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

DRAFT 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)

Client: European Commission Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs

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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
WEEE	Waste Electrical and Electronic Equipment
Z	Short-circuit impedance

Use of text background colours

Blue: draft text
Yellow: text requires attention to be commented
Green: text changed in the last update (not used in this version)

Executive summary

This is a draft version for discussion in the stakeholder meeting

To be completed

0. Introduction

This study is produced by VITO and its partners 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. It also draws on other relevant inputs such as the Commission's Impact Assessment for Regulation 548/2014[1].

The specific objectives 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 from a lifecycle analysis perspective
- provide evidence for a consideration of minimum efficiency 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
- 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

[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 widely accepted criteria for 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.

Summary of Tasks to be completed in the final version.

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 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 comig into effect sometime between 2023 and 2025. This last subtask is obviously contingent upon the findings made in the context of the previous subtasks. Any proposal to alter the level of ambition of requirements in Tier 2 and/or the introduction of additional Tier 3 requirements in the future will be discussed at the validation workshop.

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 VITO is committed and limited in the context of this study to comply with European anti-trust rules[2] and competition law and VITO also asks 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 are invited to verify if the price levels hereafter 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 anonymized and aggregated where 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)

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

The cost of Tier 2 transformers was derived from the preparatory study in Lot 2 and in the case when they 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 transformers, in part because Tier 2 GOES transformer data was not available in Lot 2 (2011). The 2013 impact assessment also updated the forecast electricity cost 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 summarized 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 Tier 1(2015) and Tier 2(2021) were introduced, but also other constraints such as discussed in section 1.5. The rationale was that prior to the entry into force of Commission Regulation 548/2014 European industry mostly produced Grain Oriented Silicon Steel (GOES) transformers with efficiencies far below the Tier 1 level but which are also relatively more compact compared with amorphous distribution transformers (AMDT)(see Lot 2(2011)).

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 witn the exception of the economic parameters are assumed 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, which is also volatile, and hence is also reviewed in 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

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

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 are copper and aluminium. For the same conductivity copper is more compact & expensive whereas aluminium is lighter in weight, has a lower purchase cost and takes a greater volume. 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 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 case scenario with estimated 450 kg Cu per transformer, the total annual demand would be maximum of 81 Kton/year which is negligible compared with 2252 Kton/year (2013)[5] EU sales for all copper conductors (e.g. including power cables). Also in Europe **neither copper nor aluminium are recognized 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

[5] Source: Lot 8 on Power Cables
[6] https://ec.europa.eu/growth/sectors/raw-materials/specific-interest/critical_en

various grades(M2, M3, M4, ..) which are classified according to their losses which is related to the sheet thickness. Obviously, low loss GOES with thinner sheets requires more processing 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(M3) GOES, or so called GOES+, occurred in 2015** after a period of price erosion[7] in 2012-2014 , see also Figure 1-1. This price surge can be explained by the Commission 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 the T&D Europe data it seems that since then prices have been declining back to their 2010 normal level (reported in the 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 normalization of supply and demand.

Table 1-5 Past and more recent transformer steel 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*	*Agoria &T&D EU 11/2016*	*EU MIP 10/2015 (line 176)*	*Review study no mark up*
Liquid immersed transformers							
M2 core steel	**1,96**	**2,82**					2,43
M3 core steel	**1,79**	**2,58**	100%	**2,58**	113%	2,04	2,22
M4 core steel	1,72	2,48				1,87	2,13
M6 core steel	**1,55**	**2,23**	76%		69%	1,54	1,42
M3 vs M6	115%	116%	132%		164%	132%	
mechanically-scribed core steel	2,75	3,95					
amorphous - fished core	3,61	5,17					
tank steel	0,74	1,08	0,74		0,76		0,76

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/

[7] Obviously this confirms steel dumping that Anti-dumping Regulation (EU) 2015/1953 deals with.

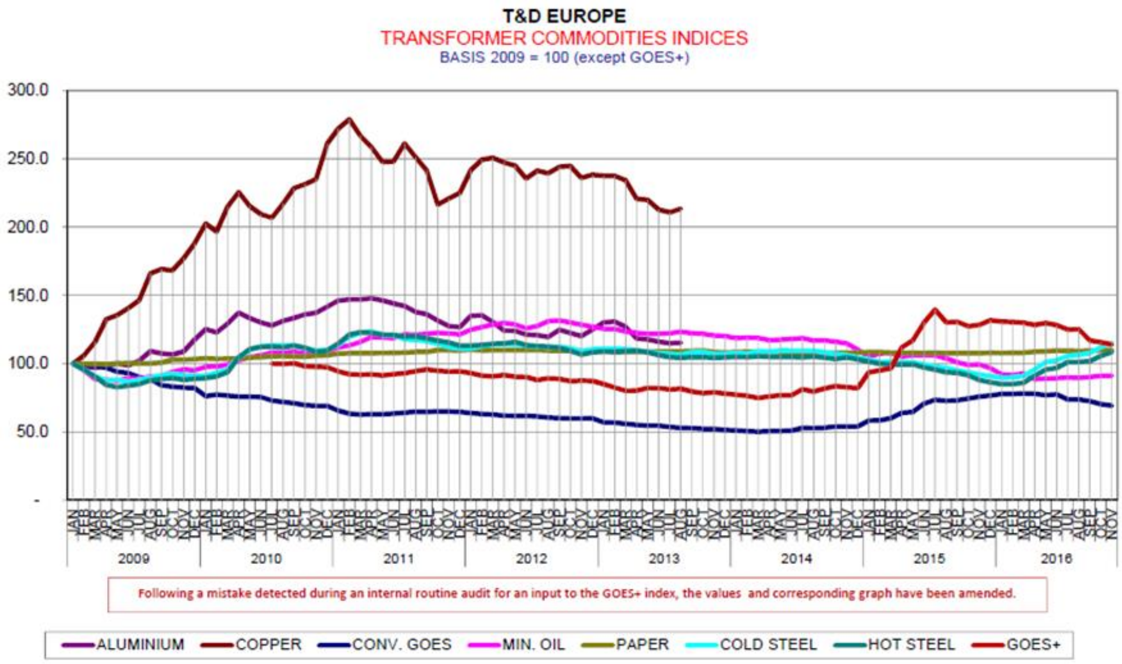

Figure 1-1 2009-2016 evolution of transformer Commodities Indices from T&D Europe

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 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 M3 (0.23 mm) or M4 (0.27 mm) steel. 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 (M2, M3, M3+domain refined). Nevertheless **intellectual property (IP) rights should not be a barrier** because amorphous steel has already been available for a long time on the market[10] and patents expired[11] while also low loss GOES is long time available[10] and neither any patents apply. .

Utilities report little uptake of amorphous transformers or Tier 2 compliant, or above, transformers thus far, however **in industry 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.

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

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 to the IA the paper price remained stable while the mineral oil price decreased substantially, see Table 1-6. Note also that Nomex[13] **high temperature inorganic insulation cost substantially more compared to mineral paper**, is used in dry type transformers but could also become important in designing more compact liquid-filled transformers. Apart from Nomex (Dupont) 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 http://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 value

As explained in the Lot 2 study transformers still have a significant 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

[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
[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

mentioned[17] that in Italy[18] it is important to manufacture distribution transformers with aluminium windings to avoid problems related to copper thieves and 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 according to this information **copper mostly maintains its value when scrapped (€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 as new)**. 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.

Table 1-7 Current (2/2/2017) scrap value[19] 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 designs of transformers 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 resulting from 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 looked at, 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.

1.1.6 Impact of current transformer commodity prices on Tier 2

As mentioned in the Lot 2 study the commodity prices of active parts of the transformer can have a large impact on the transformer price, up to 30 % (Lot 2(2011)).

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 in a scattered manner because manufacturers do not want to disclose their latest details on design, material content and manufacturing for commercial reasons. For BC1 the best BOM data available to our knowledge is included in Table 1-8.

The Tier 2 green field applications (Tier 2 Green F in Table 1-8) have a price in line with the Impact Assessment (2014) and hence for these applications **there is no evidence to review Tier 2 on economic grounds for green field applications.** We assume that this can only be achieved with the most efficient GOES or AMDT, hence it is important that an increase in demand for this steel will not cause a surge in prices relative to the price review in section 1.1.3.2.

[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
[19] http://www.tijd.be/grondstoffen/secundaire_grondstoffen/

The Tier 2 brown field application may be supposed for this simple cross-check to be a copper based transformer with the lowest loss GOES available (Tier 2 Brown F in Table 1-8). A more in depth discussion on brown field transformer technology is given in section 1.5.

Table 1-8 BC1 Tier 1&2 transformer BOM data and estimated impact on product price

	CLASP Tier 1	CLASP Tier 2+	Tier 1	Tier 2 +/-5% brown F	Tier 2 +/-5% green F	Tier 2 Brown 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	price data IA 2012	price data IA 2012
Power rating:	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		
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	AM-DG	Mitered	Mitered	Mitered	Mitered		
Core Mat'l:	HO	SA1	M4	M3	M2	M3		
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	430	387
Coil Losses (W):	**4513**	*3324*	4600	3060	3060	3262	4600	3250
Selling Price (IA):	**€ 7 711**	**€ 9 372**					**€ 7 824**	**€ 8 978**
oil weight(kg)			**357**	**280**	**380**	**417**		
other weight(kg)			**473**	**202**	**336**	**417**		
total weight(kg)			**1790**	**1550**	**1680**	**1940**		
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)			€ 2,13	€ 2,22	€ 2,43	€ 2,22		
oil price(€/kg)			€ 1,39	€ 1,39	€ 1,39	€ 1,39		
value active parts			€ 2 106	€ 3 776	€ 2 350	€ 3 984		
value oil			€ 495	€ 395	€ 552	€ 407		
value active parts + oil			€ 2 600	€ 4 170	€ 2 902	€ 4 392		
extra compared to ABB Tier 1:			€ -	€ 1 570	€ 302	€ 1 791		
Selling Price updated:	**€ 7 711**	**€ 9 372**	**€ 7 824**	**€ 10 085**	**€ 8 259**	**€ 10 403**	**€ 7 824**	
Scrap value	**€ 2 105**	**€ 1 572**	**€ 236**	**€ 1 953**	**€ 205**	**€ 2 150**		

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)
- IA is the data used in the Impact Assessment Study
- Similar to Lot 2 a mark-up of 44% was applied on the commodity prices versus the value of those parts in the transformer.

The impact of current transformer prices on the Life Cycle Cost (LCC) of the most used BC 1 for Tier1, Tier2 green field and Tier 2 brown field is summarized in Table 1-9. To assist comparison the net present value (NPV) of the scrap has been taken into account in the LCC, i.e. 'LCC total (incl. scrap@NPV)' in Table 1-9. Compared to the IA or Green Field cases the brown field case has a significantly higher projected selling price for BC1, i.e. 10403 euro compared to 8978 (+16 %). Despite this higher selling price the scrap or End-of-Life value is higher due to the copper used which has a positive effect on the LCC. **Hence when calculating the LCC of a Tier 2 brown field BC1 application including the scrap value at their end of life, there is also no evidence to question the Tier 2 levels on economic grounds.**

Table 1-9 LCC comparison for BC1 Tier1, Tier 2 (green Field) and Tier 2 brown field including and excluding the scrap value

Base Case		**BC1 DT liquid Tier1**	**BC1 DT liquid Tier2**	**BC1 DT Tier2 brown F**
transformer rating (S)	kVA	400	400	400
no load class		Ao	Ao-10%	Ao-10%
load class		Ck	Ak	Ak
CAPEX - transformer	€	7 824,09	8 977,51	10 403,00
losses per year	kWh/y	5055,5	4300,6	4300,6
discount rate	%	2%	2%	2%
LCC electricity	€ /life	11 713,69	9 964,60	9 964,60
LCC total (excl. scrap@EOL)	€ /life	19 537,78	18 942,11	20 367,60
scrap value @ EOL	€	236,00	206,00	2 150,00
NPV scrap value (incl. discount rate)	€	106,88	93,30	973,71
LCC total (incl. scrap@NPV)	€	19 430,90	18 848,81	19 393,88
marginal CAPEX for saving	€/Wp		0,83	1,85
RES value of CAPEX	€/Wp		3,00	3,00
CAPEX increase Tier 1/Tier 2	%		115%	133%

Stakeholders are invited to comment on this analysis, if they have other evidence please provide it to the study team.

1.1.7 Impact from interest, inflation and escalation rate of electriciy prices

The impact study (2014) used already different electricity prices per base case depending on the forecasted electricity price over its life time and depending on 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 used, e.g. corresponding to 4 % interest rate and 2 % inflation. The new MEErP methodology(2011) introduced also a so-called escalation rate[20]. The escalation rate is the rate of increase in the price of electricity. The impact study (2014) circumvented this by topping up electricity prices but did not use an 'electricity escalation rate', which means that Table 1-1, Table 1-2 and Table 1-3 has 0% escalation rate for the used electricity cost but used forecasted electricity prices. Note that in IA study(2013) forecasted an electricity price of 0,0849

[20] 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'

euro/kWh which closely fits the latest Eurostat[21] S2/2016 price of 0,0839 euro/kWh, which seems to be correct today but faster than expected.

The easiest way to estimate future costs is to inflate costs known today with a relevant escalation rate. However, Energyville recently studied future Belgian electricity prices[22] and forecasted that the electricity price might be 2,3 times higher in 2030 compared to 2020 in a scenario wherein nuclear and coal plants have to be phased out[23] and replaced by renewables, meaning that an electricity price escalation rate of up to 8% cannot be excluded. The rationale for this expected price increase was that current electricity is mainly produced by long running and depreciated nuclear/coal plants that might have to be replaced in future scenarios inducing extra cost that are not yet reflected in electricity price today. Also other countries might face similar costly scenarios and **as a conclusion the electricity price and escalation used in the IA (2013) might even be an underestimate providing another rationale to not postpone Tier 2.** Note that this is in line with section 1.1.8 where a direct comparison is made with capital expenditure for renewables.

