POSITION PAPER

REGULATION W.R.T. SMALL, MEDIUM AND LARGE DISTRIBUTION AND POWER TRANSFORMERS

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SUMMARY

Transmission losses in European networks vary between 1 and 2.6% of electricity generated. Distribution losses can be as high as 11.7%. On average, 7% of electricity is lost in T&D networks, making losses the single biggest electricity use in any member state.

ECI welcomes the proposed regulation with regards to small, medium and large distribution and power transformers. Through this regulation, the European Union joins a global trend to regulate transformer efficiency. Without it, there is a real risk to deteriorating efficiency for both distribution and power transformers, considering new technologies and market pressures.

The approach in the impact assessment appears robust. Assumptions err on the conservative side. Several impacts on the benefit side, such as electricity price trend, load growth, system capacity cost, true cost of losses and external costs have not been taken into account. Further impact assessment taking these factors into account can only strengthen the proposed regulation.

Lifecycle assessment of 100-1600 kVA distribution transformers, performed by ECI, demonstrates significant net environmental impacts of increased efficiency. The energy return on energy invested (EROEI) for the additional material used is a factor 100 or more.

Network losses cost European consumers annually over 11 billion euros, which the proposed regulation would reduce by 10%. The cost savings can pay for the additional investment in transformers, and eventually lower electricity prices to end-users.

The ecodesign regulation needs to be coordinated with the electricity liberalisation and the energy efficiency directives. Internalising the benefits of energy saving for network operations, and allowing for a sufficiently long period to recover the investment will result in economically efficient investments for utilities, while gradually transferring the benefits to customers.

For implementation of the regulation, a dialogue with regulators could be established to ensure adequate incentives for the introduction of higher efficiency transformers, while removing disincentives as well as to harmonize the approach to the cost of losses, its time dependence and the cost-benefit analysis. This could result in a guideline on regulatory incentives supporting the investment in economically optimum efficiency levels proposed as the regulation.

A GLOBAL TREND

In regulating transformer efficiency, Europe joins a global trend, following Australia, China, India USA and other countries. The proposed EU regulation for distribution transformers is similar to regulations in other developed economies, and very timely.

There are also examples of regulation or plans for large power transformers China has standard on efficiency of power transformers specifying maximum allowable no load and load losses.

MEPS are organized in forms of either maximum losses tables or efficiency tables calculated at certain loading level; 100% or more often 50% which represents loading closer to real operating conditions and closer to optimum efficiency as well. Japanese top runner scheme uses formulas to calculate efficiency for different transformers from their kVA value at 40% load. India applied interesting idea to specify maximum losses for two transformer loading levels 50% and 100%. This is to secure that transformers have the required proportion of no – load to load losses.

Below, there is the overview of existing transformer efficiency schemes.

Country	Title
Australia	AS 2374.1.2-2003 : Power transformers - Minimum Energy Performance Standard (MEPS) requirements for distribution transformers (10-2004)
Canada	Mandatory MEPS for Transformers (01-01-2005)
India	MEPS for Distribution Transformers of ratings 16, 25, 63, 100, 125, 200 kVA capacity (2010)
Israel	MEPS for Distribution Transformers - Israel
New Zealand	AS 2374.1.2 - Power Transformers Part 1.2: Minimum Energy Performance Standard (MEPS) requirements for distribution transformers (01-10-2004)
People's Republic of China	GB 20052-2006 - Minimum Allowable Values of Energy Efficiency and the Evaluating Values of Energy Conservation for Three-Phase Distribution Transformers (2006) Minimum allowable values of energy efficiency and the energy efficiency grades for power transformer (2010) with requirements to be met in 2014
The United States	MEPS for Distribution Transformers (2010)

MANDATORY LABELING

India	Star Rating Plan - Distribution Transformer (2010)
Israel	Energy Label for Distribution Transformers - Israel
Japan	Label Display Program for Retailers – “Top runner program” -Transformers
People's Republic of China	China Energy Label - Power Transformer (2010)

VOLUNTARY PROGRAMS

Chinese Taipei	Greenmark - Transformers (1992)
People's Republic of China	CQC Mark Certification - Power Transformer (2010)
Republic of Korea	Certification of high energy efficiency appliance program for Transformers (--)
The United States	ENERGY STAR - Transformers (1995)

IMPACT ASSESSMENT

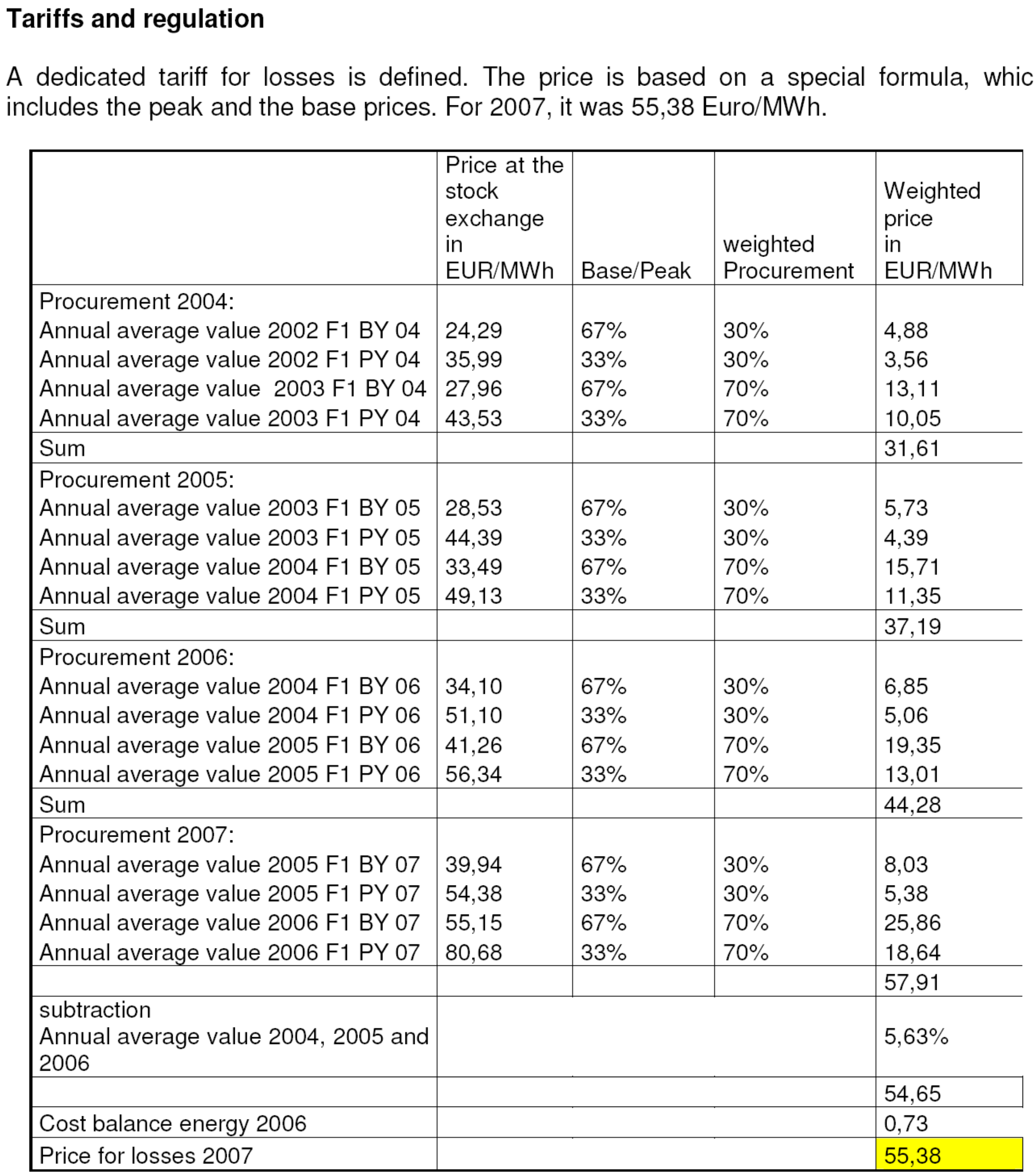
The selection of parameters entering TCO formula is strongly influences the efficiency level with optimum lifecycle cost. Below are the assumptions presented in draft impact assessment on Stakeholders Forum on November 9 in Brussels.

