71.08	65.07	41.03	77.35	70.79	44.56
LCC electricity	€ /life	1,406.79	1,287.84	812.08	1,530.99	1,401.17	881.91
LCC total (excl. scrap@EOL)	€ /life	1,663.25	1,561.86	1,175.63	2,095.20	2,004.01	1,681.72
scrap value @ EOL	€	8.85	8.85	8.85	19.47	19.47	19.47
NPV scrap value (incl. discount rate)	€	1.84	1.84	1.84	4.06	4.06	4.06
LCC total (incl. scrap@NPV)	€	1,661.40	1,560.02	1,173.79	2,091.14	1,999.95	1,677.67

Table 2-12 Base Cases for single-phase liquid-immersed medium power transformers – 15kVA and 33kVA models at 2.2% impedance – with varying NLLs for the average EI load loss class

Base Case		Liquid Single Phase A0	Liquid Single Phase AA0	Liquid Single Phase EI ave	Liquid Single Phase AAA0	Liquid Single Phase A0	Liquid Single Phase AA0	Liquid Single Phase EI ave	Liquid Single Phase AAA0
transformer rating (S)	kVA	15	15	15	15	33	33	33	33
No load losses (P0)	W	70	63	48	35	76.4	68.76	58	38.2
no load class		Ao	AAo	AAo	AAAo	Ao	AAo	AAo	AAAo
Load losses (Pk)	W	270	270	270	270	675	675	675	675
load class		Ck	Ck	Ck	Ck	Ck	Ck	Ck	Ck
Auxiliary losses (Paux)	W	0	0	0	0	0	0	0	0
PEI	%	98.167%	98.261%	98.482%	98.704%	98.624%	98.694%	98.801%	99.027%
Load Factor (α) (=Pavg/S)	ratio	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Load form factor (Kf)(=Prms/Pavg)	ratio	1.073	1.073	1.073	1.073	1.073	1.073	1.073	1.073
availability factor (AF)	ratio	1	1	1	1	1	1	1	1
Power factor (PF)	ratio	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Equivalent load factor (αeq)	ratio	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12
αopt (= sqrt ((Po+Paux)/Pk))	ratio	0.509	0.483	0.422	0.360	0.336	0.319	0.293	0.238
no load and aux. losses per year	kWh/y	613.2	551.9	420.5	306.6	669.3	602.3	508.1	334.6
load losses per transformer per year	kWh/y	33.6	33.6	33.6	33.6	84.0	84.0	84.0	84.0
losses per year	kWh/y	646.8	585.5	454.1	340.2	753.3	686.4	592.1	418.7
transformer life time	y	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00
kWh price no load and aux. Losses	€	0.098	0.098	0.098	0.098	0.098	0.098	0.098	0.098
kWh price load losses	€	0.098	0.098	0.098	0.098	0.098	0.098	0.098	0.098
CAPEX - transformer	€	256.46	274.02	321.98	363.55	564.21	602.84	685.68	799.82
losses per year	kWh/y	646.8	585.5	454.1	340.2	753.3	686.4	592.1	418.7
discount rate	%	4%	4%	4%	4%	4%	4%	4%	4%
electricity escalation rate	%	0%	0%	0%	0%	0%	0%	0%	0%
PWF	ratio	19.79	19.79	19.79	19.79	19.79	19.79	19.79	19.79
No load loss capitalization factor (A)	€/W	16.99	16.99	16.99	16.99	16.99	16.99	16.99	16.99
Load loss capitalization factor (B)	€/W	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24
TCO A/B ratio = α² (only if kWh price load/no load =)	ratio	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
TCO A/B ratio = α².(€/kWh load)/(€/kWh no load)	ratio	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
OPEX electricity	€/y	63.39	57.38	44.50	33.34	73.82	67.27	58.03	41.03
LCC electricity	€ /life	1,254.63	1,135.69	880.81	659.92	1,461.19	1,331.37	1,148.54	812.11
LCC total (excl. scrap@EOL)	€ /life	1,511.09	1,409.70	1,202.79	1,023.47	2,025.40	1,934.21	1,834.23	1,611.93
scrap value @ EOL	€	8.85	8.85	8.85	8.85	19.47	19.47	19.47	19.47
NPV scrap value (incl. discount rate)	€	1.84	1.84	1.84	1.84	4.06	4.06	4.06	4.06
LCC total (incl. scrap@NPV)	€	1,509.24	1,407.86	1,200.95	1,021.63	2,021.35	1,930.16	1,830.17	1,607.87

Use of Amorphous Transformers:
Amorphous transformers have much lower Iron losses than conventional GOES transformers do, even for those GOES designs which use lower loss steels.

It is reported that there is no extensive use of amorphous transformers in the UK or Ireland from which to provide a reliable basis for the estimation of the costs of such transformers. Equally it is reported in the stakeholder workshop that discussions with large suppliers of Amorphous Metal Transformers (AMT) provided quite contradictory information on the expected price changes from switching to AMT, with the reported price changes ranging over a greater than +60% range. This is due to the actual cost depending strongly on the price of the amorphous steel which is supplied from a tight market, but also on the suppliers attempting to pitch the price in relation to what the expected price from traditional manufacturers would be.