Inflation and interest rates change frequently over time and depend on the Central European Bank policy that is regularly reviewed[24]. Looking to the current market conditions, it can be concluded that **the in 2013 used 2% discount rate does not reflect the market today.** In 2016 the Eurozone inflation was 1,1 %[25] and the MFI interest rates on new euro-denominated loans to euro area for non-financial corporations for over ten years loans with an initial rate fixation was 1,84 %[26], hence **today a discount rate of 0,74 % is more realistic**.

The calculated impact of some reviewed discount and escalation rates on BC1 is in Table 1-10, **the current trend is even more in favour of implementing Tier 2** today.

Table 1-10 Impact on BC1 of discount rate and electricity escalation rate on life cycle cost.

Base Case		BC1 DT liquid Tier1	BC1 DT liquid Tier2	BC1 DT liquid Tier1	BC1 DT liquid Tier2	BC1 DT liquid Tier1	BC1 DT liquid Tier2
transformer rating (Sr)	kVA	400	400	400	400	400	400
no load class		Ao	Ao-10%	Ao	Ao-10%	Ao	Ao-10%
load class		Ck	Ak	Ck	Ak	Ck	Ak
Auxiliary losses (Paux)	W	0	0	0	0	0	0
transformer life time	y	40,00	40,00	40,00	40,00	40,00	40,00
kWh price no load and aux. Losses	€	0,0847	0,0847	0,0847	0,0847	0,0847	0,0847
kWh price load losses	€	0,0847	0,0847	0,0847	0,0847	0,0847	0,0847
CAPEX - transformer	€	7 824,09	8 977,51	8 256,41	0,00	8 298,35	0,00
losses per year	kWh/y	5055,5	4300,6	5055,5	4300,6	5055,5	4300,6
discount rate	%	**2%**	**2%**	**0,74%**	**0,74%**	**0,74%**	**0,74%**
electricity escalation rate	%	**0%**	**0%**	**4%**	**4%**	**8%**	**8%**
PWF	ratio	27,36	27,36	82,14	82,14	225,76	225,76
No load loss capitalization factor (A)	€/W	20,30	20,30	60,95	60,95	167,51	167,51
Load loss capitalization factor (B)	€/W	0,65	0,65	1,95	1,95	5,36	5,36
TCO A/B ratio	ratio	31,27	0,03	31,27	0,03	31,27	0,03
OPEX electricity	€/y	428,20	364,26	428,20	364,26	428,20	364,26
LCC electricity	€ /life	11 713,69	9 964,60	35 173,38	29 921,28	96 670,75	82 235,85
LCC total (excl. scrap@EOL)	€ /life	**19 537,78**	**18 942,11**	**43 429,79**	**29 921,28**	**104 969,10**	**82 235,85**

[21] 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

[22] http://www.energyville.be/sites/default/files/energy_transition_in_belgium_choices_and_costs.pdf

[23] https://nl.wikipedia.org/wiki/Kernuitstap

[24] https://www.ecb.europa.eu/stats/policy_and_exchange_rates/key_ecb_interest_rates/html/index.en.html

[25] http://ec.europa.eu/eurostat/statistics-explained/index.php/Inflation_in_the_euro_area

[26]

1.1.8 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 also 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)[27]. **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.

1.1.9 Updated conclusions and summary on Tier 2 economic justification

To be elaborated .. potential conclusion: Up to our best knowledge and the time frame given the previous assessment is realistic but we are aware that proponents of lowest CAPEX could raise scenario's with inflated transformer prices and proponents of energy savings of inflated energy OPEX?

[27] 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.

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

1.2.1 What is new in MEErP compared to 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 to adopt the the MEErP methodology (2013)[28].

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 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, see Figure 1-2 or Annex A, with the complete output of BC 1 under both methods. Note that in Figure 1-2 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.

[28] 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)

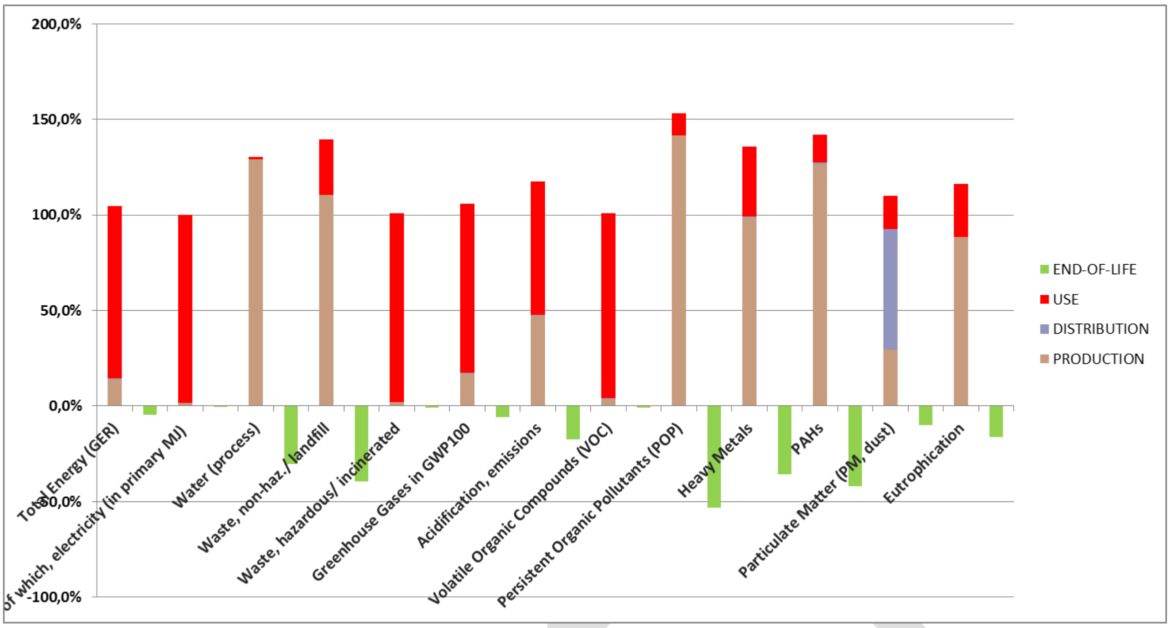

Figure 1-2 Processed graphical results from MEErP Ecoreport tool (2014) for BC1 - Distribution transformer A0+Ak

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 needed for Tier 2 versus less efficient steel for 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 0.18 mm silicon steel versus 0.23 mm. Hence a Tier 2 design with low loss steel will not create different output compared to a Tier 1 design. Such data is hard to find and would require in depth LCA studies analysing detailed manufacturing processes, which are outside 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 with respect to the year of production. The value is representative for the current electricity mix but does not account for changes in a large time frame corresponding with transformers (20-40 years).
- different approaches for recycling of Aluminium versus Copper, it only allows 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**.

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 done for CAPEX in section 1.1.8. Sufficient and reliable LCA data for a Tier1 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 1.1.8, 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) relate to the minimum load and no load losses?

1.3.1 Understanding the equations and relations behind PEI

Compared to the Lot 2 study (2011), the regulation introduced for large power transformers requirements based on the Peak Efficiency Index (PEI). The 'Peak Efficiency Index' (PEI) was defined in the 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 also can be applied to medium power transformers and hereafter we will analyse the possibilities and impact of potentially extending the use of this index.

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.

$$PEI = 1 - 2 \times (P0 + Pc0)/Sr/\mathrm{sqrt}((P0 + Pc0)/Pk) \qquad (f.1)$$

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 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:

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

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 constant 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)xPF. 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) this is the load factor for 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:

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

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 efficiciency 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 1-3, 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.

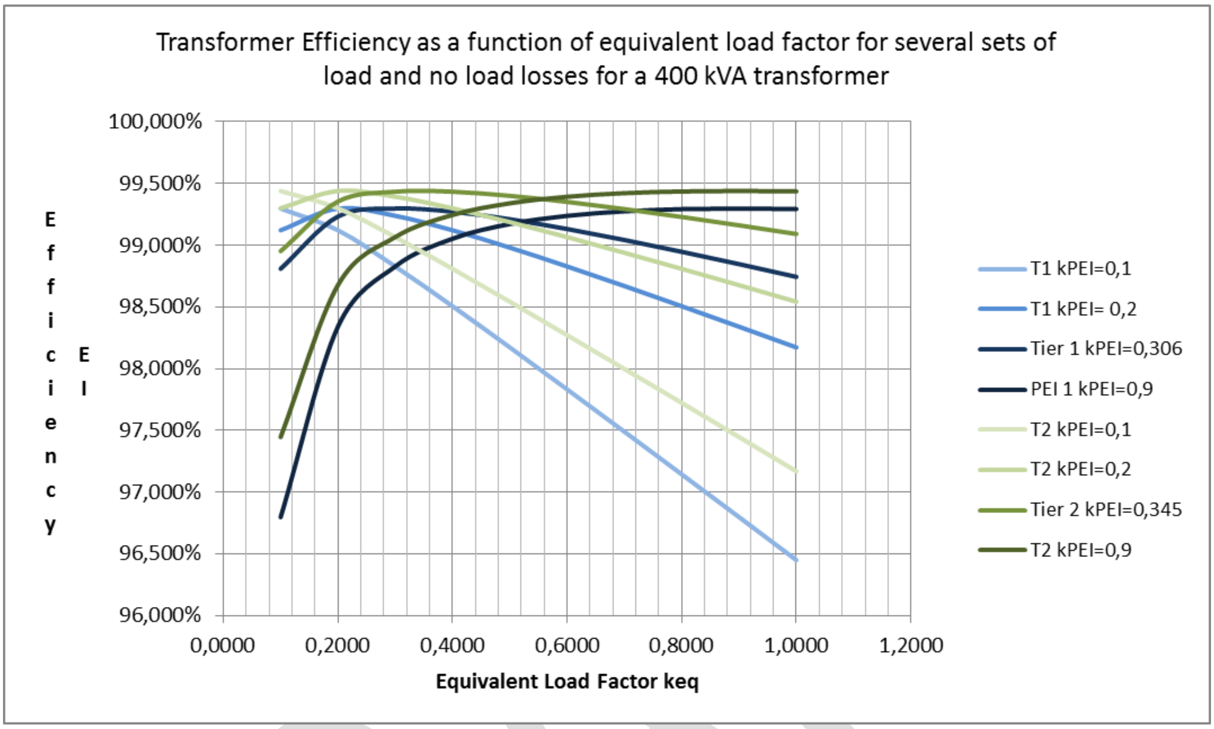

Figure 1-3 Efficiency versus loading for various designs

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 $k_{PEI}^2 x Pk = P0$:

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

Where,

- k_{PEI} is 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).

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 1-3. 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 in Figure 1-3.

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

Ideally in procurement the **expected equivalent load factor (keq)** should be estimated and **should match with 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 criteria to the minimum PEI and tender for the lowest cost capitale expenditure (CAPEX) for a transformer. It is however also possible to tender for the lowest TCO taking the the operational expenditure (OPEX). In this case the OPEX is related to the electricity cost, present worth factor(PWF) and load factor:

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

and

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

Where,

- A is the no load loss capitalization factor [€/W]
- B is the load loss capitalization 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:

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

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

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

As a consequence the ratio between capitalization 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 load factor.
All TCO and loss capitalization data for the base cases in this study is in previous 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 1-3. 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. **In principle the use of the PEI allows freedom to design a range of transformers with different combinations of Pk & P0 to match the optimum load factor** or load factor at PEI.

Note, however, that this does not warrant 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), see Figure 1-3. This could be done 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 invest in conductor material (e.g. less copper) and this will lower therefore 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 [29]. 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.

In relation to this we do not recommend to extend the use only PEI without a minimum kPEI to medium power transformers.

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

[29] 0,19 was the minimum load factor found in the Lot 2 study (2011)

1.3.5 PEI data for large power transformers

Commission Regulation (EU) No 548/2014 for large power transformers requires only a minimum PEI 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 as a complementary measure to the PEI trhe specification of a minimum optimum load factor (sqrt((P0+Pc0)/Pk)), or alternatively, the ratio of no load to load losses ((P0+Pc0)/Pk). Figure 1-4 and Figure 1-5 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 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.**

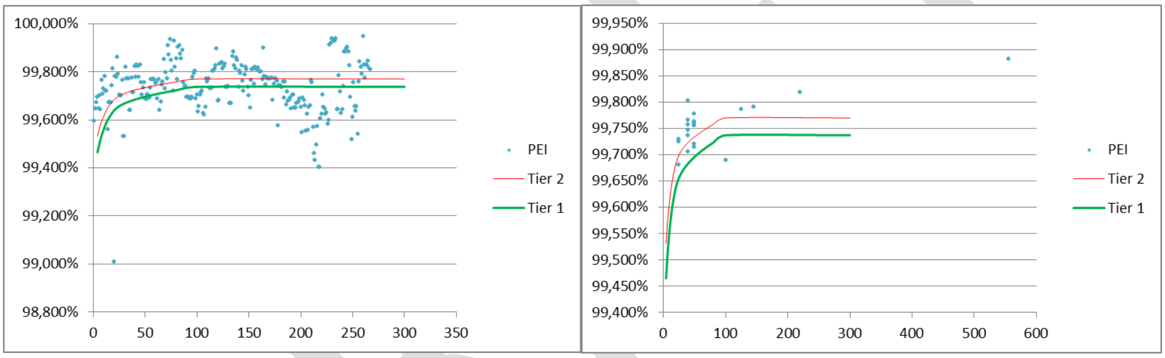

Figure 1-4 Collected Power Efficiency Index(PEI) data of installed large power transformers and Tier1&2 minimum requirements (left based on collected data from CENELEC in 2012 supplied to the study, right in Lot 2 in 2010)

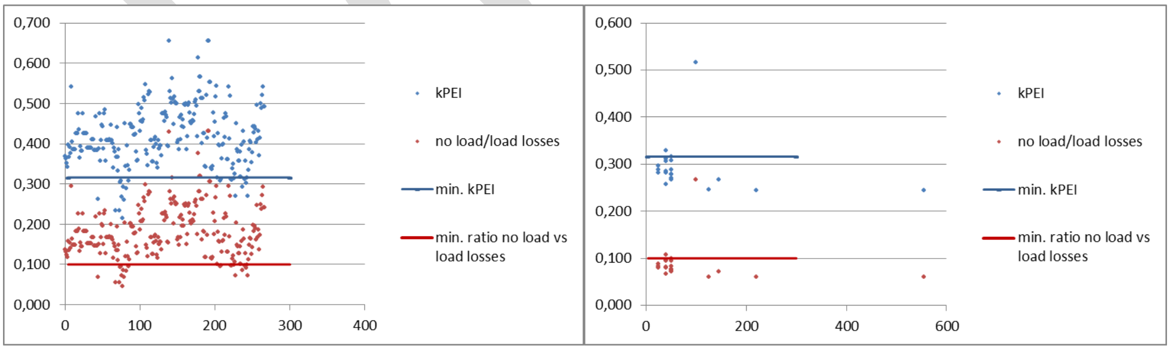

Figure 1-5 Collected optimum load factor(kPEI) or no load vs load losses ratio ((P0+Pc0)/Pk) data of installed large power transformers and Tier1&2 minimum requirements (left based on collected data from CENELEC in 2012 supplied to the study, right in Lot 2 in 2010)

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

1.4.1 Green field manufacturer enquiry

The results shown below in Table 1-11 are the responses[30] to the T&D Europe[31] tranformer manufacturer assocition enquiry into the feasability of Tier 2 transformer requirements for green field applications. **The conclusion is that there are no technical barriers 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) do some manufacturers report difficulties in producing them.