INPUTS		**BC1 Distribution**	**BC2 Industry OIL**	**BC3 Industry Dry**	**BC4 Power**	**BC5 DER Oil**	**BC6 DER Dry**	**BC7 Separation/ Isolation**
Lifetime (Years)		40	25	30	30	25	25	20
Electricity rate (€/kWh)	**Min**	0,0468€			0,035	0,075 €		0,0468€
	Base	0,0935€			0,05€	0,15 €		0,0935€
	Max	0,1403€			0,075€	0,225 €		0,1403€
Discount rate		4%						
Load Factor	**Min**	0,10	0,15	0,15	0,20	0,15	0,15	0,15
	Base	0,15	0,30	0,30	0,30	0,25	0,25	0,25
	Max	0,30	0,40	0,40	0,5	0,30	0,30	0,35
Load Form Factor		1,073	1,096	1,096	1,08	1,5	1,5	1,096
EU Stock (2011)		2.451.074	549.065	118.272	70.205	7.300	29.201	750.000
Stock Growth		1,4%			1,5%	10,5%		0%
Baseline Transformer Technology (for unit)								
Classification		D0Ck	E0Ck	C0Bk	41-326	E0Ck	C0Bk	110-750
Total Energy Losses (kWh/year)		7.859	30.091	39.727	724.886	59.093	62.415	5.738
Product Price(€)		6.334€	10.239€	27.378€	743.886€	18.248€	28.191€	1.153€
Electricity cost (€)		14.544€	43.953€	64.231€	839.561€	230.791€	146.258€	7.827€
Life Cycle Cost (€)		20.877€	54.192€	91.609€	1.773.011€	249.039€	174.449€	8.980€

We marked In yellow the cells which, in our opinion, are underestimating value of losses and they will be discussed below.

COST OF LOSSES

Below is en extract from publication Ref: E08-ENM-04-03 of ERGEG titled “Treatment of Losses by Network Operators – ERGEG Position Paper”



Tariffs and regulation

A dedicated tariff for losses is defined. The price is based on a special formula, which includes the peak and the base prices. For 2007, it was 55,38 Euro/MWh.

	Price at the stock exchange in EUR/MWh	Base/Peak	weighted Procurement	Weighted price in EUR/MWh
Procurement 2004:				
Annual average value 2002 F1 BY 04	24,29	67%	30%	4,88
Annual average value 2002 F1 PY 04	35,99	33%	30%	3,56
Annual average value 2003 F1 BY 04	27,96	67%	70%	13,11
Annual average value 2003 F1 PY 04	43,53	33%	70%	10,05
Sum				31,61
Procurement 2005:				
Annual average value 2003 F1 BY 05	28,53	67%	30%	5,73
Annual average value 2003 F1 PY 05	44,39	33%	30%	4,39
Annual average value 2004 F1 BY 05	33,49	67%	70%	15,71
Annual average value 2004 F1 PY 05	49,13	33%	70%	11,35
Sum				37,19
Procurement 2006:				
Annual average value 2004 F1 BY 06	34,10	67%	30%	6,85
Annual average value 2004 F1 PY 06	51,10	33%	30%	5,06
Annual average value 2005 F1 BY 06	41,26	67%	70%	19,35
Annual average value 2005 F1 PY 06	56,34	33%	70%	13,01
Sum				44,28
Procurement 2007:				
Annual average value 2005 F1 BY 07	39,94	67%	30%	8,03
Annual average value 2005 F1 PY 07	54,38	33%	30%	5,38
Annual average value 2006 F1 BY 07	55,15	67%	70%	25,86
Annual average value 2006 F1 PY 07	80,68	33%	70%	18,64
				57,91
subtraction Annual average value 2004, 2005 and 2006				5,63%
				54,65
Cost balance energy 2006				0,73
Price for losses 2007				55,38

In next sections we discuss components which have influence on this value

RATIO OF COST OF UNIT LOAD TO NO-LOAD LOSSES

An Australian study on analysis of losses is presented in Annex. The study is focused on differentiation of load and no load losses. The table below presents its main conclusion, which shows that the true cost of network losses varies greatly with time and location.

Distributor	No-load loss	System load	Load Loss
Market price	$38.90	$42.80	$47.30
Generation LRMC	$80.80	$90.90	$92.40
Metropolitan LRMC			
Transmission connection point	$88.10	$99.10	$106.00
Subtransmission	$103.00	$116.00	$133.00
High Voltage	$107.00	$120.00	$138.00
Low Voltage	$139.00	$155.00	$196.00
Regional LRMC			
Transmission connection point	$94.40	$106.00	$117.00
Subtransmission	$102.00	$115.00	$131.00
High Voltage	$135.00	$151.00	$190.00
Low Voltage	$172.00	$193.00	$259.00

The average exchange rate of AUS/EUR over last 2 years was 0,8€/AUS. It is visible that the average cost of losses (represented here as system load) for large power transformers (116 AUS – subtransmission) would be equivalent to 93€/MWh while for distribution transformer 154€/MWh (193 AUS). In case of transmission transformer, it is 25% higher than the adopted maximum rate in impact assessment and about 10% higher than the adopted maximum distribution transformers. Before making the argument that both continents have different power system topologies and economics, one should observe that the Australian values should be lower than the European ones in this respect.

The main purpose of the study was however to show the need of separation of load and no load losses.

The results should be interpreted this way that cost of losses should be divided into no load losses and load losses which has almost direct analogy to transformer no load and load losses.

Thus, for ***transmission transformer the cost of load loss is about 30% larger*** than no load loss.