It is reported that ESB have been in the process of tendering for single phase transformers but it was not possible to gather relevant cost data for use within this study.

2.3.4 Conclusions regarding cost effective loss reduction for single phase transformers

The justification for increased transformer efficiency is that the benefits to society from increased efficiency in terms of reduced CO_2 and kWh savings due to greater energy efficiency are such that they repay the extra material costs incurred in a more efficient transformer. The Ecodesign Directive requires a determination of the efficiency level associated with the least life cycle cost and for this to form the basis of minimum limits. The analyses presented above, which are derived from estimated costs and loss assumptions, indicate that there is likely to be little or no economic justiciation to set Ecodesign load loss limits for single phase transformers as they are actually used in European countries (exclusively EI and UK), but that there is likely to be an economic rationale to set no load limits**. However, this is predicated on significant assumptions regarding the cost and losses of single phase transformers and it has not been possible to attain data to validate these**.

Given the lack of alternative data and evidence it looks as if the Level 1 and/or Level 2 PEI losses **included in Table 12 of EN 50588-1:2015 could be used, or equivalent loss combinations from Table 2 (i.e. the AAA0 loss class) and Table 3 (the Ck class).** Anyhow, it would be preferable were manufacturers to confirm the extent to which this is technically and economically feasible, albeit that this is a difficult exercise to undertake for such a small market.

2.4 Could Tier 2 requirements be applied to single-phase transformers and what would be the potential impact?

As discussed in section 2.3 there appears to be little rationale for imposing load loss requirements on single phase transformers but a stronger case exists for no load loss requirements. The Tier 2 levels that apply to three phase transformers are set in terms of load and no load losses, thus it seems sensible to first settle the question of whether load loss requirements are justified for single phase transformers, and only afterwards address the issue of whether the Tier 2 levels are appropriate or not (at least with respect to no load losses). The related discussion with regard to the potential extension of the PEI (see section 1.3) is also pertinent here.

2.5 What risk is there of weakening the impact of Tier 1 and Tier 2 requirements for three phase transformers if requirements are not set for single phase transformers?

Single phase transformers are only used in single phase MV power networks. **These are currently only found in rural parts of Ireland and the UK** and are in use due to an historical infrastructural legacy. In theory one could install three single phase transformers instead of one three phase transformer in a three phase distribution system, but this would result in a significant increase in the installation costs and would reduce functionality with regard to power quality for load balancing and the suppression of harmonic currents. Thus there **seems to be no risk that non adoption of Ecodesign limits for single phase transformers could create a motivation for three phase operators to switch to single phase supply** in order to circumvent the incremental costs associated with three-phase transformer Ecodesign requirements. In consequence, the decision of whether or not Ecodesign limits should be set for single phase transformers should be taken on its own merits and should not be concerned with issues of regulatory asymmetry between three and single phase transformer types.

3 Task 3 on verification of existing exemptions and regulatory concessions

This task is divided into four subtasks as set out below.

3.1 Verification of scope and exemptions in Regulation 548/2014

Aim and tender request:
Article 1.2 of Regulation 548/2014 provides a list of transformers specifically designed for particular applications, which are exempted from the obligations described in its Annex I.

This task consists in proposing, if necessary, an update to the list of exemptions by including new categories or delisting existing ones. Conversely, it also aims to identify any existing regulatory exemptions in Article 1.2 which may no longer be justified.

3.1.1 Proposals for new exemptions

The study team note that T&D Europe supplied a draft review of Regulation 548/2014 and CENELEC/TC14 is also working on a document, prTS 50675:2017, which contains input for the review. They are supplied in Annexes to this report.

3.1.1.1 Medium power transformers for brown field applications with space/weight constraints relative to Tier 2

The analysis presented in Task 1 section 1.8 found that **from a technical point of view there is no need for such exemptions** apart from for pole-mounted transformers or unusual windings configurations.

As a consequence some possible exemptions are put forward in the following text that could be considered should concerns about higher costs and lower profit margins for severely space constrained brownfield sites be considered to be sufficiently important to render them necessary, see section 1.9.

The **aim of new technology should be compliance with Tier 2 and not with the exemptions**, as a consequence using technology specific characteristics hereafter should not be seen as a barrier for new technologies entering the market that don't have these characteristics.

In general, the theoretical finding in section 1.3.3 was also that **a new medium power Tier 2 PEI compliant transformer** could be developed, referred to as 'T2 kPEI=0,25' **which is in the A0-35%/Ck loss class**. This is useful for greenfield applications but could also provide an alternative for brownfield applications. Note, however, that this is a hypothetical transformer and manufacturers currently do not support the reasoning behind which is was proposed (see Task 1).

In the event that concerns about increasing DSO CAPEX costs for severely space constrained transformers results in regulators reconsidering the applicability of Tier 2 requirements, the following recommendations would apply regarding how best to subsequently proceed:

- Based on the work done in Task 1 it was concluded that it is not possible to set requirements via a table with space & weight limits related to the rating (kVA), because this would be an exhaustive task that also depends on specific factors for each DSO, and finally it was also concluded that for nearly all cases Tier 2 compliant transformers can be constructed with existing technology.