Table 1-11 T&D Europe Green Field enquiry on 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[32] 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 withstand conductor forces during short circuit. Therefore the new standard EN 50588-1:2016 also introduced an additional short-circuit test for new transformers with level of no load loss 'AAA$_0$'. Finally AMT is more expensive due to the amount and cost of material, see section 1.1.3.2. The higher price and the volume can explain the modest uptake on the European market today.

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[30] 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

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

[32] 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'

Tier 2 transformers can obviously also be made from Grain Oriented Electrical Steel (GOES) but today few examples of that can be found in manufacturers catalogues. One manufacturer has a GOES distribution transformer in their catalogue[33] with no load losses +5 % and no load losses -5% compared to Tier 2.

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**, e.g. increase the amount of copper to decrease load losses or reduce the maximum magnetic flux density in silicon steel to lower the no load losses. Hence **the introduction of Tier 2 could increase size and weight compared to Tier 1** and therefore subsequent sections will investigate the consequence of that related 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/weight resulting from the need to install the transformer in an existing enclosure, see for example Figure 1-6 and Figure 1-7. The rationale behind this investigation is that transformers are often a 'spare part' in an existing substation. In principle constraints for space and/or weight depend on the type of substation.

Figure 1-6 metal substation max. 250 kVA(left) and standard concrete prefabricated substation max. 630 kVA (right) with dimensional and weight constraints (Source: Synegrid BE (2016))

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

Figure 1-7 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 complete new transformer substation can be up to 10 times greater than the transformer itself, e.g. in Belgium for example[34] the approved unit cost for a fully installed greenfield transformer substation is 114094 euro. Obviously such an investment is out of 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 1-12. 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 are close fits to compact substations, mainly weight could become a limiting factor but also height. 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 will be further investigated in sections 1.6, 1.7 and 1.9. In general **it appears that European utilities have often been under pressure to limit the urban space they can claim for their substation and therefore they have historically elaborated tight specifications without being aware it could create lock-in effects against larger more efficient transformers.**

[34] http://www.vreg.be/nl/document/besl-2016-68 http://www.vreg.be/sites/default/files/document/besl-2016-68.pdf

Table 1-12 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 the size and weight. Hence the introduction of Tier 2 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** and the subsequent sections will provide more information on this. **As a consequence of that more transformers might use 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'. However, **for greenfield application such an exemption does not exists** and hence the largest power transformers might face transportation problems. Therefore this study launched an installers enquiry to verify transportation limits, see Annex C. The results will be discussed hereafter.

1.5.3.2 Transportation on roads

For regular road transport in Europe vehicles must comply with certain rules on 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 ton(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. Apart from that, special road transports have to be used (Figure 1-8) and these limits depend on the local circumstances and permits. In order to verify what the typical special transport limits are in Europe these questions were included in the installers enquiry of this study, see Annex C. The enquiry results are summarized in Table 1-13.

Figure 1-8 Exceptional road transport of a transformer (source: Scheuerle-Nicolas catalogue[35])

Table 1-13 Overview of road transport limits as collected in the stakeholder enquity

To be elaborated in the final version

1.5.3.3 Transportation on railways

The same as for road transport in section 1.5.3.2, also railways have their transport limits (e.g. Figure 1-9). They are not harmonized in Europe neither in a country because they can depend on the local railway infrastructure such as bridges. These questions were included in the installers enquiry of this study to verify what the typical railway limits are in Europe (see Annex C). The enquiry results are summarized in Table 1-14.

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

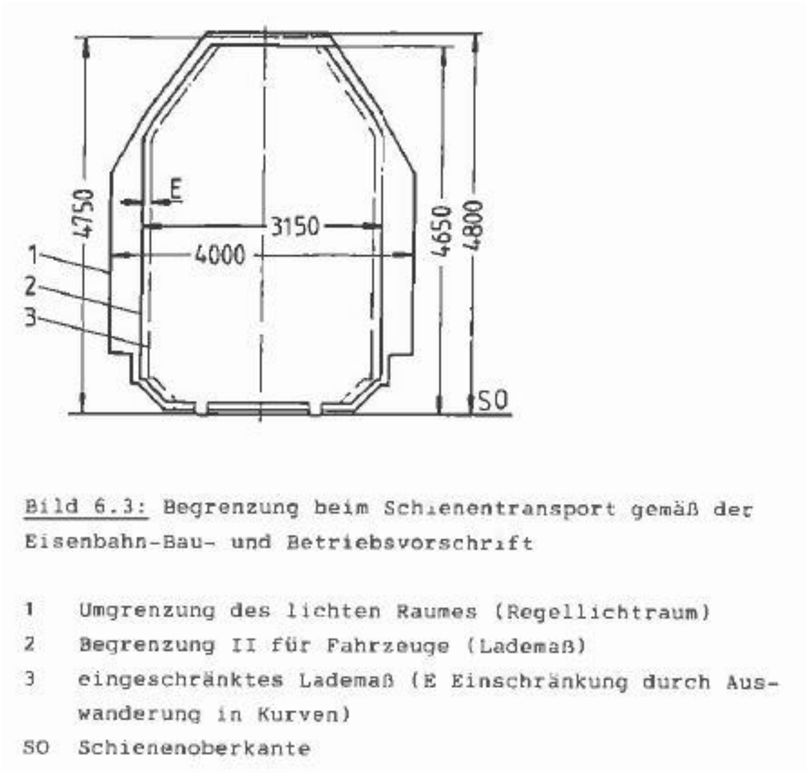

Figure 1-9 Dimensional limits for railroad transport in Germany (source: Deutsche Bahn)

Table 1-14 Overview of railway limits as collected in the stakeholder enquity

To be elaborated in the final version

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 step to go from Tier 1 to Tier 2 to reduce no load losses, see Lot 2 (2011) for technology and section 1.1.3.2 for price and availability. **Using low loss steel will decrease the cooling needs and therefore decrease the volume and weight of cooling system and transformer**, e.g. the cooling finns for air cooled systems. Low loss GOES price and availability might be the main barrier. **Using low loss steel also allows to increase the maximum magnetic flux density and therefore the size and weight of the transformer**. In view of Tier 2 and general interest in energy savings research is ongoing to upgrade GOES production plants worldwide to lower loss grades[36], hence it is reasonable to expect they will become more available at a competitive cost.

[36] 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

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)). **Copper conductor combined with more efficient GOES is an obvious choice for brown field applications**, the impact of Tier 2 for this potential brown field solution is estimated in section 1.1.6. It demonstrated that taking the scrap value of the BC 1 transformer into account, Tier 2 is still an economic choice from Total Cost of Onwbership.

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 the decrease of conductor volume and core steel volume also decreases 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[37]. The alternatives to mineral oil to use at higher temperature are typically synthetic or natural esters (e.g. MIDEL[38], ENVIROTEMP FR3[39], ..).

In 2013[40] **some manufacturers made a comparison** between a cast resin, a conventional liquid-immersed and a liquid-immersed transformer with high temperature insulation **which indicate that this is a valuable track for brownfield applicattions** with space/weight constraints.

Table 1-15 A manufacturer comparison between a cast resin, a conventional liquid-immersed and a liquid-immersed transformer with high temperature insulation (source: CIRED 2013[40])

		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	m²	3.9	2.2	1.8
Volume	m³	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

[37] http://protectiontechnologies.dupont.com/Nomex-910-transformer-insulation
[38] http://www.midel.com/
[39] http://www.envirotempfluids.com/
[40] Radoslaw SZEWCZYK et.al, 'COMPARISON OF VARIOUS TECHNOLOGIES USED FOR DISTRIBUTION TRANSFORMERS FROM AN ECO STANDPOINT' CIRED22nd International Conference on Electricity Distributionn Stockholm, 10-13 June 2013

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 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 (2000 and Later) for transformers is:
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 bolds

There are also losses in metallic clamp and bolds used in transformers and therefore using glass fibre reinforced plastic clamp and bolds can also reduce losses[41].

1.6.6 Hexagonal or 3D core form transformers

The Lot 2 (2011) Study reported in section 5.1.3.3 hexagonal core form tranformers wit GOES, they are now produced under license in India[42].

More recently in 2015 a Chinese company Haihong[43] succeeded in **designing a hexagonal or so-called 3D triangle shaped amorphous transformer** and invested in innovative mass production machinery for it. This reduces the amount of amorphous material needed which benefits weight and also has a circular core cross section which benefits short circuit behaviour. They also claim reducing 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 attach the bushing and oil filling. This is

[41] http://www.transformers-magazine.com/component/k2/2430-transformer-2020-new-vision-of-a-future-power-transformer-premiered-in-vienna.html
[42] http://raychemrpg.com/transformers/deltaformer.html
[43] http://ecotrafo.com.cn/pad.html

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 for decades Gas Insulated (GIS) transformers are on the market[44,45] based on SF6 gas cooling. 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 the 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

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

T&D Europe is committed to supply data by 9th of March; hence data will be presented and discussed in the stakeholder meeting.

1.8 Enquiry from the Belgian grid operators on Tier 2 transformers for brown field applications

The Belgian Grid operators Synergrid[46] have done a similar exercise as in section 1.7 those result will be discussed in the stakeholder meeting.. Figure 1-10 shows the results for a 400 kVA transformers with 1LV winding (242V) an excersise done with their usual suppliers. The green line in Figure 1-10 are the requirements that they did sent to a selection of manufacturers wherein Eco 2015 is Tier 1 compliant of the Regulation and Eco 2021 Tier 2. The limitations came from the construction of the existing substations, see Figure 1-6. The best Tier 2 fit (all copper windings) still did exceed the weight limit of 1800 kg by 14 %(2050 kg) Hence from these manufacturers. **It didn't result in a Tier 2 compliant transformer.** As explained in section 1.5.2, replacing the entire substation is not economic because it will cost up to 10 times more compared to the transformer. An alternative option is to investigate by a construction engineer if substations can be reinforced (e.g. floor plate) new to withstand the extra weight, but such an exercise is not yet done and will also cost extra. The other way around is that manufacturers deviate from their existing manufacturing process and use new techniques as discussed in section 1.6, of course this will not come without extra costs.

Unfortunetely this is not a stand alone case, such space weight constraints are common practice with utilities (see section 1.5.2).

[44] http://www.meppi.com/Products/Transformers/Pages/SF6Gas.aspx
[45] http://www.toshiba-tds.com/tandd/products/trans/en/gitrans.htm
[46] http://www.synergrid.be/

Type	Material (Copper or Aluminium)		Losses	PO (W)	Pk1 (W)	Pk2 (W)	Length (mm)	Width (mm)	Height TO COVER (mm)	Weight (kg)	Weight above spec
400 kVA - 4 Bushing - 15,375 kV											
ECO 2015 Specification			A_0C_K	430	4600		1250	850	1300	1800	
ECO 2015 calculation/reality	AL	AL	A_0C_K	430	4600		1110	770	1235	1400	-22%
ECO 2015 calculation/reality	AL	AL	A_0C_K	430	4600		1150	850	1430	1520	-16%
ECO 2021 Specification			A_0-10% A_K	387	3250		1250	850	1300	1800	
ECO 2021 calculation/reality	AL	AL	A_0-10% A_K	387	3250		1180	770	1460	1950	8%
ECO 2021 calculation/reality	CU	CU	A_0-10% A_K	387	3250		1250	850	1225	2050	14%
ECO 2021 calculation/reality	AL	CU	A_0-10% A_K	387	3250		1250	850	1430	2140	19%

Figure 1-10 Brown field enquiry results from the Belgian grid operators with their usual suppliers

1.9 Conclusion on Tier 2 for space/weight and transportation constraints

The final conclusion will be made after the stakeholder meeting.