For ***distribution transformer the extra value in cost of load loss is about 45%***.

No load losses have the cost of about 10% lower than energy cost but are still higher than in the EU assumptions

TREND OF ELECTRICITY PRICE

The formulae presented in introduction assume that energy prices and the loading are constant over the transformer life.

In fact this is not correct as electricity prices are currently increasing. We will not present here different electricity price projections but are only reporting EU statistics from 2009 to 2011 which is presented in Annex.

The annual price increase in average for households and industry year to year amounts 2,98% from 2009 to 2011. When going back to year 2005 and calculating this average increase for consecutive 6 years up to 2011 it will result in 4,65% annual increase. This increase highly depends on future international agreement on climate change however the conservative estimate of yearly 3% increase is plausible (some projections are even larger e.g. 5% increase). If so, such increase should be also included in **C_{kwh} value** in the lifecycle cost formula. Making it so, the initial value adopted for present moment **should be increased by 50,2% for 25 years lifetime** to reflect its averaged levelized value. Alternatively suitable correction (deduction) in interest rate should be made.

TRANSFORMER LOADING

Loading of transformers is also changing. The **annual increase in load** estimated in the SEEDT project[1] varies between **1,2 to 1,5% in selected EU countries** (it is universally observed although some differences between countries may exist). It can be calculated from difference in increase of electricity consumption and transformers overall capacity. This is because transformers are very long lasting equipment and new units are predominantly replacing old units after many years of operation. Increased loading reflects in larger load losses and this effect has been also neglected in considerations so far.

At this point we would like to address the issue of assumptions made in preparatory study about loading of large power transformers (BC4). In our opinion the impact and LCC calculation underestimates losses and their cost. This underestimation comes from too low loading assumptions. We estimate that **saving potential from large power transformers is about a half of this represented by distribution transformers**. Very rough check is that operational efficiency of distribution transformers can be improved by about 0,8% while large power transformers by about 0,1 to 0,15% and approximately 3-4 times more electricity passes through large power transformers (step up, transmission, primary distribution) than distribution transformers. This is also confirmed by T&D presentation titled PROGRESS REPORT ON T&D EUROPE ENQUIRIES which was presented in Brussels meeting of LPT Technical Sub Group for Eco-design directive for Transformers on 28th September 2012. Their investigation indicated an average load factor of 0.54 % (Square root load = 2210/7671)

INTEREST RATE

What interest rate should be used for valuing losses?

Some stakeholders propose to use the Weighted Average Cost of Capital (WACC).

However, the WACC is not a suitable interest rate for calculating the total cost of ownership, due to the risk provisions it includes. Therefore a discount rate consisting of the risk free rate increased with inflation is proposed instead.

NET ECONOMIC IMPACT

The proposed regulation will have a significant effect on transformer prices. However, it will also significantly reduce network losses by about 10%. Network losses in Europe amount to over 222 TWh/year, costing European consumers over 11 Beuro each year. Regulating transformer efficiency can save over 1 billion euro per year in network losses, which can cover the investment cost, as well as lower electricity prices to consumers.

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[1] http://seedt.ntua.gr/

EXTERNALITIES[2][3]

In the preparatory study for transformers, considerations about external cost of energy have been neglected.

With the average value for coal of 7 € cent per kWh, oil 5€ cent per kWh and gas 2€ cent per kWh the approximate value for EU electricity mix will be around 3€ cent per kWh i.e. ***30 €/ MWh.***

The external cost figures from EUR 20198 study and European electricity mix are presented in Annex.

NET ENVIRONMENTAL IMPACT

It can argued that the upfront environmental cost of improving efficiency should be taken into account. High efficiency transformers safe energy & CO2 emissions, but what about the energy to produce the additional materials to improve transformer efficiency?

Lifecycle assessment demonstrates that over 99% of the environmental impact of a distribution transformer can be attributed to its lifetime electricity losses.

For example, improving the efficiency of a 1600 kVA transformer will save 400 tons of CO_2 over the equipment's lifetime, while using an extra 700 kg of copper, causing 2 tons of CO_2 emissions. In this case, the environmental payback is a factor 200[4]. Moreover, copper & other materials can be recycled with much lower CO_2 emissions at the end of the transformer's lifetime.

SYSTEM CAPACITY COST

System Capacity Cost is a separate component of factor A and B but for simplicity reasons we propose to add it directly to cost of energy losses.

In Annex we present how we derived the following values:

Transmission transformer: 11,37$/MWh

Distribution transformer: 11,84$/MWh

We regret we could not find any other more recent case in literature but we propose to update this US case, by using one to one €/$ exchange rate and conservative 1% annual increase in power segment equipment prices. This yields values of:

Transmission transformer: 15,33€/MWh

Distribution transformer: 15,95€/MWh

Comparing these values to ERGEG price of losses shows extra portion of about 30%.

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[2] http://www.eea.europa.eu/data-and-maps/indicators/en35-external-costs-of-electricity-production-1

[3] http://www.externe.info/

[4] http://www.leonardo-energy.org/eco-sheet-16-mva-industrial-transformer-designs

HARMONICS AND REACTIVE POWER

Now, about neglecting additional losses. The effect of harmonics and reactive power is discussed in Annex.

The precise assessment of extra losses incurred by harmonics and reactive power is very difficult however the conservative assessment that about 5 TWh both in transformers and electrical networks are lost on top of purely sinusoidal and voltage phased with current conditions. Out of this around half can be saved through the use of properly designed transformers.

RISK OF NEW MARKET OF HIGH LOSS TRANSFORMERS

Recently we are observing a trend of sacrificing transformer efficiency for continuity of supply. Leonardo ENERGY analysed this topic and holds position that no trade of should be made between these two. Such opinion is inspired by intervention of EDF during last Stakeholders Forum.

Such trend can also be observed in large power transformers (cf. presentation of Georg Schett from ABB who presented Smart Grid transformers on EU-Asia Switch conference in Beijing China).

Another source is US DoE publication titled “Large Power Transformers and the U.S. Electric Grid”, DOE / OE / ISER June 2012:

“New recovery transformer (RecX) concept may provide some relief. The U.S. Department of Homeland Security’s (DHS) Science and Technology Directorate, along with their partners, the Electric Power Research Institute, ABB, and CenterPoint Energy (CNP), and the support of DOE and DHS Office Infrastructure Protection, have developed a prototype EHV transformer that will drastically reduce the recovery time associated with EHV transformer issues. The Recovery Transformer (RecX) is lighter (approximately 125 tons), smaller and easier to transport and quicker to install than a traditional EHV transformer. The prototype transformer delivery and set up was successfully demonstrated in March of 2012 in an exercise that included the Large Power Transformers and the U.S. Electric Grid transportation, installation, assembly, commissioning and energization of the transformer in less than 1 week. The RecX is currently operating in CNP’s grid for a one-year monitoring period. The RecX is a 345:138kV, 200 MVA per phase transformer (equivalent to 600MVA) and was designed to be an applicable replacement for over 90 percent of transformers in this voltage class, which is the largest voltage class of EHV transformers.