- Without creating a significant loophole one **could grant an exemption for** economic reasons applicable to transformers destined for severely space constrained brownfield applications that are:
  - compliant with **Tier 1** or lower losses; and,
  - have a core with **maximum specific core losses** at a relative high magnetic flux density **(≤0.80 W/kg @ 1.7 T**); and,
  - for rating up to 160 kVA: the conductivity of the conductor material <27 mΩ.mm @ 20°C. The rationale is that smaller transformers are often installed in rural areas where theft protection is more complicated and this allows aluminium to be used; and,
  - for rating above 160 kVA: the conductivity of the conductor material <17 mΩ.mm @ 20°C. This can be easily be achieved with copper conductors but it should be noted that the high copper price was the root of the economic problem for severely space constrained brownfield transformers (see 1.1.8), therefore an alternative is provided below;

  Alternatively, for a transformer designed to operate at a high load and high temperature (for which the idea is to have more compact but higher loaded transformers) and exception could be granted if:
  - the transformer is IEC 60076 part 14 compliant and **can operate at a temperature** of 120 °C or above; and,
  - the **load losses are compliant with Tier 2** Table 1.1 at **75°C** and its respective rated power, but never two classes below its rated power at 120 °C, e.g. 500 kVA (@75°C) values can be used instead of 630 kVA (@120°C); and,
  - the **no load losses compliant with Tier 2** Table 1.1 at its respective rated power; and,
  - have a core with **maximum specific core losses** at a relatively high magnetic flux density (≤0.80 W/kg @ 1.7 T).

The previously formulated exemption could also be used for pole-mounted transformers and replace Table 1.6 and/or transformers with unusual windings Table 1.3 in Regulation 548/2014.

3.1.1.2 Large power transformers for green field applications with transportation constraints relative to Tier 2

Currently for large power transformers there is only an exemption for like-for-like replacements. As explained in section 1.5.3 **it is recommended to extend this to green field applications for very large transformers**.

Therefore a new exemption for applications that require compact and/or lightweight applications, could be specified as follows:

- are compliant with the PEI of Tier 1; and,
- have a core with maximum specific core losses at a relative high magnetic flux density (≤1,00 W/kg @ 1.7 T). Compared to distribution transformers this allows the use of a thicker gauge (see 1.1.3.2), which might be needed for large power transformers; and,

- one of the following limits is exceeded: 40 tonne weight, 2,6 m width, 4 m high and 12 m long); and,
- the conductivity of the conductor material <17 mΩ.mm @ 20°C.

The previously formulated approach is an approach that is idependant of the site at which the transformer should be used. Therefore it could open the door for a broad use of this exemption and in order to limit this one could add the following complementary site specific requirements:

- for TSOs and DSOs that have to follow the Utilities Directive (2014/25/EU); due to the public procurement procedure they have official documents available. Therefore it can be required to have a negative award report that no Tier 2 transformer could be procured before starting to procure an non-compliant transformer. This negative award report should be included in the new tender and could be part of the technical construction file of the bidder for an incompliant transformer.; or,
- Private companies that do not have to follow the Utilities Directive should contact the local TSO/DSO; they would need to ask for a written confirmation of the TSO to which they are connected that they are unable to supply a Tier 2 compliant transformer.

Note, however, that this procedure could be time consuming for one-to-one replacements and that exceptions could be granted in case of a failure of an existing transformer.

3.1.2 Review of existing exemptions

Connected to the previously proposed definition in section 3.1.1 **it is also recommended to add the proposed technical characteristics for maximum specific core loss to most of the current exemptions**. This is especially the case for the existing exemption for 'large power transformers which are like for like replacements in the same physical location/installation for existing large power transformers, where this replacement cannot be achieved without entailing disproportionate costs associated to their transportation and/or installation'.

Note that this 'exemption' can also be added as an alternative Tier 2 requirement for a separate category of transformers within the scope of the regulation. In principle, it is a matter of wording and the structure of the regulation, but having it within the requirements could result in a greater stimulus to carry out market surveillance.

3.1.3 Consideration of the scope

Because existing space/weight constraints for distribution substations have potentially created a lock-in effect into Tier 1 transformers for some parts of the market it is recommended to **extend the scope of the regulation to substations and add minimum dimensions and weight characteristics.** Such data could at least be added in a technical guideline and thus the issuance of a standardisation mandate to address this is highly recommended. For example, in order to continue to avoid lock-in effects for single pole-mounted transformers one could also address poles for distribution transformers, see 3.4.1. Also, European consumers could benefit from an economy of scale when harmonizing transformer pole constructions and thus a European standardisation mandate could be considered.

There is also an issue of whether or not to include repaired transformers with specific requirements in an update of Regulation 548/2014, but this is discussed in the next section.