So far our findings are that:

- For brownfield applications in medium power transformers there might be limitations when only using today's mainstream manufacturing technology. Apparently a lock-in effect has been created by utilities that specify compact substations with space/weight constraints that cannot be solved without using new manufacturing techniques/designs. Also, utilities do not have harmonized space/weight constraints over Europe but have own requirements and do not buy catalogue transformers the way industrial clients do. However, taking into account all the technical progress margin documented in section 1.6 we think Tier 2 is technically feasible in 2021. Cost however might be high compared to savings for some individual cases for specific utilities but not for the base case brownfield transformer analysed in section 1.1.6. A greenfield substation replacement was found to be uneconomic;
- Very large power transformers in greenfield applications might face transportation limits. Hence the exemption in Regulation 548/2014 for only 'like for like replacements' might be insufficient. Nevertheless they still could underspecify kPEI versus the real equivalent load factor to reduce weight. Hence, as long as there is no minimum kPEI in the regulation this loophole can be used;
- Given the previously discussed brownfield and greenfield limitations some new exemptions might be considered to avoid some excessive costs for some individual cases. Stakeholders are invited to provide suggestions for this, which will be discussed in Task 3.

1.10 Is Tier 3 an option?

This conclusion will be made after the stakeholder meeting.

So far our findings are that:

- For large power transformers a minimum kPEI can be added in Tier 3, see section 1.3.5. It should also be checked with the manufacturers if PEI cannot be further increased.;
- If a Tier 3 is considered for medium power transformers it should mainly be focused on further reducing no load losses, e.g. A0-10% i.e. AA0 towards AAA0. Further reducing the load losses would continue to result in a kPEI different from the Base Cases and is therefore not recommended.;
- Dry type medium power transformers versus liquid power transformers have for the same rating very different loss requirements in Tier 2, this might be reviewed in Tier 3. Technology neutral requirements might be considered or a functional classification (e.g. fire resistance, ..). It can also be discussed in Task 4. One should also verify if there is no market transformation towards less efficient dry type transformers after Tier 2 because they have less ambitious loss requirements and could become economic more competitive. Apart from dry type versus liquid also new type of electronic distribution transformers might enter the market in future and therefore a more technology neutral or functional approach could be considered.
- Dry type versus liquid transformers for the same rating and identical load or no load classes defined in EN 50588 have different losses, e.g. AA0 minimum 675 Watt for dry type versus 387 Watt for a liquid 400 kVA transformer.
- Task 2 in section 2 suggests considering minimum no load losses for single phase LV/MV transformers, they could be considered in Tier 3. Similar requirements could also be considered for small LV/LV transformers that currently also are exempted, especially if they could become significant as isolation transformers used in electric vehicle charging stations.

2 Task 2 on Consideration of minimum requirements for single-phase 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 during Tier 2 to also apply to single-phase transformers.

An investigation will be 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.

Key issues for consideration at Stakeholder meeting:

Single phase transformers occupy a very small niche market in the EU's transformer market accounting for just 238 MVA of installed capacity per annum.

In practice, within the EU these products are only sold and used in EI and the UK for use within remote & isolated rural single-phase distribution networks.

There appears to be negligible risk of single phase transformers increasing their market share at the expense of 3-phase transformers due to unsymmetrical regulations concerning 3 phase transformer losses because the decisions regarding whether to apply single or 3 phase supply are governed by factors which are on a wholly different technical and economic scale to the incremental cost issues associated with 3-phase transformer loss regulations. They are also entirely of an historic legacy nature.

Thus in practice the potential regulation of these products is an issue which only affects EI and the UK rather than the EU as a whole.

In consequence, it could be argued that:

- it is only sensible to consider the issue using the load profiles, costs and economics that apply in these two economies (rather than the EU as a whole)
- that as the UK has (not yet formally) announced its intention to leave the EU , it may therefore be justified to only consider the Irish case for the Ecodesign regulatory determination, although an analysis of the pros and cons of regulation within a UK context may also be helpful to UK policy making process.

However, it is not clear if the MEErP permits the use of anything other than EU average values supported by sensitivity analyses; although, the former have little meaning in this context. Even the predominant products sold and load factors vary between EI and the UK in a systematic manner.

We therefore invite the stakeholder process to consider these matters of principle before we finalise the analysis, as they are likely to have a significant impact on the findings. Given the uncertainty with regard to the approach to be followed the remaining sections below report provisional findings using EU average tariff data, MEErP discount rates and a range of initial assumptions regarding CAPEX costs and load factors.

Data sources

As is clear from the discussion the majority of data on these products concerns the Irish and UK markets. 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[47] and supplied to the EC for use in this study. Data on the performance of amorphous transformers is publically available from ABB.

2.1 Stock and sales of single-phase transformers

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 these products are essentially exclusively used within the EU in 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 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[48].

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 2,2m low voltage customers, 0,6m 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.

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.

[47] CENELEC WG21 PROPOSALS FOR SINGLE PHASE TRANSFORMERN EFFICIENCIES, A. Walsh
[48] 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[49] and are summarised in the following table.

Table 2-1 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*.

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

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 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 2-2. 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%). 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 improve their real efficiency.

Table 2-2 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

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 2-3. 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

Table 2-3 Single-phase transformer NLL reported in ABB brochure

kVA	GOES typical NLL	AMT NLL
15	55	20

25	65	30
50	105	35
75	155	55
100	200	75
167	235	95

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.

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.

Thus far the study has not identified 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). Table 2-4 shows these provisional base case models and associated analytical results for the 25 and Table 2-5 for the 50kVA models that are typical in the UK – these also assumes 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 three-phase transformer costs for any given load class and no-load class can be scaled as a function of their rated capacity to derive estimates of single phase transformer capital costs. Ideally actual cost data for single phase transformers will be forthcoming ahead of the final draft to allow these provisional figures to be replaced with real cost data. The table shows how 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 clas 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 2-4 Base Cases for single-phase liquid-immersed medium power transformers – 25kVA models for UK-average NLL – 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
interest rate	%	4%	4%	4%	4%	4%	4%	4%	4%	4%
inflation rate	%	2%	2%	2%	2%	2%	2%	2%	2%	2%
kWh price no load and aux. Losses	€	0.0847	0.0847	0.0847	0.0847	0.0847	0.0847	0.0847	0.0847	0.0847
kWh price load losses	€	0.0847	0.0847	0.0847	0.0847	0.0847	0.0847	0.0847	0.0847	0.0847
CAPEX - transformer	€	489.01	507.07	522.63	489.01	507.07	522.63	489.01	507.07	522.63
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	%	2%	2%	2%	2%	2%	2%	2%	2%	2%
PWF	ratio	27.36	27.36	27.36	27.36	27.36	27.36	27.36	27.36	27.36
No load loss capitalization factor (A)	€/W	20.30	20.30	20.30	20.30	20.30	20.30	20.30	20.30	20.30
Load loss capitalization factor (B)	€/W	0.02	0.02	0.02	0.16	0.16	0.16	1.15	1.15	1.15
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	51.00	50.89	50.82	55.79	54.76	54.01	88.42	81.04	75.77
LCC electricity	€ /life	1,395.15	1,392.24	1,390.17	1,526.25	1,497.85	1,477.56	2,418.80	2,216.85	2,072.60
LCC total (excl. scrap@EOL)	€ /life	1,884.16	1,899.31	1,912.80	2,015.25	2,004.92	2,000.19	2,907.80	2,723.91	2,595.23
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)	€	6.68	6.68	6.68	6.68	6.68	6.68	6.68	6.68	6.68
LCC total (incl. scrap@NPV)	€	1,877.48	1,892.63	1,906.12	2,008.57	1,998.24	1,993.51	2,901.12	2,717.23	2,588.55

Table 2-5 Base Cases for single-phase liquid-immersed medium power transformers – 50kVA models for UK-average NLL – 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
interest rate	%	4%	4%	4%	4%	4%	4%	4%	4%	4%
inflation rate	%	2%	2%	2%	2%	2%	2%	2%	2%	2%
kWh price no load and aux. Losses	€	0.0847	0.0847	0.0847	0.0847	0.0847	0.0847	0.0847	0.0847	0.0847
kWh price load losses	€	0.0847	0.0847	0.0847	0.0847	0.0847	0.0847	0.0847	0.0847	0.0847
CAPEX - transformer	€	978.01	1,014.14	1,045.26	978.01	1,014.14	1,045.26	978.01	1,014.14	1,045.26
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	%	2%	2%	2%	2%	2%	2%	2%	2%	2%
PWF	ratio	27.36	27.36	27.36	27.36	27.36	27.36	27.36	27.36	27.36
No load loss capitalization factor (A)	€/W	20.30	20.30	20.30	20.30	20.30	20.30	20.30	20.30	20.30
Load loss capitalization factor (B)	€/W	0.02	0.02	0.02	0.16	0.16	0.16	1.15	1.15	1.15
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	83.77	83.63	83.56	89.63	88.29	87.55	129.50	120.01	114.74
LCC electricity	€ /life	2,291.54	2,287.80	2,285.73	2,451.77	2,415.26	2,394.98	3,542.67	3,283.02	3,138.76
LCC total (excl. scrap@EOL)	€ /life	3,269.55	3,301.94	3,330.99	3,429.78	3,429.40	3,440.23	4,520.68	4,297.15	4,184.02
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)	€	13.36	13.36	13.36	13.36	13.36	13.36	13.36	13.36	13.36
LCC total (incl. scrap@NPV)	€	3,256.19	3,288.58	3,317.63	3,416.42	3,416.04	3,426.87	4,507.32	4,283.79	4,170.66

Table 2-5 and Table 2-7 shows the exactly equivalent analysis for the single phase transformer rated capacities that dominate the Irish market, i.e. for 15 and 33 kVA models respectively.

Table 2-6 Base Cases for single-phase liquid-immersed medium power transformers – 15kVA 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	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
interest rate	%	4%	4%	4%	4%	4%	4%	4%	4%	4%
inflation rate	%	2%	2%	2%	2%	2%	2%	2%	2%	2%
kWh price no load and aux. Losses	€	0.0847	0.0847	0.0847	0.0847	0.0847	0.0847	0.0847	0.0847	0.0847
kWh price load losses	€	0.0847	0.0847	0.0847	0.0847	0.0847	0.0847	0.0847	0.0847	0.0847
CAPEX - transformer	€	363.24	379.11	392.46	363.24	379.11	392.46	363.24	379.11	392.46
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	%	2%	2%	2%	2%	2%	2%	2%	2%	2%
PWF	ratio	27.36	27.36	27.36	27.36	27.36	27.36	27.36	27.36	27.36
No load loss capitalization factor (A)	€/W	20.30	20.30	20.30	20.30	20.30	20.30	20.30	20.30	20.30
Load loss capitalization factor (B)	€/W	0.02	0.02	0.02	0.16	0.16	0.16	1.15	1.15	1.15
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	36.16	36.06	35.98	40.95	39.92	39.17	73.58	66.20	60.93
LCC electricity	€ /life	989.21	986.30	984.23	1,120.31	1,091.91	1,071.62	2,012.86	1,810.91	1,666.66
LCC total (excl. scrap@EOL)	€ /life	1,352.46	1,365.41	1,376.69	1,483.55	1,471.02	1,464.09	2,376.10	2,190.01	2,059.12
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)	€	4.01	4.01	4.01	4.01	4.01	4.01	4.01	4.01	4.01
LCC total (incl. scrap@NPV)	€	1,348.45	1,361.40	1,372.68	1,479.55	1,467.01	1,460.08	2,372.09	2,186.01	2,055.11

Table 2-7 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
interest rate	%	4%	4%	4%	4%	4%	4%	4%	4%	4%
inflation rate	%	2%	2%	2%	2%	2%	2%	2%	2%	2%
kWh price no load and aux. Losses	€	0.0847	0.0847	0.0847	0.0847	0.0847	0.0847	0.0847	0.0847	0.0847
kWh price load losses	€	0.0847	0.0847	0.0847	0.0847	0.0847	0.0847	0.0847	0.0847	0.0847
CAPEX - transformer	€	764.94	797.71	825.39	764.94	797.71	825.39	764.94	797.71	825.39
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	%	2%	2%	2%	2%	2%	2%	2%	2%	2%
PWF	ratio	27.36	27.36	27.36	27.36	27.36	27.36	27.36	27.36	27.36
No load loss capitalization factor (A)	€/W	20.30	20.30	20.30	20.30	20.30	20.30	20.30	20.30	20.30
Load loss capitalization factor (B)	€/W	0.02	0.02	0.02	0.07	0.07	0.07	0.16	0.16	0.16
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	43.70	43.57	43.49	45.93	45.34	45.01	49.56	48.23	47.48
LCC electricity	€ /life	1,195.51	1,191.77	1,189.69	1,256.56	1,240.34	1,231.32	1,355.74	1,319.22	1,298.94
LCC total (excl. scrap@EOL)	€ /life	1,960.44	1,989.47	2,015.08	2,021.50	2,038.04	2,056.71	2,120.67	2,116.93	2,124.33
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)	€	8.82	8.82	8.82	8.82	8.82	8.82	8.82	8.82	8.82
LCC total (incl. scrap@NPV)	€	1,951.62	1,980.66	2,006.26	2,012.68	2,029.22	2,047.89	2,111.85	2,108.11	2,115.51

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 transformer 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 2-8 to Table 2-11. Table 2-8 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 2-9 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 2-10 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 2-11 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 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 assumption that the CAPEX of single phase transformers is scalable UK and Irish tariff values are assumed in place of EU average values.