We think it may be that this concept may mobilize manufacturers to hinder the process of large power transformer efficiency regulation.

The development of new insulation materials has led to thermal classes (per IEC 60085) of 200°C or more, much higher than old “H” class. Good practice in the past was to grant the user safety margin between insulation performance at high temperature and required maximum hot spot temperature. Now the gap is no longer granted to user and relatively very large temperature is allowed in windings and core (less important) despite very intensive forced cooling (and associated auxiliary losses). However, even if auxiliary losses are doubled or tripled, the largest threat to efficiency and losses come from small dimensions so relatively large no load losses but mainly from increase in load losses the resistance and associated load loss at 250°C is about to triple compared to 75°C .

The temperature characteristics of resistance is explained in Annex.

HARMONIZATION WITH THE ELECTRICITY REGULATORY FRAMEWORK

The electricity liberalization directive introduced among the following elements that impact directly any regulation on transformers:

- unbundling competitive parts of the industry (e.g. supply to customers) and non-competitive parts (e.g. operation of the networks);
- introduction of independent regulators to monitor the sector and regulate non-competitive parts of the industry.

Independent regulators handle the determination of the remuneration scheme and remuneration levels for network operators. Transformers in these networks fall into the category of regulated assets, being therefore subject to the regulators' rules. Assumptions made for the Eco-design analysis should not diverge fundamentally from those applicable to the electricity regulatory schemes in practice, particularly in the following items:

- considered **price** to value losses (annual average vs hourly wholesale prices, carbon price corrections, other references for price…);
- considered **time distribution** of losses (annual average value vs hourly values – facilitated by smart electricity systems);
- **economic viability** of extra-investments for higher efficiency.

Eco-design regulations aim to set a unified approach across Europe, which could clash with the heterogeneous electricity regulation schemes around Europe (see annex). In this perspective, the Agency for the Cooperation of Energy Regulators (ACER) has implemented the "Regional Cooperation" programme, that aims to work with National Regulatory Authorities and Transmission System Operators to ensure the compatibility of regulatory frameworks within and between the regions with the aim of creating a competitive internal electricity market. ACER has created a dedicated Electricity Regional Initiative (ERI) to implement the Regional Cooperation programme. A dialogue between ACER-ERI and the Eco-design group is recommended in order to address the potential disincentives for the introduction of higher efficiency transformers.

Recommendations

An eco-design regulation on transformers would bring benefits to the society as a whole, through losses reduction in an economically efficient way. However, being the network operators in charge of extra-cost of higher efficiency equipment, it is important that the National Regulatory Authorities allow them to recover such extra-cost plus a reasonable benefit. Once this achieved, the benefits of loss savings can be transferred to consumers.

The value of losses should be cost-reflective, including environmental cost and time dependence. Wholesale electricity prices do not appear to offer the best basis for investment decisions.

In an input-based regime, the regulator may allow the cost of efficient transformers, but should take into account the expected loss reduction in the allowed cost of losses, and this for the expected life-time of the equipment.

Under an output-based scheme, the regulator should keep the allowed cost of losses high enough for a sufficiently long period of time. The allowed physical losses (loss targets) can be set on the basis of historic performance, e.g. the average of the actual loss values of a number of previous years. The historic period should be long enough to provide a stable target and avoid overweighting the actual performance in the last years. The loss targets can be automatically reset annually using the principle of moving rolling average or can be fixed for a sufficiently long predetermined period (2 or 3 regulatory periods). In this way, the benefits will be transferred gradually to customers through a continuous tightening of the loss targets over time incorporating the actual achievements in reducing losses from previous years. While allowing the network companies to recover properly the extra-investments.

For implementation of the regulation, a dialogue with regulators could be established to ensure adequate incentives for the introduction of higher efficiency transformers, while removing disincentives as well as to harmonize the approach to the cost of losses, its time dependence and the cost-benefit analysis. This could result in a guideline on regulatory incentives supporting the investment in economically optimum efficiency levels proposed as the regulation.

In smart electricity systems, benchmarking energy efficiency rapidly becomes more feasible to facilitate managing and controlling energy losses in distribution networks.

CONCLUSION

This document is presenting arguments supporting ambitious transformer efficiency regulation. In our opinion the results of preparatory study, impact assessment and interventions made by some stakeholders in the subject discussion are underestimating the value of losses in life cycle assessment and life cycle cost.

Furthermore in the largest economies like US or China the attitude seems more favorable for ambitious regulation. US stakeholders complain about not sufficiently ambitious regulations. China has regulated large power transformers efficiency. The new standards in China require utilities to carry out TOC calculations using the sale price of electricity, not wholesale cost. Further they have to take into account the scrap value at the end of life. Both of these shorten the payback period and increase benefits from owning efficient transformers.

Now we would like to indicate other values in assumptions of impact assessment which are more appropriate in our opinion.

Capacity cost :	15€/MWh increase in C_{kWh}
Load losses cost increase	40% for C_{kWh} F in factor B
Externalities	30€/MWh
Electricity price increase	50,2% increase in C_{kWh} (similar reasoning was also applied by T&D Europe but with no extra value)

Harmonics and reactive power – unspecified but significant effect on additional losses

Interest rate	2,5%
Load factor	at least 50% larger than assumed in Impact Assessment

We applied these corrections conservatively:

Lifetime (Years)		40	25	30	30	25	25	20
Electricity rate (€/kWh)	**Min**	0,0468€ - 0,075			0,035-0,55	0,075 €		0,0468€
	Base	0,0935 - 0,120			0,05 -0,10	0,15 €		0,0935€
	Max	0,1403€			0,075-0,12	0,225 €		0,1403€
Discount rate		4% - 2,5%						
Load Factor	**Min**	0,10	0,15	0,15	0,20 0,30	0,15	0,15	0,15
	Base	0,15 0,18	0,30	0,30	0,30 0,45	0,25	0,25	0,25
	Max	0,30	0,40	0,40	0,5 0,60	0,30	0,30	0,35

ANNEX I: TOTAL COST OF OWNERSHIP

The best method to perform economical analysis and comparison of energy using products is to calculate its life cycle cost sometimes called total cost of ownership over the life span.

The well known formula is:

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

where:

- PP is the purchase price of transformer,
- A represents the assigned cost of no-load losses per watt,
- P_o is the rated no-load loss,
- B is the assigned cost of load losses per watt,
- P_k is the rated load loss.

P_o and P_k are transformer rated losses.

The choice of the factors A and B is difficult since they depend on the expected loading of the transformer, which is often unknown, energy prices, which are volatile, as well as interest rate and the anticipated economic lifetime. However there are also some other factors which are usually neglected but are essential for making the most optimum selection of a transformer.