3.2 Analysis of criteria to include the repair of transformers in Regulation 548/2014

Aim and tender request:
Regulation 548/2014 does not currently specify minimum energy efficiency requirements for the repair of transformers. Transformers can be repaired under a myriad of different situations and their service life can be extended significantly as a result. In some cases, repaired transformers may be equivalent to new products, but are not covered by the regulation. Cases of the market for repaired transformers being unintentionally driven by energy conservation regulations (applicable to new models) have been reported in the US and other jurisdictions.
The task here is to investigate whether the existing regulation should be extended to cover the repair of transformers in (extreme) cases where these transformers result in products which could be considered to be new. This would require collecting some figures about the market for repaired transformers in the EU, as well as the views of manufacturers and electricity companies on the possibility to develop criteria for determining when repaired transformers can be considered as new, without creating confusion.

3.2.1 Limitations from CE marking legislation

In considering this it is important to be aware that since the transformer Commission Regulation (EU) No 548/2014 came into force, all transformers have to carry a CE mark and have to follow the **Regulation on CE marking (765/2008)**. Existing transformers often do not have this CE marking and do not necessarily have the documentation to prove compliance. Bringing products on the market is documented in the 'Blue Guide on the implementation of EU products rules 2016' available from the EC[77].

Amongst other aspects it defines the responsibilities of the manufacturer, i.e.:

- carry out the applicable conformity assessment or have it carried out, for example verify compliance with applicable European Directives
- draw up the required technical documentation
- draw up the EU Declaration of Conformity (EU DoC)
- accompany the product with instructions and safety information
- satisfy the following traceability requirements:
  - keep the technical documentation and the EU Declaration of Conformity for 10 years after the product has been placed on the market or for the period specified in the relevant Union harmonisation act
  - ensure that the product bears a type, batch or serial number or other element allowing its identification
  - indicate the following three elements: his (1) name, (2) registered trade name or registered trade mark and (3) a single contact postal address on the product, or when not possible because of the size or physical characteristics of the products, on its packaging and/or on the accompanying documentation

[77] http://ec.europa.eu/growth/tools-databases/newsroom/cf/itemdetail.cfm?item_id=7326

- affix the conformity marking (CE marking and where relevant other markings) to the product in accordance with the applicable legislation
- ensure that procedures are in place for series production to remain in conformity
- where relevant, certify the product and/or the quality system.

Note that the **Regulation (EU) No 548/2014** establishes ecodesign requirements 'for placing on the market or putting into service'. The **Blue Guide on the implementation of EU products rules 2016** (Notice- 2016/C 272/01)' also explains when Union Harmonisation Legislation on Products apply (p. 15), a/o. it says that:

- **once it reaches the end-user it is no longer considered a new product and the Union harmonisation legislation no longer applies;**
- the Union harmonisation legislation applies to newly manufactured products but also to used and second-hand products, including products resulting from the preparation for re-use of electrical or electronic waste, imported from a third country when they enter the Union market for the first time;
- Union harmonisation legislation applies when the product is made available (or put into service) **on the Union market for the first time**. It also applies to used and second-hand products imported from a third country, including products resulting from the preparation for re-use of electrical or electronic waste, when they enter the Union market for the first time, but not to such products already on the market. It applies even to used and second-hand products imported from a third country that were manufactured before the Union harmonisation legislation became applicable;
- a product, which has been subject to important changes or overhaul aiming to modify its original performance, purpose or type after it has been put into service, having a significant impact on its compliance with Union harmonisation legislation, must be considered as a new product;
- products which have been repaired or exchanged (for example following a defect), without changing the original performance, purpose or type, are not to be considered as new products according to Union harmonisation legislation;
- a product is made available on the market when supplied for distribution, consumption or use on the Union market in the course of a commercial activity, whether in return for payment or free of charge;
- the making available of a product supposes an offer or an agreement (written or verbal) between two or more legal or natural persons for the transfer of ownership, possession or any other right concerning the product in question after the stage of manufacture has taken place;
- putting into service takes place at the moment of first use within the Union by the end user for the purposes for which it was intended.

Therefore this **CE legislation already limits the possibilities of repaired transformers that have a CE marking, especially when they change characteristics because the full CE marking procedure might have to be redone** including new technical documentation, EU DoC, serial number, etc. However, **for old transformers that did not yet have a CE marking there are no such limitations.** Therefore when older transformers without a CE marking are resold, evidence might be needed to prove they were manufactured before the CE requirements came into effect. This might be difficult to prove and therefore in practice they are phased out from the second hand market.

According to DSOs repair of medium power transformers is not a common practice because the installation costs are so high that utilties don't take the risk. The rated capacity of distribution transformers can vary from 15 – 1000 kVA and such products are generally only worth repairing if the problem needing repair is something as simple as a broken bushing (which can easily be replaced) on a relatively new transformer. In general, utilities will never want to buy repaired transformers from outside the utility, and would also not want to repair their existing transformers if it involves anything more than a bushing. The reason for this is that the cost of replacing and then installing a transformer is a multiple of the cost of the transformer, so that to cover these costs the transformer must work reliably in situ for at least 20 years. Any possibility of failure would result in excessive costs e.g. those including the replacement cost of the transformer, hire of generators, switching to restore supply, and penalty payments for outages.