Table 2-8 Base Cases for single-phase liquid-immersed medium power transformers – 25kVA and 50kVA models – 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
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	0.0847	0.0847	0.0847	0.0847
kWh price load losses	€	0.0847	0.0847	0.0847	0.0847	0.0847	0.0847
CAPEX - transformer	€	489.01	522.48	693.21	978.01	1,044.97	1,386.42
losses per year	kWh/y	725.3	663.9	418.7	925.4	846.5	531.2
discount rate	%	2%	2%	2%	2%	2%	2%
PWF	ratio	27.36	27.36	27.36	27.36	27.36	27.36
No load loss capitalization factor (A)	€/W	20.30	20.30	20.30	20.30	20.30	20.30
Load loss capitalization factor (B)	€/W	0.29	0.29	0.29	0.29	0.29	0.29
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	61.43	56.24	35.46	78.38	71.70	44.99
LCC electricity	€ /life	1,680.44	1,538.36	970.05	2,144.08	1,961.41	1,230.72
LCC total (excl. scrap@EOL)	€ /life	2,169.45	2,060.85	1,663.25	3,122.09	3,006.38	2,617.13
scrap value @ EOL	€	14.75	14.75	14.75	29.50	29.50	29.50
NPV scrap value (incl. discount rate)	€	6.68	6.68	6.68	13.36	13.36	13.36
LCC total (incl. scrap@NPV)	€	2,162.77	2,054.16	1,656.57	3,108.73	2,993.01	2,603.77

Table 2-9 Base Cases for single-phase liquid-immersed medium power transformers – 25kVA and 50kVA models – 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
interest rate	%	4%	4%	4%	4%	4%	4%	4%	4%
inflation rate	%	2%	2%	2%	2%	2%	2%	2%	2%
kWh price no load and aux. Losses	€	0.0847	0.0847	0.0847	0.0847	0.0847	0.0847	0.0847	0.0847
kWh price load losses	€	0.0847	0.0847	0.0847	0.0847	0.0847	0.0847	0.0847	0.0847
CAPEX - transformer	€	489.01	498.57	522.48	693.21	814.34	978.01	1,044.97	1,386.42
losses per year	kWh/y	680.4	662.9	619.1	373.8	1093.2	900.5	821.6	506.3
discount rate	%	2%	2%	2%	2%	2%	2%	2%	2%
PWF	ratio	27.36	27.36	27.36	27.36	27.36	27.36	27.36	27.36
No load loss capitalization factor (A)	€/W	20.30	20.30	20.30	20.30	20.30	20.30	20.30	20.30
Load loss capitalization factor (B)	€/W	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29
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	57.63	56.15	52.44	31.66	92.59	76.27	69.59	42.88
LCC electricity	€ /life	1,576.58	1,535.99	1,434.50	866.19	2,532.91	2,086.38	1,903.71	1,173.02
LCC total (excl. scrap@EOL)	€ /life	2,065.59	2,034.56	1,956.99	1,559.39	3,347.25	3,064.39	2,948.67	2,559.43
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)	€	6.68	6.68	6.68	6.68	13.36	13.36	13.36	13.36
LCC total (incl. scrap@NPV)	€	2,058.91	2,027.88	1,950.30	1,552.71	3,333.89	3,051.03	2,935.31	2,546.07

Table 2-10 Base Cases for single-phase liquid-immersed medium power transformers – 15kVA and 33kVA models – 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
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	0.0847	0.0847	0.0847	0.0847
kWh price load losses	€	0.0847	0.0847	0.0847	0.0847	0.0847	0.0847
CAPEX - transformer	€	293.40	313.49	415.93	645.49	689.68	915.04
losses per year	kWh/y	725.3	663.9	418.7	789.3	722.4	454.7
discount rate	%	2%	2%	2%	2%	2%	2%
PWF	ratio	27.36	27.36	27.36	27.36	27.36	27.36
No load loss capitalization factor (A)	€/W	20.30	20.30	20.30	20.30	20.30	20.30
Load loss capitalization factor (B)	€/W	0.29	0.29	0.29	0.29	0.29	0.29
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	61.43	56.24	35.46	66.85	61.18	38.51
LCC electricity	€ /life	1,680.44	1,538.36	970.05	1,828.81	1,673.74	1,053.46
LCC total (excl. scrap@EOL)	€ /life	1,973.84	1,851.85	1,385.97	2,474.29	2,363.41	1,968.50
scrap value @ EOL	€	8.85	8.85	8.85	19.47	19.47	19.47
NPV scrap value (incl. discount rate)	€	4.01	4.01	4.01	8.82	8.82	8.82
LCC total (incl. scrap@NPV)	€	1,969.84	1,847.84	1,381.96	2,465.47	2,354.60	1,959.68

Table 2-11 Base Cases for single-phase liquid-immersed medium power transformers – 15kVA and 33kVA models – 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
interest rate	%	4%	4%	4%	4%	4%	4%	4%	4%
inflation rate	%	2%	2%	2%	2%	2%	2%	2%	2%
kWh price no load and aux. Losses	€	0.0847	0.0847	0.0847	0.0847	0.0847	0.0847	0.0847	0.0847
kWh price load losses	€	0.0847	0.0847	0.0847	0.0847	0.0847	0.0847	0.0847	0.0847
CAPEX - transformer	€	293.40	313.49	368.37	415.93	645.49	689.68	784.46	915.04
losses per year	kWh/y	646.8	585.5	454.1	340.2	753.3	686.4	592.1	418.7
discount rate	%	2%	2%	2%	2%	2%	2%	2%	2%
PWF	ratio	27.36	27.36	27.36	27.36	27.36	27.36	27.36	27.36
No load loss capitalization factor (A)	€/W	20.30	20.30	20.30	20.30	20.30	20.30	20.30	20.30
Load loss capitalization factor (B)	€/W	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29
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	54.79	49.59	38.46	28.82	63.81	58.14	50.15	35.46
LCC electricity	€ /life	1,498.69	1,356.61	1,052.15	788.29	1,745.43	1,590.36	1,371.96	970.08
LCC total (excl. scrap@EOL)	€ /life	1,792.09	1,670.10	1,420.52	1,204.22	2,390.92	2,280.04	2,156.42	1,885.12
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)	€	4.01	4.01	4.01	4.01	8.82	8.82	8.82	8.82
LCC total (incl. scrap@NPV)	€	1,788.08	1,666.09	1,416.51	1,200.21	2,382.10	2,271.22	2,147.61	1,876.30

Use of Amorphous Transformers:
Amorphous transformers have much lower Iron losses than conventional, even those which will now use of 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 stimation of the costs of such transformers. Equally it is reported that discussions with large suppliers of Amorphous Core Transformers provided quite contradictory information on the expected price changes from switching to amorphous ranging over a greater than +60% range. This is partly due to the actual cost depending strongly on that of the amorphous steel which is supplied from a tight market, and also on the suppliers attempting to pitch the price in relation to what the expected price from traditional manufacturers is anticipated to be.

It is reported that ESB have been in the process of tendering for single phase transformers and it is hoped this may supply a basis to assess actual amorphous price levels that can be used to establish the relationship between costs and technical feasibility of this technology.

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 provisional analyses presented above 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.** The study team is awaiting new information as well as guidance on matters of principle in order to be able to complete the analysis and make final conclusions on this topic.

A related issue is whether there is any logic in setting PEI limits for such products or potentially simply no load loss limits. This topic will be discussed in the 2nd stakeholder meeting.

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 on three phase transformers if requirements are not set for single phase transformers?

Single phase transformers are only used in single phase power MV networks. **These are currently only found in rural parts of Ireland and the UK** and are in use due to an historical infrastructural legacy. The incremental investments that would be needed to convert three-phase systems to single-phase systems are very substantial and are much greater than the incremental costs of adopting Tier 1 or Tier 2 three phase transformers, 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:

Regulation 548/2014 provides in Article 1.2 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, the identification of any existing regulatory exemptions in Article 1.2 which are no longer justified is also investigated.

3.1.1 Proposals for new exemptions

Note that T&D Europe has 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. Those findings are not yet included in this report but during the study Stakeholder meeting on 29/3it is requested that a summary of their findings should be presented. **Thus, in the following text only some of the major findings related to the work in the draft Task 1&2 chapters are discussed.**

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

The question of whether such products should be exempt depends on the findings of Task 2 related to brown field requirements.

In principle it is possibile to **define such transformers**:

- based on a table with space & weight limits related to the rating(kVA). Depending on the eventual findings from Task 2 this could be an exhaustive task that may not be possible to conduct in the existing project time frame.
- **based on technical characteristics** that are designed to avoid the creation of a significant loophole, for example the maximum specific core losses at a relative high magnetic flux density (e.g. ≤0.77 W/kg @ 1.5 T, see Table 5-3 in Lot 2). An additional parameter for compact transformers could be to limit the conductivity of the conductor material (e.g. to ≥16.7 mΩ.mm @ 20°C). Due to its simplicity, this might be a preferential option. For market surveillance, a certificate of material origin could be required to be included with the technical construction file as well as a material sample.

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 based on the space and weight findings presented in that section. **Here again the minimum space & weight limit for this transformer category could be combined with maximum specific core loss limits** to define the exemption.

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 can also be added as an alternative Tier 2 requirement for a separate category of transformers within the scope of the Regulation. The main difference is the legal status of these transformers and market surveillance needs.

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 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 a standardisation mandate addressing this is highly recommended.

These minimum dimensions and weight characteristics should match transformer manufacturer capabilities and manufacturers are invited to supply such data.

In order to continue to avoid lock in effects for single pole mounted transformers it is also recommended to **extend the scope of the regulation to address poles for distribution transformers**, wherein single poles for transformer stations should be replaced over time by dual pole or lattice frame constructions (see 3.4.1). Also, consumers in Europe could benefit from the economy of scale when harmonizing transformer pole constructions and thus a European standardisation mandate could be considered.

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

Aim and tender request:
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 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 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.

If appropriate, a proposal for a regulatory extension to apply to the repair of transformers should be developed and discussed at the validation workshop.

3.2.1 Limitations from CE marking legislation

In all this it is important to be aware that since the transformer Commission Regulation (EU) No 548/2014 went 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 proof compliance. Bringing products on the market is documented in the 'Blue Guide on the implementation of EU products rules 2016' available from the EC[50].

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

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

Note that the Regulation (EU) No 548/2014 establishes ecodesign requirements 'for placing on the market or putting into service'. The Blue Book 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 (47) 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 label, 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 label there is not such a limitation.** Nevertheless, evidence might be needed to proof they were manufactured before the CE requirements.

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

Note that this interpretation conflicts with the T&D Europe interpretation[51]: '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.'

[51] http://www.tdeurope.eu/data/T&D%20Europe%20Transformers%20Eco-design%20PP%2015052015.pdf

3.2.2 Requirements for second hand transformers that are not compatible with Tier 1&2

Because second hand transformers can constitute a loophole to the current Regulation 548/2014 it would be possible to add requirements for second hand transformers to the Regulation. In all this, the EC should check if this approach is compatible with other CE Regulation.

Second hand transformers can be defined as transformers that change ownership and that are incompatible with the existing requirements for new transformers.

Requirements for second hand transformers could be set in line with the Tiers for new transformers.

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.

This task consists in verifying whether Table I.3 needs to be expanded for particular types of transformers which are not covered by the existing cases. Additionally, existing regulatory concessions should be reconsidered in the light of technological progress and market understanding. This requires both desk research and expert advice. Any proposal to change Table I.3 will be discussed at the stakeholder meeting (29/3).

3.3.1 Task understanding and challenges

We understand 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. Within CENELEC standardization committees data is has been prepared to enable quantification of this effect. As far as could be some simplifications and narrower tolerances can be expected from this work.

3.3.2 Proposal

CENELEC and T&D Europe are invited to present their proposals in stakeholder meeting on 29/3.

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. This will inform an assessment of whether regulatory concessions for pole-mounted transformers should be maintained or should be phased out. This also requires a techno-economic analysis, as well as desk research and expert advice. Any proposal to change Table I.6 will be discussed at the validation 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 other brownfield applications discussed in section 1.5. So far, the Regulation 548/2014 does not specify the type of pole construction however this can play an important role in understanding this limit. The best way to increase the stiffness and stability of a pole mounted transformer construction is to increase the second area moment[52] 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 ecological. For greenfield applications such single pole constructions can be avoided in case of stability problems. For brownfield application adding a second pole can be considered, Table 3-1 contains the LCC calculation for a 160 kVA pole mounted Tier 2 transformer compliant Tier 2 concessions versus Tier 2 for liquid transformers. Prices for such transformers are unknown, stakeholder can 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[53] for a second pole. This example shows that adding a second pole and using a more efficient transformer has a lower LCC. **Hence in principle there is no technical rationale to maintain this concession, it is rather a lock in effect into existing procedures and installations.**

[52] https://en.wikipedia.org/wiki/Second_moment_of_area

[53] 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 Tier 2 concessions for pole mounted and 'BC 2pole' is compliant for Tier 2 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 align this with the brown field exemptions discussed in section 3.1.1.1.

Note that the Regulation can also benefit from the review of some definitions and standards from efficiency measurements, e.g. as mentioned on the first stakeholder meeting ‘It is important that the efficiency of the transformer has to be measured at the terminals (otherwise opens opportunity to claim high performance associated with dropping functions’. This work should run in parallel with this study within CENELEC.

4 Task 4 on 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.

Any proposal to consider additional product requirements for power transformers will be discussed at the Stakeholder meeting on 29/3.

4.1 Conclusions based on Task 1 MEErP versus MEEuP

Ecodesign impact results according MEErP are presented in section 1.2 and Figure 1-2. In Figure 1-2 the green columns represent the positive and non-unneglectable impact from recycling on production related impact which are the brown columns. In Figure 1-2 the MEErP default values for metal recycling were used but in practice this impact can be larger because transformer land fill disposal without recycling is unlikely. In order to stimulate this recycling and to consider the scrap value in the Life Cycle Cost (see section 1.1.4), **it can be recommended to include detailed Bill-of-Material also in catalogue data and thus not only on transformer name plates as it is today**.
For transportation there was major impact modelled on 'Particulate Matter'(blue column in Figure 1-2); this should be addressed by reducing vehicle emmissions during transport but is outside the scope of this review of Regulation 548/2014 on transformers.