Below we introduce 2 factors which have such influence. The factor A which reflects no-load loss capitalisation is expressed by this formula:

$$A = \frac{(1+i)^n - 1}{i \cdot (1+i)^n} \times \left(C_{kWh} \times 8760 + Sc \right)$$

Factor B reflecting load loss capitalisation will be

$$B = A \times \left(\frac{I_l}{I_r} \right)^2 \times F$$

where:

i = interest rate [%/year]

n = lifetime [years]

C_{kWh} = kWh price [EUR/kWh]

8760 = number of hours in a year [h/year]

I_l = loading current [A]

I_r = rated current [A]

New factors usually neglected are

Sc = system capacity cost

F = ratio of cost of unit load losses to no-load losses

ANNEX II:CAPACITY COST

The consideration presented below are based on IEEE Loss Evaluation Guide for Power Transformers and Reactors (C57.120.91)

Annual cost of system capacity in [$/W x year] –is annual cost of generation, transmission and primary distribution capacity required to supply 1W of load to distribution transformer coincident with the peak load (does not include the cost of distribution capacity in case of the substation transformer). It reflects the cost of peaking generation, transmission and distribution capacity

This cost annually in 1992 was estimated as follows:

Generation	41,92 $/kW
Transmission	13,90 $/kW

(Assumptions: gas turbine 450$/kW, fossil fuel 1550, nuclear 2500 $/kW)

More sophisticated method would be the calculation of cost of additional generation, transmission and distribution capacity needed to compensate capacity loss caused by losses, by taking into account equipment replacement costs. It can be done with dividing replacement costs by corresponding peak loads. After that it is necessary to calculate annual capacity cost by referring this cost to annual value. Appropriate depreciation, rate of return, taxes and insurance are used. Such calculation yielded the following results based on 1981 Edison Electric Institute report:

Generation	99,59 $/kW
Transmission	23,27$/kW
Distribution	39,27 $/kW

Totally; 162,13$/kW for distribution and 122,86$/kW for transmission

Additionally it is necessary to multiply these values with so called peak responsibility factor which is intended to compensate for the transformer peak load losses not occurring at the system peak losses. This means that only a fraction of the peak transformer losses will contribute to the system peak demand. This value can be determined from the ratio of transformer load at time of system peak to transformer peak load

It should be pointed out that peak responsibility factor is squared as losses are proportional to the load squared. The following are recommended values (RUS Bulletin 1724E-301 : Guide for the Evaluation of Large Power Transformer Losses UNITED STATES DEPARTMENT OF AGRICULTURE)

Transformer Type	K	K^2
Transmission substation	0.9	0.81
Distribution substation	0.8	0.64

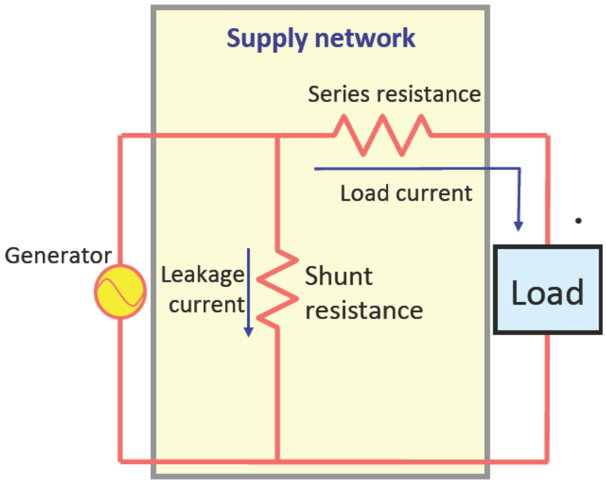
To make these values comparable to pure price of electrical energy they need to be multiplied by K square and divided by 8,760 to express monetary value per MWh. This would yield the following values:

Transmission transformer: 11,37$/MWh

Distribution transformer: 11,84$/MWh

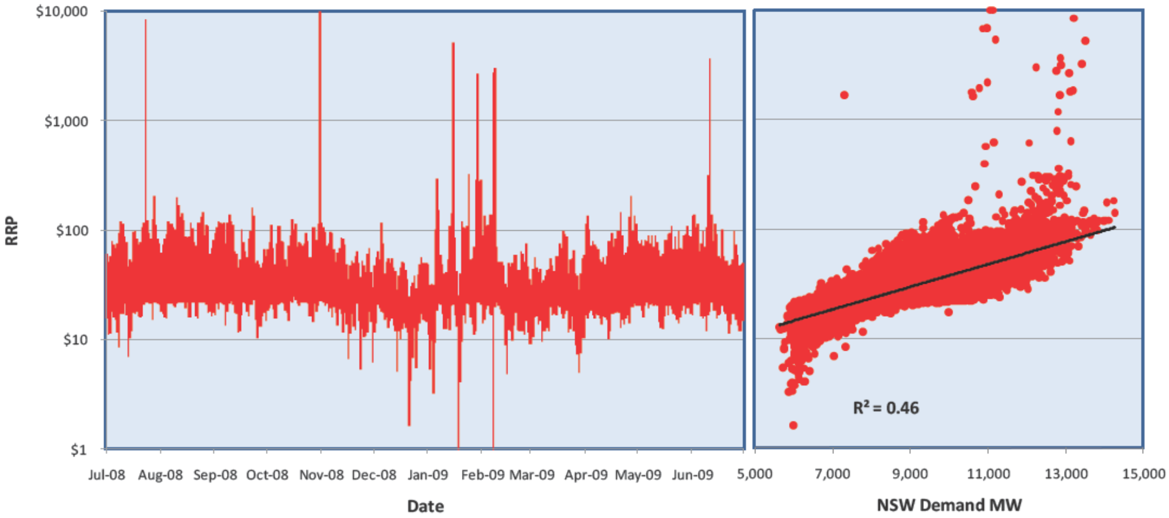
ANNEX III:AUSTRALIAN ANALYSIS ON DIFFERENTIATION OF LOAD AND NO LOAD LOSSES

In 2011 the study titled “The cost of losses for future network investment in the new networks regime” was commissioned by Harry Colebourn from Energeia Pty Ltd. In this report the author analysed average loss costs by voltage level and specifically for the NSW Region of the Australian National Energy Market (NEM). However, it provides a clear indication that a significant change in the cost of losses now needs to be factored into investment analysis more universally.
First of all the differentiation in losses was proposed:

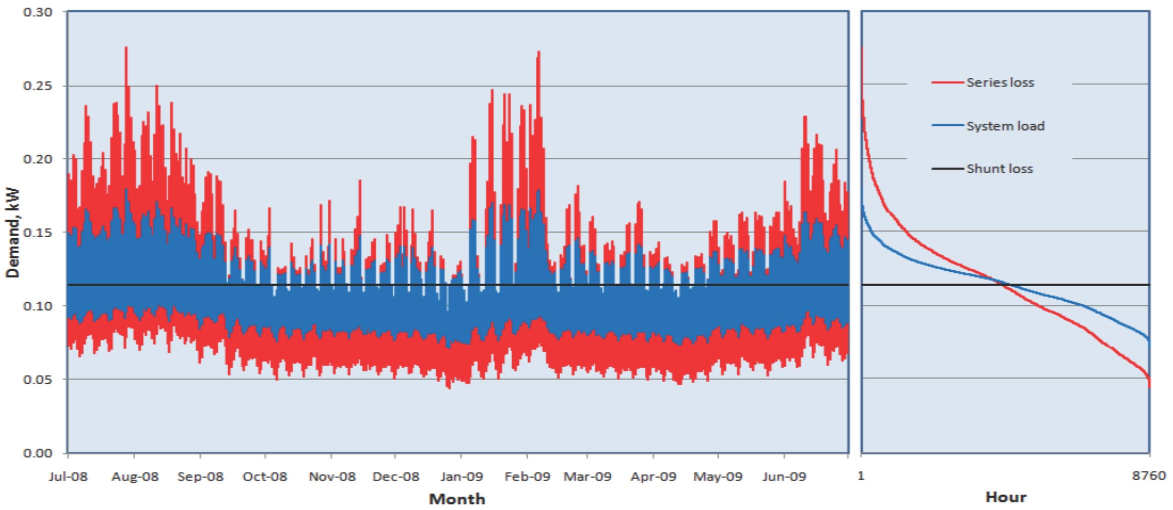


No-load (shunt) losses occur all the time and are relatively constant. They occur due to unavoidable leakage within electrical equipment like transformers, capacitors and meters. Load (series) losses occur due to the delivery of energy through the network. They vary approximately with the square of the loading. Series losses occur due to the electrical resistance in components of the network like lines and transformers

The regional reference price RRP is largely differentiated as presented below:



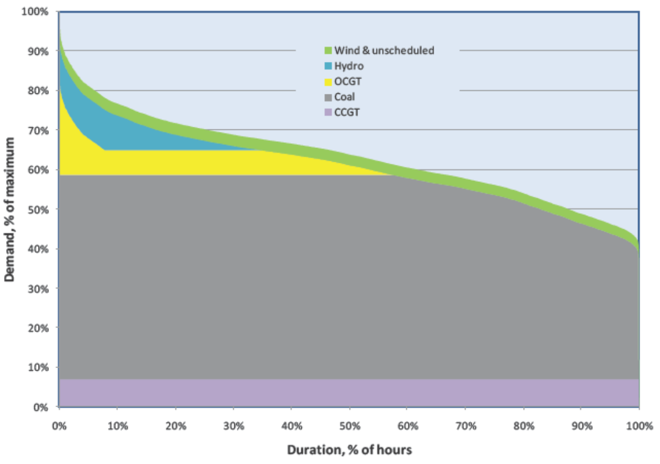
The load loss has largely “peaky” character



Open cycle gas turbines which are operated almost exclusively at peak time are much more expensive

Generation pattern assumes generation is operated to minimise overall costs

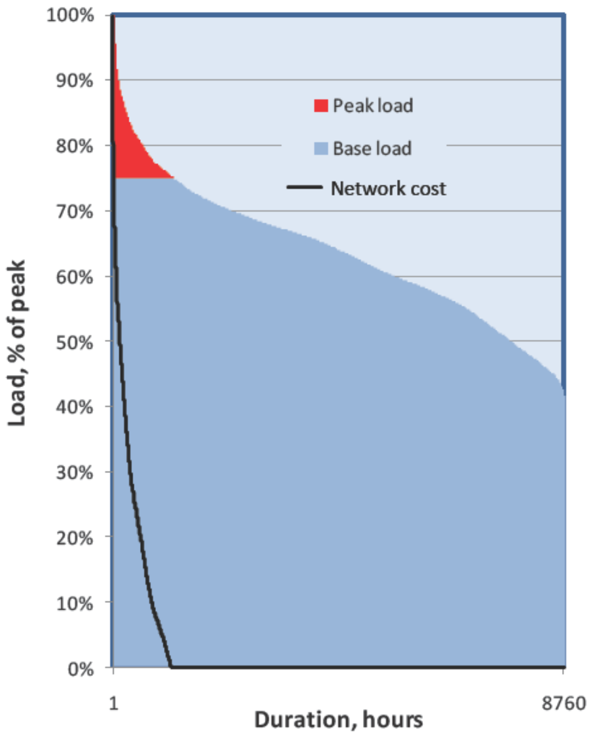
Generation type	LRMC excl. CPRS $/MWh	 incl. CPRS $/MWh
Wind & unscheduled	$ 114	$ 114
OCGT	$ 162	$ 190
Coal	$ 60	$ 81
CCGT	$ 60	$ 77



Network capacity is required to meet peak period loads. The LRMC (long run marginal cost) of network capacity is around 80% of average network charges.

Capacity cost allocation is to the peak 30% of the load

Capacity cost allocation is dependent upon the load profile.



In his analysis the author proposes sophisticated model of loss allocation in which he proves that that system load (series) losses are much higher than no-load (shunt) losses.

ANNEX IV: EXTERNAL COST OF ELECTRICITY

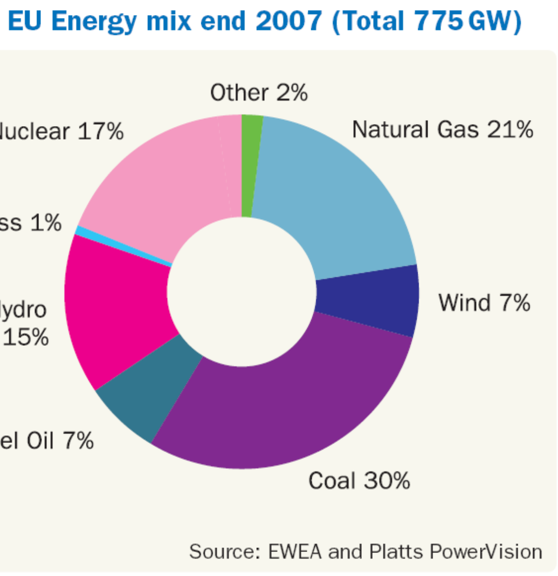
European Commission performed the study EUR 20198 on External Costs - Research results on socio-environmental damages due to electricity and transport.