According to TSOs the repair of power transformers is in many cases the most economical solution.

Also scrapping relatively young transformers can be environmentally questionable. The Ecoreport for a 40 year old BC1 distribution transformer showed that the use phase accounts for 88% of the GWP, see section 1.2. This means that **scrapping a transformer before 5 years**[78] **of service life does not make sense** from an environmental perspective.

CENELEC is working on a more extended definition iof what constitutes a repaired and/or second hand transformer in document prTS 50675:2017. Also, according to manufacturers, **new technologies could be considered that result in retrofitted or upgraded transformers becoming more efficient**.

According to T&D Europe's interpretation[79]: 'Repaired transformers which remain the property of the same customer are not subject to the eco-design regulation. Repaired or renovated transformers which are put back on the market need to be eco-design compliant.' This interpretation is also supported by TSO's (as represented by ENTSO-E).

Nevertheless, from the information presented above **the study team conclude that change of ownership**, or so called second hand transformers, **can constitute a loophole** for the regulation because these products only have to comply with the requirements when they entered the market for the first time.

A solution is to explicitly consider all repaired, retofitted or resold transformers as new products brought on the market unless they do not change ownership and they are still functioning within their originally foreseen life time (<20 years). But this **would require ammending Regulation (EU) No 548/2014 and Blue Guide on the implementation of EU products rules 2016** (Notice- 2016/C 272/01) to accomodate this.

[78] > (1-0.88)x40 years
[79] http://www.tdeurope.eu/data/T&D%20Europe%20Transformers%20Eco-design%20PP%2015052015.pdf

3.3 Verification of concessions for transformers with unusual combinations of winding voltages

Aim and tender request:

Table I.3 of Annex I in Regulation 548/2014 provides a list of concessions for transformers built with special, or unusual combinations of winding voltages, or dual voltage in one or both windings. There have already been indications that this list may not be, on the one hand, fully exhaustive, and on the other, fully justified.

3.3.1 Task understanding and challenges

It is understood that transformer losses can increase for special voltage combinations because more insulation will increase the magnetic circuit and windings in a proportional manner to the transformer rating.

In this context it should be noted that the corrections of **Table I.3** in Regulation 548/2014 do not apply to pole-mounted transformers treated within **Table I.6** and this is **inconsistent**.

According to the manufacturers any potential amendments to concessions for transformers with unusual combinations of winding voltages should **avoid killing new technologies** which might be needed **for voltage regulation** or power quality in more complex grids with distributed energy.

However it has been reported that **some transformer manufacturers are using these concessions to take advantage of the margin in losses** (10-15%) and sell dual ratio transformers at a cheaper price than single ratio ones, even if only a single ratio is required. This is a trick to sell a formally Eco-design compliant transformer, but that is not in line with the spirit of the regulation, to customers who do not care about losses but only about price.

3.3.2 Proposal

CENELEC is working on a proposal to address this within document prTS 50675:2017.

Our recommendation is to **complement Table 1.3** within Regulation 548/2014 **with the same requirements as formulated in section 3.1.1.1** on potential requirements for exempted severely space constrained brownfield transformers.

3.4 Verification of concessions for pole-mounted transformers

Aim and tender request:

Table I.6 of Annex I in Regulation 548/2014 provides concessions for transformers which are not operated on the ground, but are mounted on poles. Pole-mounted transformers have weight limitations and, in principle, cannot achieve the same levels of efficiency as ground-mounted ones. These concessions were the result of long discussions with manufacturers, electricity companies and Member States.

This task consists in gathering a fresh understanding of the market for pole-mounted transformers in the EU and using this information to inform an assessment of whether regulatory concessions for pole-mounted transformers should be maintained or should be phased out. The proposal to change Table I.6 was discussed at the stakeholder workshop.

3.4.1 Single pole versus multiple pole constructions

At the origin of this concession are weight limits for pole mounted transformers such as for some other brownfield applications as discussed in section 1.5. So far, Regulation 548/2014 does not specify the type of pole construction, however, this can be an important factor influcencing the practical constraints. The best way to increase the stiffness and stability of a pole-mounted transformer construction is to increase the second area moment[80] of the construction. This can be done by using a second pole or a lattice frame construction, see Figure 3-1. Such a lattice frame construction, or second pole, will use less material for the same stiffness and will therefore be easier to transport, more economical and have consequently a lower ecological impact compared to single pole. For greenfield applications such single pole constructions can be avoided in cases where there are stability concerns. In the case of brownfield applications adding a second pole can also be considered. Table 3-1 contains the LCC calculation for a 160 kVA pole-mounted transformer which is compliant with the Tier 2 concessions for pole mounted transformers and the equivalent values for a Tier 2 compliant liquid transformer. Prices for such transformers are unknown, although stakeholders were invited to provide input. As an example Table 3-1 contains an estimated price for a 160 kVA Tier 2 transformer based on Tier 1&2 400 kVA BC 1 extrapolation with a supplement of 500 euro[81] for a second pole. This example shows that adding a second pole and using a more efficient transformer has a lower LCC. Of course for an existing installation other costs will also arise when a second pole needs to be installed (such as rewiring, gaining planning permission, etc.). When a second pole is required it may not be possible to identify a suitable position for it to be placed beside the existing one, so that the existing pole would also need to be relocated, along with all the attachments. This can become very expensive. A second pole is more visually intrusive and may attract planning permission objections. These may result in requiring it be relocated to a site further away with greater losses on the associated circuits, which will now necessarily be longer. Hence, in principle, there is no technical rationale to maintain this concession, especially not for greenfield applications. It is rather a lock-in effect into existing procedures and installations for which such an exemption could be maintained. **Therefore it can be concluded that at least the exemption should be limited to 'single pole transformers for one-to-one replacement in existing installations'**. There was a consensus on this point in the 2nd stakeholder meeting.