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

This issue was raised in the first stakeholder meeting on 16/9. Harmonics were already discussed in section 3.2.1.5 in the Lot 2 study(2011) and therefore the technical background will not be repeated in this study. The conclusion was that harmonics will increase no load losses and using energy efficient transformers with low no load losses(@50Hz) is the way forward to address them. **This confirms to maintain Tier 2 in Regulation 548/2014 or not to dilute it.**
Note that harmonic distortion can also be address 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 reviewing Tier 3 neither in a Tier 3.

4.3 Other issues

Note that within **the Regulation 548/2014 only new products are addressed**, not existing products neither installations such as substations.

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

Also it is not recommended to address within the Regulation 548/2014 review other insulation materials such as mineral oil because accidental release to the environment can be address at installation level.

Also, as explained in the Lot 2 transformer it is not proposed to consider transformer noise limits for products because this can also be addressed at installation level and is so for not brought forward by stakeholders to address within the Ecodesign product requirements for transformers.

Stakeholders can bring forward topics and evidence of their significance for issues to consider in the review of Regulation 548/2014 (if any) in the stakeholder meeting on 29/3.

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. Recommendations are to be backed by solid technical and economic evidence and presented in a structured way, following the order of Tasks 1 to 4.
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 will be included as annexes.

5.1 Overview of position papers

WILL BE ELABORATED IN THE FINAL VERSION AFTER THE STAKEHOLDER MEETING ON 29/3.

5.2 Potential amendments to existing minimum requirements for Tier 2

WILL BE ELABORATED IN THE FINAL VERSION AFTER THE STAKEHOLDER MEETING ON 29/3.

5.3 Consideration of minimum requirements for single-phase transformers

WILL BE ELABORATED IN THE FINAL VERSION AFTER THE STAKEHOLDER MEETING ON 29/3.

5.4 Potential amendments to exemptions in Regulation 548/2014

WILL BE ELABORATED IN THE FINAL VERSION AFTER THE STAKEHOLDER MEETING ON 29/3.

5.5 Potential inclusion of transformer repair criteria in Regulation 548/2014

WILL BE ELABORATED IN THE FINAL VERSION AFTER THE STAKEHOLDER MEETING ON 29/3.

5.6 Potential amendments to concessions for transformers with unusual combinations of winding voltages

WILL BE ELABORATED IN THE FINAL VERSION AFTER THE STAKEHOLDER MEETING ON 29/3.

5.7 Potential amendments to concessions for pole-mounted transformers

WILL BE ELABORATED IN THE FINAL VERSION AFTER THE STAKEHOLDER MEETING ON 29/3.

5.8 Consideration of other environmental impacts or criteria

WILL BE ELABORATED IN THE FINAL VERSION AFTER THE STAKEHOLDER MEETING ON 29/3.

Annex A COMPARISON OF END-OF-LIFE IN MEEUP (LOT 2) VERSUS MEERP (REVIEW) RESULTS

Results from MEEuP Ecoreport tool (2005) for BC1 - Distribution transformer A0+Ak

Life cycle Impact per product:	Date	Author
BC1 - Distribution transformer A0+Ak	0	BIO

Life Cycle phases -->		PRODUCTION			DISTRI-	USE	END-OF-LIFE*			TOTAL
Resources Use and Emissions		Material	Manuf.	**Total**	BUTION		Disposal	Recycl.	**Total**	
Materials	**unit**									
Bulk Plastics	g			**557967**			557967	0	**557967**	**0**
TecPlastics	g			**0**			0	0	**0**	**0**
Ferro	g			**1421195**			14212	1406983	**1421195**	**0**
Non-ferro	g			**548028**			5480	542548	**548028**	**0**
Coating	g			**12067**			121	11947	**12067**	**0**
Electronics	g			**0**			0	0	**0**	**0**
Misc.	g			**62679**			627	62052	**62679**	**0**
Total weight	g			**2601937**			578407	2023530	**2601937**	**0**
								see note!		
Other Resources & Waste							debet	credit		
Total Energy (GER)	MJ	179077	39733	**218810**	**4917**	**1200258**	39326	30550	**8776**	**1432760**
of which, electricity (in primary MJ)	MJ	5697	23796	**29493**	**12**	**1197161**	0	0	**0**	**1226666**
Water (process)	ltr	5899	354	**6253**	**0**	**79854**	0	0	**0**	**86107**
Water (cooling)	ltr	8581	11100	**19681**	**0**	**3191839**	0	0	**0**	**3211520**
Waste, non-haz./ landfill	g	9893055	132181	**10025236**	**2039**	**1487951**	31898	0	**31898**	**11547124**
Waste, hazardous/ incinerated	g	553	3	**556**	**41**	**27585**	557967	0	**557967**	**586149**
Emissions (Air)										
Greenhouse Gases in GWP100	kg CO2 eq.	7711	2212	**9923**	**290**	**52423**	2932	2280	**652**	**63289**
Ozone Depletion, emissions	mg R-11 eq.	negligible								
Acidification, emissions	g SO2 eq.	128579	9544	**138123**	**888**	**309667**	5840	2856	**2984**	**451662**
Volatile Organic Compounds (VOC)	g	867	7	**875**	**90**	**479**	86	39	**46**	**1490**
Persistent Organic Pollutants (POP)	ng i-Teq	32101	580	**32681**	**12**	**8172**	236	0	**236**	**41100**
Heavy Metals	mg Ni eq.	27558	1358	**28917**	**103**	**21083**	10564	0	**10564**	**60667**
PAHs	mg Ni eq.	23068	7	**23076**	**195**	**2849**	0	1	**-1**	**26119**
Particulate Matter (PM, dust)	g	6563	1470	**8033**	**14975**	**11073**	49587	48	**49538**	**83619**
Emissions (Water)										
Heavy Metals	mg Hg/20	13784	1	**13784**	**3**	**7855**	3316	0	**3316**	**24958**
Eutrophication	g PO4	431	20	**451**	**0**	**41**	190	0	**190**	**682**
Persistent Organic Pollutants (POP)	ng i-Teq	negligible								

Results from MEErP Ecoreport tool (2014) for BC1 - Distribution transformer A0+Ak

	Life Cycle phases -->		PRODUCTION			DISTRI-	USE	END-OF-LIFE			TOTAL	RBR
	Resources Use and Emissions		Material	Manuf.	Total	BUTION		Disposal	Recycl.	Stock		
	Materials	**unit**										
1	Bulk Plastics	g			**4 267**		**43**	2 371	1 940	0	**0**	
2	TecPlastics	g			**0**		**0**	0	0	0	**0**	
3	Ferro	g			**1 421 195**		**14 212**	71 770	1 363 636	0	**0**	
4	Non-ferro	g			**548 028**		**5 480**	27 675	525 833	0	**0**	
5	Coating	g			**0**		**0**	0	0	0	**0**	
6	Electronics	g			**0**		**0**	0	0	0	**0**	
7	Misc.	g			**40 981**		**410**	14 073	27 318	0	**0**	
8	Extra	g			**575 398**		**0**	226 649	354 503	0	**-5 754**	
9	Auxiliaries	g			**0**		**0**	0	0	0	**0**	
10	Refrigerant	g			**0**		**0**	0	0	0	**0**	
	Total weight	g			**2 589 870**		**20 145**	342 539	2 273 230	0	**-5 754**	
									see note!			
	Other Resources & Waste							debet	credit			
11	Total Energy (GER)	MJ	146 513	17 114	**163 627**	**4 485**	**1 027 350**	1 237	-51 818		**1 144 881**	**0**
12	of which, electricity (in primary MJ)	MJ	4 971	10 179	**15 151**	**12**	**1 025 935**	0	-1 842		**1 039 256**	**0**
13	Water (process)	ltr	3 076	149	**3 225**	**0**	**31**	0	-759		**2 497**	**0**
14	Water (cooling)	ltr	3 947	4 677	8 624	0	45 634	0	-955		53 304	0
15	Waste, non-haz./ landfill	g	2 017 086	61 308	**2 078 394**	**2 039**	**548 844**	24 069	-770 364		**1 882 981**	**0**
16	Waste, hazardous/ incinerated	g	306	3	**309**	**41**	**16 189**	0	-109		**16 430**	**0**
	Emissions (Air)											
17	Greenhouse Gases in GWP100	kg CO2 eq.	7 497	957	**8 454**	**290**	**43 866**	2	-2 834		**49 779**	**0**
18	Acidification, emissions	g SO2 eq.	127 819	4 133	**131 953**	**887**	**195 056**	73	-48 552		**279 418**	**0**
19	Volatile Organic Compounds (VOC)	g	867	6	**873**	**90**	**22 920**	0	-242		**23 641**	**0**
20	Persistent Organic Pollutants (POP)	ng i-Teq	32 097	580	**32 677**	**12**	**2 715**	14	-12 300		**23 117**	**0**
21	Heavy Metals	mg Ni eq.	27 543	1 346	**28 890**	**103**	**10 648**	32	-10 474		**29 199**	**0**
22	PAHs	mg Ni eq.	23 065	5	**23 071**	**195**	**2 624**	0	-7 651		**18 239**	**0**
23	Particulate Matter (PM, dust)	g	6 377	635	**7 013**	**14 971**	**4 167**	36	-2 412		**23 775**	**0**
	Emissions (Water)											
24	Heavy Metals	mg Hg/20	13 620	44	**13 664**	**3**	**4 552**	4	-5 223		**13 000**	**0**
25	Eutrophication	g PO4	629	7	**636**	**0**	**200**	62	-178		**720**	**0**

Annex B MEErP TOOL (2014) INPUTS

Pos nr	MATERIALS Extraction & Production Description of component	Weight in g	Category Click &select	Material or Process select Category first !	Recyclable?
1	Core steel	865000,0	3-Ferro	22 - St sheet galv.	
2	Aluminum wire	123000,0	4-Non-ferro	27 - Al sheet/extrusion	
3	Copper wire	336000,0	4-Non-ferro	29 - Cu winding wire	
4	Copper sheet	89028,4	4-Non-ferro	31 - Cu tube/sheet	
5	Steel tank	556194,7	3-Ferro	23 - St tube/profile	
6	Paper	33360,8	7-Misc.	58 - Office paper	
7	Resin	0,0	2-TecPlastics	15 - Epoxy	
8	Ceramic	12553,4	8-Extra	104-ceramics	
9	Oil	553700,0	8-Extra	102-Mineral oil	
10	Cardboard	7620,4	7-Misc.	57 - Cardboard	
11	Nomex	0,0	2-TecPlastics	20 - Aramid fibre	
12	other plastic parts	4267,4	1-BlkPlastics	2 - HDPE	
13	Wood	9144,5	8-Extra	103-Wood	

Pos nr	MANUFACTURING Description	Weight in g	Percentage Adjust	Category index (fixed)
201	**OEM Plastics Manufacturing** (fixed)	4267		21
202	**Foundries Fe/Cu/Zn** (fixed)	0		35
203	**Foundries Al/Mg** (fixed)	0		36
204	**Sheetmetal Manufacturing** (fixed)	1077028		37
205	**PWB Manufacturing** (fixed)	0		54
206	**Other materials** (Manufacturing already included)	1508574		
207	**Sheetmetal Scrap** (Please adjust percentage only)	53851	5%	38

Pos nr	DISTRIBUTION (incl. Final Assembly) Description		Answer	Category index (fixed)
208	**Is it an ICT or Consumer Electronics product <15 kg ?**		NO	60
209	**Is it an installed appliance (e.g. boiler)?**		YES	61
				63
210	**Volume of packaged final product in m^3**	in m3	4,38	64
				65

Pos nr	USE PHASE direct ErP impact Description		unit	Subtotals	
226	ErP Product (service) Life in years	40	years		
	Electricity				
227	On-mode: Consumption per hour, cycle, setting, etc.	2849,680948	kWh	2849,680948	
228	On-mode: No. of hours, cycles, settings, etc. / year	1	#		
229	Standby-mode: Consumption per hour	0	kWh	0	
230	Standby-mode: No. of hours / year	0	#		
231	Off-mode: Consumption per hour	0	kWh	0	
232	Off-mode: No. of hours / year	0	#		
	TOTAL over ErP Product Life	113,99	MWh (=000 kWh)	66	
	Heat				
233	Avg. Heat Power Output	0	kW		
234	No. of hours / year	0	hrs.		
235	Type and efficiency (Click & select)			86-not applicable	
	TOTAL over ErP Product Life	0,00	GJ		
	Consumables (excl, spare parts)			material	
236	Water	0	m^3/year	84-Water per m3	
237	Auxilliary material 1 (Click & select)	0	kg/ year	86 -None	
238	Auxilliary material 2 (Click & select)	0	kg/ year	86 -None	
239	Auxilliary material 3 (Click & select)	0	kg/ year	86 -None	
240	Refrigerant refill (Click & select type, even if there is no re	0	kg/ year	3-R404a; HFC blend; 3920	
	Maintenance, Repairs, Service				
241	No. of km over Product-Life	500	km / Product Life	87	
242	Spare parts (fixed, 1% of product materials & manuf.)	25899	g	1%	

Pos nr	DISPOSAL & RECYCLING Description				
253	product (stock) life L, in years	40	Please edit values with red font		
		current	L years ago	period growth PG in %	CAGR in %/a
254	unit sales in million units/year	0,140	0,000	0,0%	0,0%
255	product & aux. mass over service life, in g/unit	2615768	2615768	0,0%	0,0%
256	total mass sold, in t (1000 kg)	367,2538811	0	0,0%	0,0%