External cost figures for electricity production in the EU for existing technologies (in € cent per kWh)

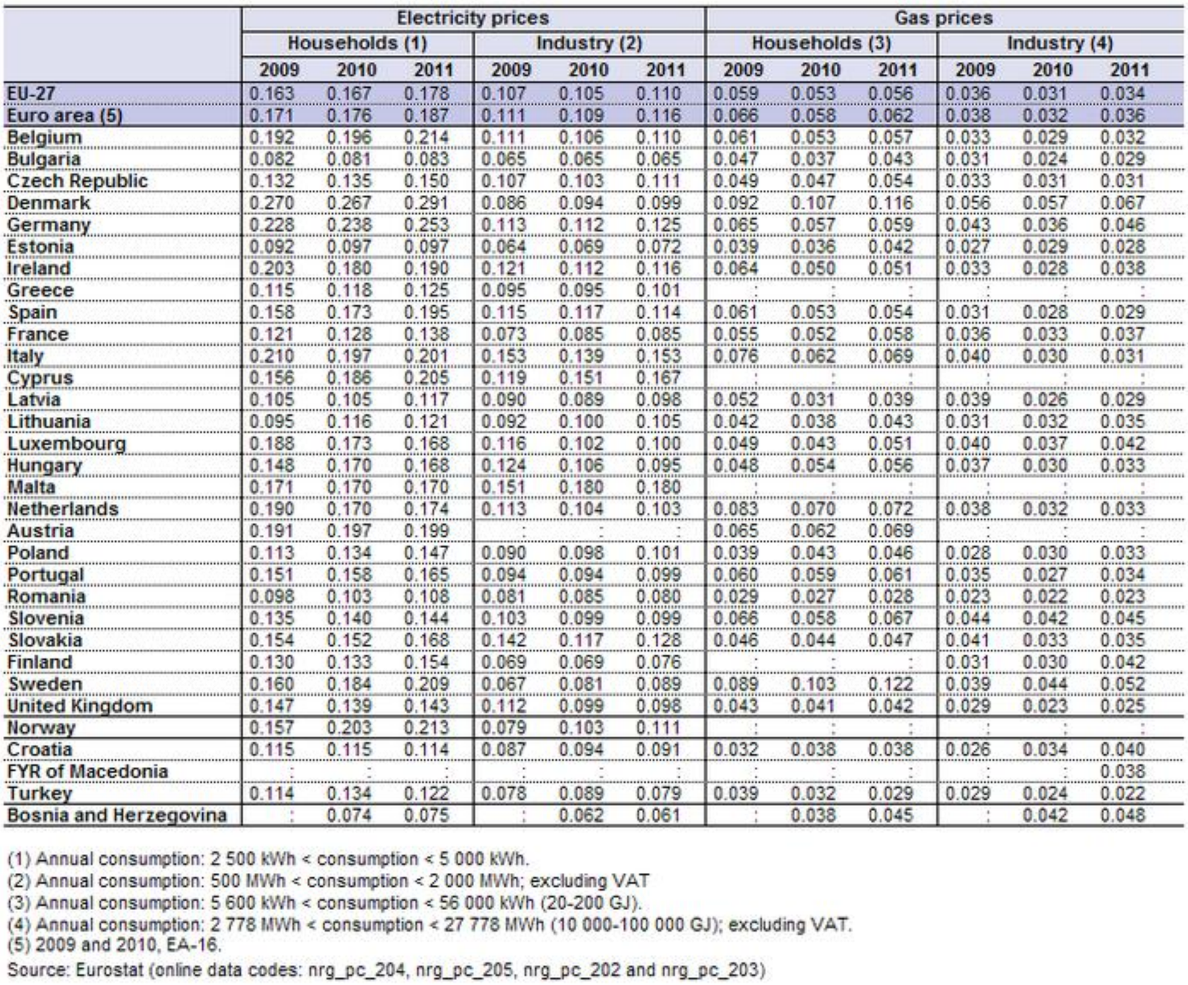
Country	Coal & lignite	Peat	Oil	Gas	Nuclear	Biomass	Hydro	PV	Wind
AT				1-3		2-3	0.1		
BE	4-15			1-2	0.5				
DE	3-6		5-8	1-2	0.2	3		0.6	0.05
DK	4-7			2-3		1			0.1
ES	5-8			1-2		3-5**			0.2
FI	2-4	2-5				1			
FR	7-10		8-11	2-4	0.3	1	1		
GR	5-8		3-5	1		0-0.8	1		0.25
IE	6-8	3-4							
IT			3-6	2-3			0.3		
NL	3-4			1-2	0.7	0.5			
NO				1-2		0.2	0.2		0-0.25
PT	4-7			1-2		1-2	0.03		
SE	2-4					0.3	0-0.7		
UK	4-7		3-5	1-2	0.25	1			0.15

** sub-total of quantifiable externalities (such as global warming, public health, occupational health, material damage)*
*** biomass co-fired with lignites*

The electrical energy mix in Europe in 2007



With the average value for coal of 7 € cent per kWh, oil 5€ cent per kWh and gas 2€ cent per kWh the approximate value for EU electricity mix will be around 3€ cent per kWh i.e. ***30 €/ MWh***



	Electricity prices						Gas prices					
	Households (1)			Industry (2)			Households (3)			Industry (4)		
	2009	2010	2011	2009	2010	2011	2009	2010	2011	2009	2010	2011
EU-27	0.163	0.167	0.178	0.107	0.105	0.110	0.059	0.053	0.056	0.036	0.031	0.034
Euro area (5)	0.171	0.176	0.187	0.111	0.109	0.116	0.066	0.058	0.062	0.038	0.032	0.036
Belgium	0.192	0.196	0.214	0.111	0.106	0.110	0.061	0.053	0.057	0.033	0.029	0.032
Bulgaria	0.082	0.081	0.083	0.065	0.065	0.065	0.047	0.037	0.043	0.031	0.024	0.029
Czech Republic	0.132	0.135	0.150	0.107	0.103	0.111	0.049	0.047	0.054	0.033	0.031	0.031
Denmark	0.270	0.267	0.291	0.086	0.094	0.099	0.092	0.107	0.116	0.056	0.057	0.067
Germany	0.228	0.238	0.253	0.113	0.112	0.125	0.065	0.057	0.059	0.043	0.036	0.046
Estonia	0.092	0.097	0.097	0.064	0.069	0.072	0.039	0.036	0.042	0.027	0.029	0.028
Ireland	0.203	0.180	0.190	0.121	0.112	0.116	0.064	0.050	0.051	0.033	0.028	0.038
Greece	0.115	0.118	0.125	0.095	0.095	0.101	:	:	:	:	:	:
Spain	0.158	0.173	0.195	0.115	0.117	0.114	0.061	0.053	0.054	0.031	0.028	0.029
France	0.121	0.128	0.138	0.073	0.085	0.085	0.055	0.052	0.058	0.036	0.033	0.037
Italy	0.210	0.197	0.201	0.153	0.139	0.153	0.076	0.062	0.069	0.040	0.030	0.031
Cyprus	0.156	0.186	0.205	0.119	0.151	0.167	:	:	:	:	:	:
Latvia	0.105	0.105	0.117	0.090	0.089	0.098	0.052	0.031	0.039	0.039	0.026	0.029
Lithuania	0.095	0.116	0.121	0.092	0.100	0.105	0.042	0.038	0.043	0.031	0.032	0.035
Luxembourg	0.188	0.173	0.168	0.116	0.102	0.100	0.049	0.043	0.051	0.040	0.037	0.042
Hungary	0.148	0.170	0.168	0.124	0.106	0.095	0.048	0.054	0.056	0.037	0.030	0.033
Malta	0.171	0.170	0.170	0.151	0.180	0.180	:	:	:	:	:	:
Netherlands	0.190	0.170	0.174	0.113	0.104	0.103	0.083	0.070	0.072	0.038	0.032	0.033
Austria	0.191	0.197	0.199	:	:	:	0.065	0.062	0.069	:	:	:
Poland	0.113	0.134	0.147	0.090	0.098	0.101	0.039	0.043	0.046	0.028	0.030	0.033
Portugal	0.151	0.158	0.165	0.094	0.094	0.099	0.060	0.059	0.061	0.035	0.027	0.034
Romania	0.098	0.103	0.108	0.081	0.085	0.080	0.029	0.027	0.028	0.023	0.022	0.023
Slovenia	0.135	0.140	0.144	0.103	0.099	0.099	0.066	0.058	0.067	0.044	0.042	0.045
Slovakia	0.154	0.152	0.168	0.142	0.117	0.128	0.046	0.044	0.047	0.041	0.033	0.035
Finland	0.130	0.133	0.154	0.069	0.069	0.076	:	:	:	0.031	0.030	0.042
Sweden	0.160	0.184	0.209	0.067	0.081	0.089	0.089	0.103	0.122	0.039	0.044	0.052
United Kingdom	0.147	0.139	0.143	0.112	0.099	0.098	0.043	0.041	0.042	0.029	0.023	0.025
Norway	0.157	0.203	0.213	0.079	0.103	0.111	:	:	:	:	:	:
Croatia	0.115	0.115	0.114	0.087	0.094	0.091	0.032	0.038	0.038	0.026	0.034	0.040
FYR of Macedonia	:	:	:	:	:	:	:	:	:	:	:	0.038
Turkey	0.114	0.134	0.122	0.078	0.089	0.079	0.039	0.032	0.029	0.029	0.024	0.022
Bosnia and Herzegovina	:	0.074	0.075	:	0.062	0.061	:	0.038	0.045	:	0.042	0.048