Moreover, it should also be noted that **new local safety-regulations may only permit transformers to be placed on the ground (e.g. as is the case in Norway),** which means that this issue could become less relevant were other countries to follow similar safety practices.

Finally, **some manufacturers** do not support the specific concessions made for pole-mounted transformers because with better technology they **claim to be capable of simply meeting the Tier 2 requirements in Table 1.1**.

[80] https://en.wikipedia.org/wiki/Second_moment_of_area
[81] Note: according to our info this is the price for a street lighting pole

Figure 3-1 Dual pole transformer in Wallonia (BE)(Left) (source: www.gregor.be) and single pole in France (right) (source: https://fr.wikipedia.org/wiki/Poste_%C3%A9lectrique)

Table 3-1 LCC calculation for 160 kVA pole-mounted transformer wherein 'BC pole' is compliant with the Tier 2 concessions for pole-mounted transformers and 'BC 2pole' is compliant with Tier 2 requirements for liquid transformers.

Base Case		BC pole liquid Tier2	BC 2pole liquid Tier2
transformer rating (Sr)	kVA	160	160
No load losses (P0)	W	270	189
no load class		C0-10%	Ao-10%
Load losses (Pk)	W	3102	1750
load class		Ck+32%	Ak
Auxiliary losses (Paux)	W	0	0
PEI	%	98,856%	99,281%
Load Factor (k) (=Pavg/S)	ratio	0,15	0,15
Load form factor (Kf)(=Prms/Pavg)	ratio	1,073	1,073
availability factor (AF)	ratio	1	1
Power factor (PF)	ratio	0,9	0,9
Equivalent load factor (keq)	ratio	0,18	0,18
load factor@PEI (kPEI)	ratio	0,295	0,329
no load and aux. losses per year	kWh/y	2365,2	1655,6
load losses per transformer per year	kWh/y	869,0	490,3
losses per year	kWh/y	3234,2	2145,9
transformer life time	y	25,00	25,00
kWh price no load and aux. Losses	€	0,15	0,15
kWh price load losses	€	0,15	0,15
CAPEX - transformer	€	**3 129,64**	**4 091,00**
losses per year	kWh/y	3234,2	2145,9
discount rate	%	**2%**	**2%**
electricity escalation rate	%	**0%**	**0%**
PWF	ratio	19,52	19,52
No load loss capitalization factor (A)	€/W	25,65	25,65
Load loss capitalization factor (B)	€/W	0,82	0,82
TCO A/B ratio	ratio	0,03	0,03
OPEX electricity	€/y	485,14	321,89
LCC electricity	€ /life	9 471,55	6 284,35
LCC total (excl. scrap@EOL)	€ /life	**12 601,19**	**10 375,35**

3.4.2 Proposals for Tier 2

It is recommended to withdraw Table 1.6 and use the potential brown field exemptions discussed in section 3.1.1.1.

3.5 General considerations on verification of existing exemptions and regulatory concessions

Note that Regulation 548/2014 could also benefit from the review of some of the definitions and standards applying to efficiency measurements, e.g. as mentioned in the first stakeholder meeting 'It is important that the efficiency of the transformer has to be measured at the terminals (otherwise it opens the opportunity to claim high performance associated with dropping functions)'. This work should run in parallel with the corresponding study within CENELEC.

The definition of **medium power transformers is currently limited to 36 KV** (Table 1.1 in Regulation 548/2014). Therefore, for power transformers with a rated capacity of less than 4 MVA but with voltages higher than 36 kV the **PEI criterion must be applied** (Table 1.7 in Regulation 548/2014). According to the information received by the study team this could result in disproportionately large dimensions for those transformers. For example, a 33/11kV, 3150KVA transformer is considered a medium power transformer for which the maximum losses will apply, while a 45kV and 50KVA transformer (i.e. for auxiliary services in a substation) is considered to be a Large Power Transformer (LPT) for which the PEI requirements apply. The consequence is that the PEI value for a transformer smaller than 4 MVA at a voltage value higher than 36 kV has more restrictive loss demands than for a transformer of the same size with a voltage lower than 36 kV. This is **not logical**.