Pos nr	Per fraction (post-consumer)	1 Bulk Plastics	2 TecPlastics	3 Ferro	4 Non-ferro	5 Coating	6 Electronics	7a Misc., excluding refrigant & Hg	7b refrigerant	7c Hg (mercury), in mg/unit	8 Extra	9 Auxiliaries	TOTAL (CARG avg.)	
257	current fraction, in % of total mass (or mg/unit Hg	0,2%	0,0%	54,9%	21,2%	0,0%	0,0%	1,6%	0,0%	0,0	22,2%	0,0%	100,0%	
258	fraction x years ago, in % of total mass	0,2%	0,0%	54,9%	21,2%	0,0%	0,0%	1,6%	0,0%	0,0	22,2%	0,0%	100,0%	
259	CAGR per fraction r, in %	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%		
	current product mass in g	*4310*	*0*	*1435407*	*553509*	*0*	*0*	*41391*	*0*	*0*	*581152*	*0*	*2615768*	
260	stock-effect, total mass in g/unit	0	0	0	0	0	0	0	0	0,0	0	0	*0*	0%
261	EoL available, total mass ('arisings') in g/unit	4310	0	########	553509	0	0	41391	0	0,0	581152	0	########	100%
262	EoL available, subtotals in g		4310		1988915		0	41391	0	0,0	581152	0	########	
													AVG	
263	EoL mass fraction to re-use, in %						1%			1%		5%	*1,0%*	
264	EoL mass fraction to (materials) recycling, in %	29%	29%		94%		50%	64%	30%	39%	60%	30%	*85,9%*	
265	EoL mass fraction to (heat) recovery, in %	15%	15%		0%		0%	1%	0%	0%	0%	10%	*0,0%*	
266	EoL mass fraction to non-recov. incineration, in %	22%	22%		0%		30%	5%	5%	5%	10%	10%	*2,3%*	
267	EoL mass fraction to landfill/missing/fugitive, in %	33%	33%		5%		19%	29%	64%	55%	29%	45%	*10,8%*	
268	TOTAL	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*	*100%*	*100,0%*	
269	EoL recyclability****, (click& select: 'best', '>avg', 'avg' (basecase); '<avg'.; 'worst')	**avg**	**avg**	**avg**	**avg**	**avg**	**avg**	**avg**	**avg**	**avg**	**avg**	**avg**	***avg***	
		0%	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*0%*		

L is product (stock) life = period between product purchased and product discarded

PG=growth rate over period of L years= (value current - value L years ago)/(value L years ago)

CAGR=Compound Annual Growth Rate = (1+ PG)^(1/L) - 1 (^= to the power)

EoL available mass' or 'arisings' = Total mass available for End-of-Life (EoL) management = recycmax * current fraction * product mass, with recycmax=1/(1+CAGR)^L,

'stock' = the surplus (or deficit) of mass in stock (in use or stored with consumer) due to growth (or decline) of the unit sales or the share of the materials fraction over a period that equals the product life. stock= stock-effect arisings - product mass*current fraction ; '

're-use'= fraction of EoL available mass in components that can be re-used in new products. The generic credit relative to the re-used mass is 75% on all impacts and for all fractions, taking into account the impact of collection, sorting, cleaning, etc. (as opposed to MEEuP 2005, where the collection effort was calculated separately). In case the specific re-use credit found for a specific product deviates from the default it is recommended to adapt the mass fraction

recycling'= fraction of EoL available mass that is recycled for its materials. For metals this is already included in the production impact, based roughly on the fraction mentioned (values cannot be edited). For plastics, electronics, miscellaneous materials, refrigerants, mercury and the extra materials these values need to be edited (overwrite default values). The credit relates to the recyled mass and depends on the main virgin material that will be displaced by the recycled mass, the remaining value at final disposal (e.g. heat recovery) and/or avoidance of operations for disposal of hazardous substances (pyrolysis). E.g. for plastics the most popular displaced material is wood (e.g. 27 MJ/kg is < 50% of bulkplastics value) and remaining value at final disposal is 50% of the

For electronics (PWBs, ICs, controllers, displays, etc.) main credits come from recovery of metals (Cu, Fe, tin, traces of Au, Pt, Pd), glass (from displays, cullet displaces virgin material mainly in fiberglass insulation) and avoidance of treatment of hazardous substances (e.g. Pb, Cd, etc.). Note that the WEEE recast impact assessment report found official electronics recycling rates to be low (in 2005: 20% for tools, 27% for ITC equipment, 35-40% for TVs/monitors) but suspects actual, unreported (possibly incorrect) recycling activities to be substantially higher. For miscellaneous materials recycling fractions fully depend on the materials involved and a weighted average needs to be determined beforehand. For 'Misc.', including refrigerants and Hg, credit comes from re-use after purification, avoiding treatment as hazardous waste, etc. . For all materials, except metals (where it is assumed to be higher), a credit of 40% on all impacts is assumed related to the recycled mass. See MEErP Methodology Report Part 2 for more guidance.

'(heat) recovery' = fraction of EoL available mass where the combustion heat is used, e.g. for district heating. In the context of ErP it is assumed to apply only to plastics and all other materials for which a feedstock energy value is given. The credit is 75% of feedstock energy (net combustion value) and GWP.

'non-recov. Incineration' = fraction of EoL available mass that is incinerated without heat recovery, either because there is no effective contribution to the combustion (non-combustibles) , the incineration plant has no clients for waste heat, etc.. Impacts of 'incineration' as given in the Unit Indicator table (see MEErP Methodology Report Part 2, Table 13, row 92) apply.

'landfill/fugitive/missing' = fraction of EoL available mass that goes to landfill, that escapes during use (for substances that are gaseous or evaporate at atmospheric conditions like most refrigerants and mercury) and that are unaccounted for (illegal dumping etc.). Impacts of 'landfill' as given in the Unit Indicator table (see MEErP Methodology Report Part 2, Table 13, row 89) apply.

'recyclability' relates to the potential of the new products to change the course of the materials flows , e.g. due to faster pre-disassembly or other ways to bring about less contamination of the mass to be recycled (see MEErP Methodology Report Part 2) . Therefore it is economically likely that the recycled mass at EoL will displace more virgin material in other applications . The recyclability does not influence the mass balance but it does give a reduction or increase up to 10% on all impacts of the recycled mass. It is forward looking, e.g. values different from 'avg' (=base case) should only be filled in for design options.

nr	INPUTS FOR EU-Totals & economic Life Cycle Costs Description		unit
A	Product Life	**40**	years
B	Annual sales	0,1404	mln. Units/year
C	EU Stock	2,25	mln. Units
D	Product price	€ 8 977,51	Euro/unit
E	Installation/acquisition costs (if any)	€ 0,00	Euro/ unit
F	Fuel rate (gas, oil, wood)		Euro/GJ
G	Electricity rate	€ 0,085	Euro/kWh
H	Water rate		Euro/m3
I	Aux. 1: None		Euro/kg
J	Aux. 2 :None		Euro/kg
K	Aux. 3: None		Euro/kg
L	Repair & maintenance costs	€ 0,00	Euro/ unit
M	Discount rate (interest minus inflation)	4%	%
N	Escalation rate (project annual growth of running costs)	2%	%
O	Present Worth Factor (PWF) (calculated automatically)	27,54	(years)
P	Ratio efficiency STOCK: efficiency NEW, in Use Phase	1,00	

Annex C QUESTIONNAIRE FOR INSTALLERS ON TRANSFORMERS CONSTRAINTS AND LIMITATIONS

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)
Client: European Commission, Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs

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

Questionnaire for Installers on Transformers constraints and limitations

Dear Madams and Sirs,

This enquiry is designed to gather data to determine the effect that Tier 2 efficiency requirements would have on transformer constraints. More information on the scope of work can be found on the project website: https://transformers.vito.be/. This questionnaire document is intended to structure your data input to reflect the current and future situation in the transformer market (EU) appropriately.
The enquiry is a **joint enquiry with CENELEC CLC/TC14** and hence **if you have filled in such an enquiry before you can also send it to share the work for the ongoing study.**
Note that VTIO is committed to comply with antitrust rules. As a result, the present enquiry does not require the participants to provide (i) individualized and /or raw information on the technical specifications of transformers they supply confidential to their customers nor (ii) to provide any other commercially sensitive information. Similarly, the respondents to this enquiry should not voluntarily provide such information in response to this enquiry if this does not belong to the public domain and/or cannot be disclosed within the report of supplied to the European Commission services. This questionnaire document is only intended to structure your data input to reflect the current and future situation in the transformer market (EU) appropriately. The primary objective of this enquiry it to gather sufficient information to assess if Tier 2 requirements of EU regulation 548/2014, applicable in 2021, are still technologically justified.
You are kindly invited to reply to this Enquiry indicating, if possible, what are the most typical values to be considered in your area for the different types of transformers.
This enquiry consists of two sections, where data can be provided by filling the proposed tables. Please add as many columns as necessary (one column per each transformer). In case not all requested data are available, feel free to indicate "N.A." – "Not Available" – in the cells with missing data.
The deadline to submit your answers is December 19th, 2016.

Best Regards,

Paul Van Tichelen on behalf of the project team
Paul.vantichelen@vito.be
Sent to: transformers@vito.be

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1st SECTION: TRANSFORMERS GENERAL DATA AND CONSTRAINTS

Transformer category[1]					
Rated power[2] of each winding [MVA / MVA / ...]					
Frequency [Hz]					
Number of phases					
Type (liquid / dry)					
Rated voltage of each winding [kV / kV / ...]					
Highest voltage for equipment of each winding Um [kV / kV / ...]					
Vector Group[3]					
Regulation type[4]					
Type of cooling[5]					
Impedance[6] [%]					
Maximum dimensions[7] (length x width x height) [mm]					
Maximum weight [kg]					
Minimum clearance between live parts and ground [mm]					
Minimum free distance required around the transformer [mm]					
Please clarify the reason for the constraints[8] and the consequence of exceeding them					

(1) Please specify the transformer application by indicating the relevant letter among the options in the following list:

A. Arc furnace transformer
B. Distribution transformer

...

C. Earthing transformer
D. Generator step-up transformer
E. Ground mounted distribution transformer
F. HVDC converter transformer
G. Medium Voltage (MV) to Medium Voltage (MV) interface transformer
H. Offshore transformer – Oil platform
I. Offshore transformer – Wind collector substation
J. Offshore transformer – Wind turbine
K. Phase-shifting transformer
L. Photovoltaic application transformer
M. Pole mounted distribution transformer
N. Rectifier transformer
O. Starting transformer
P. Subsea transformer
Q. System intertie transformer
R. Traction transformer for fixed installations
S. Traction transformer for rolling stock
T. Variable Speed Drive transformer (VSD)
U. Wind turbine onshore transformer

In case a specific application is missing, feel free to add additional letters to the list above

(2) If different values of apparent power are assigned under different cooling methods, please indicate the highest of these values, which is the rated power
(3) As defined in EN 60076-1, paragraph 7. In particular:

   a. if a transformer is specified with a reconfigurable winding connection (reconnectable windings), the alternative coupling voltage and connection shall be noted in brackets. For example: 110 / 11 (5,5) kV indicates a reconnectable LV winding
   b. if a tertiary winding is provided as stabilizing winding, the "d" symbol shall be preceded by the "+" sign and no phase displacement shall be indicated. For example: YNa0+d indicates the presence of a tertiary stabilizing winding

(4) Please specify either "None", "DETC" or "OLTC". In case voltage variation is provided on more than one winding, please indicate each winding voltage and its regulation type separately
(5) If the transformer has several assigned cooling methods, please indicate all of them
(6) Referred to the highest value of rated power and to the rated voltage (i.e. rated tap position). In case of more than two windings, please indicate between which winding pair and at which power the value refers
(7) Parameters not constrained can be left unspecified (e.g. if the length and the width are constrained, but the height is not, it can be indicated or example: 6000 x 4000 x H)
(8) For example: size of door in existing substation, width limitation on transport, limits on pole weight, etc...

...

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2nd SECTION: TRANSPORTATION DIMENSIONAL AND WEIGHT CONSTRAINTS

Please indicate in the following table what are the transportation constraints to be considered in your country (maximum values). In case more than one type of constraint exists (e.g. constraints may be different depending on the installation site), feel free to add rows to the table below and use the column "Comments" to clarify the rationale.