A potential solution would be to add a specific PEI table similar to Table 1.1 in Regulation 548/2014 applicable for voltages up to 72.5 kV but imposing less ambitous requirements, see Table 3-2.

Power kVA	TIER 1	TIER 2
25	97,742	98,251
50	98,584	98,891
100	98,867	99,093
160	99,012	99,191
250	99,112	99,283
315	99,154	99,32
400	99,209	99,369
500	99,247	99,398
630	99,295	99,437
800	99,343	99,473
1000	99,36	99,484
1250	99,418	99,487
1600	99,424	99,494
2000	99,425	99,502
2500	99,442	99,514
3150	99,445	99,518

Table 3-2 Proposal received(Annex 20, ORMAZABAL-ALKARGO-GEDELSA) for PEI of large power transformers with voltages up to 73kV

Another update is needed **to define the cooling losses to be included in the PEI** curve and kPEI; **this work is elaborated within prTS 50675:2017**. To avoid the creation of a loophole, the standards adopted after regulation 548/2014 was published, have included within the PEI calculation the losses represented by the cooler consumption at the kPEI. The standard EN 50629 also explains this. The standards prescribe the use of cooling losses occurring at kPEI within the calculation of the PEI.

Finally it should be noted that **losses included in Table 1.1 of Regulation 548/2014 stop at 25kVA and Table at 50 kVA**, which means the same fixed values would apply for lower or intermediate capacity ratings. In principle, one could require that they be extrapolated relative to the rating $S(kVA)^{0,75}$ for lower and intermediate capacity ratings.

4 Task 4 - Analysis of other environmental impacts

Aim and tender request:
The preparatory study for power transformers completed in 2011 concluded that the use phase is, by far, the most significant one in terms of their environmental impact. The Ecodesign methodology (MEErP) used for this preparatory study was revised in 2013 with a view to elaborating upon the material efficiency aspects.

Taking advantage of the data collection and fresh calculations made in Task 1, this task consists in an investigation of significant environmental impacts, other than energy, for which it would be justified to consider additional requirements in the context of the review of Regulation 548/2014.

4.1 Conclusions based on Task 1 MEErP versus MEEuP

Ecodesign impact results according to the MEErP are presented in section 1.2. In Figure 1-3 the green columns represent the positive and non-neglectable impact from recycling on the production related impact which are shown in the brown columns.

In Figure 1-3 the MEErP default values for metal recycling were used but in practice this positive impact from recycling can even be larger because transformer land fill disposal without recycling is unlikely given the scrap value. In order to stimulate recycling and to better consider the scrap value in the Life Cycle Cost (see section 1.1.4), **it can be recommended to also require the inclusion of detailed Bill-of-Material information within transformer digital data required for market surveillance and not only on the transformer name plates as is the case today**. For smaller LV/LV transformers (<5 kVA) the name plate information can be reduced because of the lack of available area. To consider the issues regarding the maintainance of digital data would require an in-depth technical and legal assessment, which is beyond the scope of this study. Nevertheless, having the information in digital form can provide benefits for the preservation of and access to information. Under this scenario access to product information from competitors will also be different and might involve data encryption and security. For data storage a solution will also be needed to cope with manufacturer bankruptcy. A public database maintained by the EC could provide a solution. When data is made available on websites it might be necessary to restrict access to respect manufacturer IP.

In the case of transportation environmental impacts there was a major modelled impact from 'Particulate Matter' (shown in the blue column of Figure 1-3). This should be addressed by reducing vehicle emmissions during transport but is outside the scope of this review of Regulation 548/2014 for transformers.

4.2 Impact on grid power quality from high harmonic distortion caused by power electronic converters

This issue was raised in the first stakeholder meeting on 16/9/16. Harmonics were already discussed in section 3.2.1.5 in the Lot 2 study (2011) and therefore the technical issues are not reassessed in this study. The conclusion of this earlier work was that harmonics will increase no load losses but that using energy-efficient transformers with low no load losses(@50Hz) is the best way forward to address them. **This consideration supports the rationale for maintaining the Tier 2 requirements specified in Regulation 548/2014 and of not diluting them.**

Note that harmonic distortion can also be addressed within the generator or load circuits but this is outside the scope of Regulation 548/2014. Therefore specific requirements related to harmonics are not recommended for consideration within potential Tier 3 requirements.

4.3 Other issues

Note that **the Regulation 548/2014 only addresses new products**, but does not address existing products or installations such as substations.

Therefore, for example, the issue concerning the use of Polychlorinated Biphenyls (PCBs) as transformer liquid in new installations is irrelevant because they are already banned by EC Directive 96/59/EC.

Also it is not recommended to address within the review of Regulation 548/2014 the environmental impacts of other insulation material choices, such as biodegradable natural esters compared to mineral oil, because accidental release to the environment can be addressed at the installation level. Nevertheless biodegradable natural esters could be included in an Ecolabel, i.e. within Regulation (EC) No 66/2010 on the EU Ecolabel[82].