	Length [mm]	Width [mm]	Height [mm]	Weight [kg]	Comments
Railway transportation					
Road transportation					

Annex D PROCESSED INSTALLER REQUIREMENT DATA FROM ENQUIRY ON A SELECTION OF TRANSFORMERS

Received data for 250 kVA liquid transformers:

		brownfied country specifications							
country		BE	D	NL	F	PL	ES	N	N
sample (s) or representative (r)		r	s REWAG2015	r spec 11/2016	r with protect.	s	r Iberdrola2014	s	s Hafslund
Transformer category(1)		DT	DT	DT	DT-Enedis	DT	DT	DT	DT
Rated power of each winding (kVA)		250/250/250	250	250	250	250	250	200	200
Number of phases		3	3	3	3	3	3	3	3
Type (liquid / dry)		liquid	liquid	liquid	liquid	liquid	liquid	liquid	liquid
Rated voltage of each winding (kV)	high side (kV)	15,4	20,8	23	20	21	20	22	22
	Low Side (kV)	0,42	0,4	0,4	0,4	0,42	0,42	0,42	0,42
	Low Side (kV) 2 LV windings	0,242							
Highest voltage for equipment of each winding Um (kV)	high side (kV)	17,5	24	24	20	24	24	24	24
	low side (kV)	3,6	DIN EN 50386	EN 50386 (1kV		1	1,1	1,1	1,1
Vector Group(3)		DYN11a11	DYN5	DYN5 or DYN1:	DYN11	DYN5	DYN11	Yyn0 or DYN11	Yyn0
Regulation type		DETC		DETC		DETC	DETC	DETC	DETC
Tapping				±2x2.5%			±2x2.5%		
Type of cooling		onan	onan	onan	-	onan	onan	onan	onan
Impedance(6) [%]		4	4	4	4	4	4	4	4,45
max. length (mm)		1200	1200	1200	1200	1350	1300	1200	1120
max. width (mm)		700	800	800	800	900	910	750	750
max. heigth (mm)		1245	1600	1600	1300	1700	1680	1500	1130
max. weight (kg)		1200	1500	1360	1200	1200	1400	NA	1105
Tier 1 (CkA0) or Tier 2(AkA0-10%)									
LV winding material									
HV winding material									
low loss steel (<0,9 W/kg@1,7T/50Hz)									
oil type									
insulation type									
operating temperature(Pk)									
stimated price increase in % of Tier 1 desig									
Sound power level			<47	<47					
Minimum clearance between live parts and ground [mm]		EC60076-3	55	100					IEC 60076-3
Minimum free distance required around the transformer [mm]					150				
Please clarify the reason for the constraints(8) and the consequence of exceeding them		existing substations	=+10 % allowed on dimensions	100 mm clearance for fork lift note: AMDT are not allowed	is include in compact substation Max floor : 1200kg DSO need to manage faults on transformers and replace in existing substation (	Size of door in existing substation, limits on pole weight			

		brownfied country specifications (received after manufacturer enquiry launch)		
country		SI	IT	IT
sample (s) or representative (r)		r	r areti	r e-distributzione
Transformer category(1)		DT	DT	DT
Rated power of each winding (kVA)		250	250/187	250
Number of phases		3	3	3
Type (liquid / dry)		liquid	liquid	liquid
Rated voltage of each winding (kV)	**high side (kV)**	21(10,5)	20,8(8,4)	20 or 15 or 10
	Low Side (kV)	0,42	0,42(0,242)	0,42
	Low Side (kV) 2 LV windings			
Highest voltage for equipment of each winding Um (kV)	**high side (kV)**	24	24	24
	low side (kV)	1,1	1,1	1,1
Vector Group(3)		Dyn5	Dyn11	Dyn11
Regulation type		DETC	DETC	DETC
Tapping				
Type of cooling		onan	onan	onan
Impedance(6) [%]		4	4(0,42)/2,8(0,242)	4 (or 6)
max. length (mm)		1400	1400	1400
max. width (mm)		750	850	800
max. heigth (mm)		NA	NA	1750
max. weight (kg)		1500	NA	2000
Tier 1 (CkA0) or Tier 2(AkA0-10%)				
LV winding material				
HV winding material				
low loss steel (<0,9 W/kg@1,7T/50Hz)				
oil type				
insulation type				
operating temperature(Pk)				
stimated price increase in % of Tier 1 desig				
Sound power level				
Minimum clearance between live parts and ground [mm]		130(230)	NA	NA
Minimum free distance required around the transformer [mm]		100	200	NA
Please clarify the reason for the constraints(8) and the consequence of exceeding them		restrictions on the size (width) of the transformer space in the existing compact TP	size of door in existing substation	

Received data for 400 kVA liquid transformers:

		brownfied country specifications					
country		BE	D	NL	PL	ES	N
sample (s) or representative (r)		r	s REWAG2015	r spec 11/2016	s	r Iberdrola2014	r
Transformer category(1)		DT	DT	DT	DT	DT	DT
Rated power of each winding (kVA)		400/400/400	400	400	400	400	500
Number of phases		3	3	3	3	3	3
Type (liquid / dry)		liquid	liquid	liquid	liquid	liquid	liquid
Rated voltage of each winding (kV)	high side (kV)	15,4	20,8	23	21	20	22
	Low Side (kV)	0,42	0,4	0,4	0,42	0,42	0,42
	Low Side (kV) 2 LV windings	0,242					
Highest voltage for equipment of each	high side (kV)	17,5	24	24	24	24	24
	low side (kV)	3,6	DIN EN 50386	EN 50386 (1kV)	1	1,1	1,1
Vector Group(3)		DYN11a11	DYN5	DYN5 or DYN11	DYN5	DYN11	Yyn0 or DYN11
Regulation type		DETC		DETC	DETC	DETC	DETC
Tapping				±2x2.5%		±2x2.5%	
Type of cooling		onan	onan	onan	onan	onan	onan
Impedance(6) [%]		4	4	4	4 and 4.5	4	4
max. length (mm)		1250	1300	1320	1400	1620	1500
max. width (mm)		850	900	800	900	1020	900
max. heigth (mm)		1300	1700	1600	1700	1750	2100
max. weight (kg)		1800	1800	1850	1500	1750	NA
Tier 1 (CkA0) or Tier 2(AkA0-10%)							
LV winding material							
HV winding material							
low loss steel (<0,9 W/kg@1,7T/50Hz)							
oil type							
insulation type							
operating temperature(Pk)							
imated price increase in % of Tier 1 des							
Sound power level			<50	<50			
Minimum clearance between live parts and ground [mm]		EC60076-3	55	100			IEC 60076-3
Minimum free distance required around the transformer [mm]							
Please clarify the reason for the constraints(8) and the consequence of exceeding them		existing substations	=+10 % allowed on dimensions	100 mm clearance for fork lift note: AMDT are not allowed	Size of door in existing substation, limits on pole weight		

		brownfied country specifications (received after manufacturer enquiry launch)				
country		SI	IT	IT	SK	SK
sample (s) or representative (r)		r	r areti-1	r e-distributzione	r	r
Transformer category(1)		DT	DT	DT	DT	DT
Rated power of each winding (kVA)		400	400/300	400	400	400
Number of phases		3	3	3	3	3
Type (liquid / dry)		liquid	liquid	liquid	liquid	liquid
Rated voltage of each winding (kV)	high side (kV)	21(10,5)	20,8(8,4)	20 or 15 or 10	33	22
	Low Side (kV)	0,42	0,42(0,242)	0,42	0,42	0,42
	Low Side (kV) 2 LV windings					
Highest voltage for equipment of each	high side (kV)	24	24	24	NA	NA
	low side (kV)	1,1	1,1	1,1	NA	NA
Vector Group(3)		Dyn5	Dyn11	Dyn11	Dyn1	Dyn1
Regulation type		DETC	DETC	DETC	OLTC (13step)	OLTC (6step)
Tapping						
Type of cooling		onan	onan	onan	onan	onan
Impedance(6) [%]		4	4,3(0,42)/3,2(0,242)	4 (or 6)	NA	NA
max. length (mm)		1400	1600	1600	NA	NA
max. width (mm)		750	880	1030	NA	NA
max. heigth (mm)		NA	NA	1850	NA	NA
max. weight (kg)		1500	2500	2000	4260	1300
Tier 1 (CkA0) or Tier 2(AkA0-10%)						
LV winding material						
HV winding material						
low loss steel (<0,9 W/kg@1,7T/50Hz)						
oil type						
insulation type						
operating temperature(Pk)						
imated price increase in % of Tier 1 des						
Sound power level						
Minimum clearance between live parts and ground [mm]		130(230)	NA	NA	NA	NA
Minimum free distance required around the transformer [mm]		100	200	NA	NA	NA
Please clarify the reason for the constraints(8) and the consequence of exceeding them		restrictions on the size (width) of the transformer space in the existing compact TP	size of door in existing substation			

Received data for 630 kVA liquid transformers:

		brownfied country specifications							
country		BE	D	NL	F	PL	ES	N	S
sample (s) or representative (r)		r	s REWAG2015	r spec 11/2016	r classical	s	r Iberdrola2014	r	r
Transformer category(1)		DT	DT	DT	DT-Enedis	DT	DT	DT	DT
Rated power of each winding (kVA)		630/630/630	630	630	630	630	630	630	800
Number of phases		3	3	3	3	3	3	3	3
Type (liquid / dry)		liquid	liquid	liquid	liquid	liquid	liquid	liquid	liquid
Rated voltage of each winding (kV)	high side (kV)	15,4	20,8	23	20	21	20	22	22
	Low Side (kV)	0,42	0,4	0,4	0,4	0,42	0,42	0,42	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
	low side (kV)	3,6	DIN EN 50386	EN 50386 (1kV)		1	1,1	1,1	1,1
Vector Group(3)		DYN11a11	DYN5	DYN5 or DYN11	DYN11	DYN5	DYN11	Yyn0	Yyn0 or DYN
Regulation type		DETC		DETC		DETC	DETC	DETC	
Tapping				±2x2.5%			±2x2.5%		
Type of cooling		onan	onan	onan		onan	onan	onan	onan
Impedance(6) [%]		4	4	4	4	4 and 4.5	4	4 or 6	5,8
max. length (mm)		1500	1500	1500	1700	1400	1650	1550	1500
max. width (mm)		850	900	820	920	900	1140	900	900
max. heigth (mm)		1360	1800	1680	1650	1700	1870	2100	1400
max. weight (kg)		2400	2500	2650	2500	2000	2400	NA	2300
Tier 1 (CkA0) or Tier 2(AkA0-10%)									
LV winding material									
HV winding material									
low loss steel (<0,9 W/kg@1,7T/50Hz)									
oil type									
insulation type									
operating temperature(Pk)									
Estimated price increase in % of Tier 1 design									
Sound power level			<50	<52					
Minimum clearance between live parts and ground [mm]		EC60076-3	55	100				IEC 60076-3	
Minimum free distance required around the transformer [mm]					200				
Please clarify the reason for the constraints(8) and the consequence of exceeding them		existing substations	=+10 % allowed on dimensions	100 mm clearance for fork lift note: AMDT are not allowed	In urban areas, it would be impossible to address faults on transformers rated 630 to 1000 kVA in existing secondary substations, since the space would not be big enough and the pad would not be designed for higher weight. Max floor 2500	Size of door in existing substation, limits on pole weight			

		brownfied country specifications (received after manufacturer enquiry launch)		
country		SI	IT	IT
sample (s) or representative (r)		r	r areti-1	r e-distributzione
Transformer category(1)		DT	DT	DT
Rated power of each winding (kVA)		630	630/472	630
Number of phases		3	3	3
Type (liquid / dry)		liquid	liquid	liquid
Rated voltage of each winding (kV)	high side (kV)	21(10,5)	20,8(8,4)	20 or 15 or 10
	Low Side (kV)	0,42	0,42(0,242)	0,42
	Low Side (kV) 2 LV windings			
Highest voltage for equipment of each	high side (kV)	24	24	24
	low side (kV)	1,1	1,1	1,1
Vector Group(3)		Dyn5	Dyn11	Dyn11
Regulation type		DETC	DETC	DETC
Tapping				
Type of cooling		onan	onan	onan
Impedance(6) [%]		4	6,7(0,42)/5,1(0,242)	4 (or 6)
max. length (mm)		1500	1600	1800
max. width (mm)		800	930	1030
max. heigth (mm)		NA	NA	1850
max. weight (kg)		2000	2500	2000
Tier 1 (CkA0) or Tier 2(AkA0-10%)				
LV winding material				
HV winding material				
low loss steel (<0,9 W/kg@1,7T/50Hz)				
oil type				
insulation type				
operating temperature(Pk)				
Estimated price increase in % of Tier 1 design				
Sound power level				
Minimum clearance between live parts and ground [mm]		130(230)	NA	NA
Minimum free distance required around the transformer [mm]		100	200	NA
Please clarify the reason for the constraints(8) and the consequence of exceeding them		restrictions on the size (width) of the transformer space in the existing compact TP	size of door in existing substation	

Annex E QUESTIONNAIRE FOR DISTRIBUTION TRANFORMER MANUFACTURERS (MV/LV) FOR BROWN FIELD AND GREEN FIELD APPLICATIONS

Questionnaire for 250 kVA liquid, 400 kVA liquid, 630 kVA liquid, 100 kVA pole mounted, 160 kVA pole mounted transformers
Example for 400 kVA:

		brownfield average	brownfield borderline	brownfield reference designs						Tier 1 greenfield reference design		Tier 2 greenfield reference design	
country				type									
sample (s) or representative (r)													
Transformer category(1)		DT	DT										
Rated power of each winding (kVA)		400	400										
Number of phases		3	3										
Type (liquid / dry)		liquid	liquid										
Rated voltage of each winding (kV)	high side (kV)	high side (kV)	15,4										
	Low Side (kV)	Low Side (kV)	0,4										
	Low Side (kV) 2 LV windings												
Highest voltage for equipment of each	high side (kV)	24	24										
	low side (kV)	1,1	3,6										
Vector Group(3)		Dyn11	Dyn11										
Regulation type		DETC	DETC										
Tapping			±2x2.5%										
Type of cooling		onan	onan										
Impedance(6) [%]		4	4		?	?	?	?	?	?	?	?	?
max. length (mm)		1398	1250		?	?	?	?	?	?	?	?	?
max. width (mm)		895	800		?	?	?	?	?	?	?	?	?
max. heigth (mm)		1692	1300		?	?	?	?	?	?	?	?	?
max. weight (kg)		1740	1500		?	?	?	?	?	?	?	?	?
Tier 1 (CkA0) or Tier 2(AkA0-10%)					Tier 1	Tier 2	Tier 1	Tier 2	Tier 2				
LV winding material					Alu	Alu	Alu	Alu	Alu	Alu	Alu	Alu	Alu
HV winding material					Alu	Alu	Alu	Alu	Alu	Alu	Alu	Alu	Alu
low loss steel (<0,9 W/kg@1,7T/50Hz)					≤0,9W/kg	≤0,9W/kg	≤0,9W/kg	≤0,9W/kg	≤0,9W/kg	≤0,9W/kg	≤0,9W/kg	≤0,9W/kg	≤0,9W/kg
oil type					mineral	mineral	mineral	mineral	mineral	mineral	mineral	mineral	mineral
insulation type					cellulose	cellulose	cellulose	cellulose	cellulose	cellulose	cellulose	cellulose	cellulose
operating temperature(Pk)					75°C	75°C	75°C	75°C	75°C				
imated price increase in % of Tier 1 des													
Sound power level													
Minimum clearance between live parts and ground [mm]													
Minimum free distance required around the transformer [mm]													
Please clarify the reason for the constraints(8) and the consequence of exceeding them													