Also, as explained in the Lot 2 transformer study, it is not proposed to consider transformer noise limits for transformers because this can also be addressed at the installation level and stakeholders have not suggested that this should be addressed within the Ecodesign product requirements for transformers.

4.3.1 Chrome(VI) free coating production process

The RoHS Directive(2002/95) already restricts hazardous substances in electric & electronic devices on the EU market and it is not allowed for these to contain Cr(VI), amongst other substances, since the 1st of July 2006. Despite this, during the production process of GOES coatings, Cr(VI) is currently (1/2017) used but the liquid Cr(VI) is converted into Cr(III) during the annealing process. Hence Cr(VI) is no longer present in the final product and therefore coated GOES produced this way is ROHS compliant.

Nonetheless, due to the implementation of the REACH Regulation (EC) No 1907/2006 from 21.09.2017 Cr(VI) will need to apply to specific authorisation[83] to be used in the production process within Europe. Therefore European manufacturers have developed and invested in alternative Cr(VI) free coating processes, which result in an initial capital investment and also higher operational cost for procuring compliant coating materials. However, non-European manufacturers are not obliged to do this because processed GOES material with Cr(III) can still be imported. As a consequence European manufacturers are at an economic disadvantage and there is a risk that the aim of REACH to reduce the use of hazardous Cr(VI) will be missed because its workplace health impact is exported to factories outside the EEA. Note that this impact cannot be modelled with the MEErP, see section 1.2.2.

After consulting two European manufacturers[84] it was also confirmed that using Cr(VI) free coatings will not create a single manufacturer monopoly and all European

[82] http://ec.europa.eu/environment/ecolabel/the-ecolabel-scheme.html
[83] https://echa.europa.eu/regulations/reach/authorisation/applications-for-authorisation
[84] ThyssensKrupp (see minutes of stakeholder workshop) and Accelor Mittal (phone call with Sigrid Jacobs)

manufacturers are adapting to REACH. Hence there will not be a monopoly position that impacts the long term GOES price nor creates an associated risk for a shortage of supply.

Therefore, as a new implementing measure within the Ecodesign Directive (2009/125/EC) it could be considered that **transformer materials should be produced in a manner that respects the REACH Regulation** (1907/2009). The verification process would be for the transformer steel to either have a certificate of origin[85] to show it is produced within Europe, or in the case of imported steel, a signed declaration that the manufacturing has been done on a comparable manner without using Cr(VI) and similar to the REACH requirements. An alternative and softer policy measure is to include this requirement in an Ecolabel for transformers, e.g. within Regulation (EC) No 66/2010 on the EU Ecolabel[86].

[85] https://iccwbo.org/resources-for-business/certificates-of-origin/

[86] http://ec.europa.eu/environment/ecolabel/the-ecolabel-scheme.html

5 Understanding of Task 5 on Conclusions and recommendations

Aim and tender request:
This task collects the findings made in Tasks 1 to 4 with a view to making targeted recommendations to improve, extend or reduce the coverage of Regulation 548/2014.

An inventory of any technical and position papers (both solicited and unsolicited), submitted by social, economic and policy actors in the context of Tasks 1 to 4 will be included in this task. The actual papers are included in the annexes of this report.

5.1 Overview of position papers

An overview of position papers is given in the annexes to this document, see also Table 5-1. In total 25 inputs were received. Often they are from stakeholder associations. In total about 140 people registered at the project website that was also used for communication with the stakeholders (https://transformers.vito.be/).

The comments and position papers were collected in advance of the 2nd stakeholder workshop, therefore it is also worth reading the minutes of the 2nd stakeholder workshop held on 29/3/2017.

Finally detailed answers from the study team were provided after the workshop while compiling this final report. These replies are marked in red in the annex, for example '>R: Text updated taking this input into account'.

Table 5-1 Overview of stakeholder input received that is included in an Annex to this report

Annex H Minutes of informative stakeholder Workshop for the review of Commission Regulation 548/2014 on transformers
Annex J Hitachi metals comments
Annex K comment Norway NVE
Annex L comment EDP Portugal
Annex M Input ECI
Annex N Input Thyssen Krupp
Annex O E-destribuzione Italy
Annex P Norway NVE input
Annex Q EU_T&D Europe input
Annex R Fogelberg input (Sweden)
Annex T Armazabal input
Annex 10 CG Global input
Annex 11 Eurelectric comment on draft

Annex 12 Piraeus University comment
Annex 13 IEC TC 96 comment
Annex 14 John_Bjarne Sund input (S)
Annex 15 ENTSOE comment
Annex 16 SBA comment
Annex 17 EREA input after meeting
Annex 18 ENEDIS input after meeting
Annex 19 Thyssen Krupp after meeting
Annex 20 ORMAZABAL after meeting
Annex 21 T&D Europe after meeting
Annex 22 HME after meeting
Annex 23 ECOS after meeting
Annex Eurelectric report before meeting
Annex CENELEC prTS50675

5.2 Recommendations

The recommendations of the study team and their background are included in the sections of the report addressing the respective tasks. During the final editing process the stakeholder input that the study team received was taken into account. A summary of review options is presented in the beginning of this document, see section 0.