(1) Annual consumption: 2 500 kWh < consumption < 5 000 kWh.
(2) Annual consumption: 500 MWh < consumption < 2 000 MWh; excluding VAT
(3) Annual consumption: 5 600 kWh < consumption < 56 000 kWh (20-200 GJ).
(4) Annual consumption: 2 778 MWh < consumption < 27 778 MWh (10 000-100 000 GJ); excluding VAT.
(5) 2009 and 2010, EA-16.

Source: Eurostat (online data codes: nrg_pc_204, nrg_pc_205, nrg_pc_202 and nrg_pc_203)

Electricity prices in Europe in years 2009-2011

ANNEX V: EFFECT OF HARMONICS AND REACTIVE POWER ON TRANSFORMER EFFICIENCY

In the presence of non linear loads which are prevailing now, any transformer experiences additional losses. These losses occur predominantly in windings and are related to current distortion but may also be present in transformer core and are related to voltage distortion. The precise calculation of these losses is impossible as the level of distortion and its spectrum is largely unknown. However is some transformers, particularly industrial, they can be as large as double of nominal losses. SEEDT calculated that additional losses in distribution transformers in Europe are in the range of 2-3 TWh. By using energy efficient transformers some fraction of these losses can be reduced.

Another factor influencing transformer efficiency is running it with reactive power flowing in transformer. The reactive power decreases nominal capacity of the T&D system but has also another adverse effect on losses. Beside power loss in transformer itself, an additional power loss in electricity network is generated due to flow of reactive power consumption (loss) in a transformer. After transformer switching, electric energy is taken from the network, and the no-load current starts to flow. The current consists of two components:

Reactive component necessary to excite magnetic flux in the transformer core.

Active component consumed by losses caused by hysteresis, eddy currents and additional losses due to irregularity of magnetic field distribution, inhomogeneity of core sheet structure, not perfect sheet insulation, variations of magnetization direction etc.)

Additional losses in electricity network supplying the transformer from the no-load current are significant enough that they should not be totally neglected. To estimate these additional losses we should know the network resistance (which is not easy in real life for AC flows). Determination of network resistance between the source of energy (power station), and the transformer is very difficult, practically impossible. Therefore the concept of energy equivalent coefficient of reactive power was introduced. This coefficient indicates how many of kW active power losses are generated in the network when 1 kVar of reactive power is taken from this network. This value is often assumed at 0,1 kW/kVar what means that every 1 kVar of reactive power generates in the network 0,1 kW of the active power loss. As reactive component of no-load current is quite significant the associated losses are significant as well. The influence of reactive component (reactance) of short-circuit voltage is lower and thus effect from no load operation is much lower.

This aspect was analysed in Supertrafo project when 4 transformers were monitored for 4 years. In extreme cases with high coefficient of active losses caused by reactive power when reactive power is not effectively compensated and no load current is high and having steep characteristics against supply voltage the network losses may even double.

Modern transformers with low values of no load current (and no load losses) can effectively limit this effect but not entirely.

ANNEX VI: DEPENDENCE OF ELECTRICAL RESISTANCE ON TEMPERATURE

In normal electrical applications, the resistance of a copper conductor can be calculated by the following formula, which is valid up to about 200 °C:

$R=R_{20}(1+\alpha_{20}\Delta T)$

where:

R20 is the conductor resistance at temperature of 20 °C, in Ω

α_{20} is the temperature coefficient of resistance at 20 °C, per K. = 0.0039 for copper.

ΔT = Tk –20 is the temperature difference, in degrees K

Tk is the final temperature, in K.

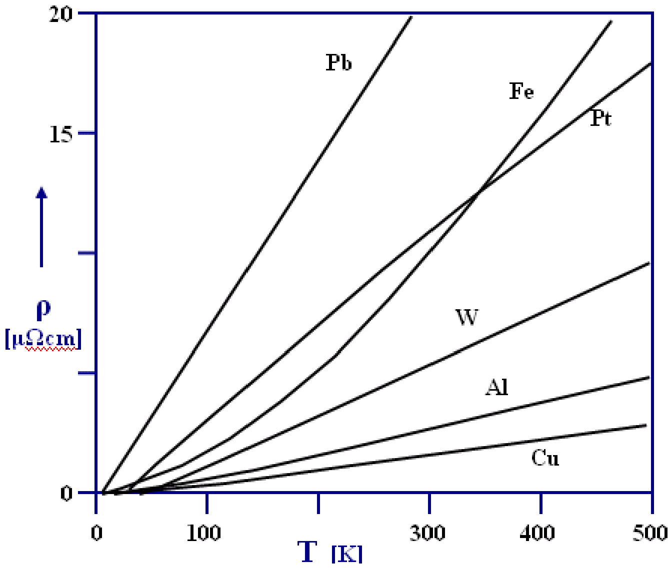
At temperatures higher than +200 °C, the relation describing the conductor's resistance becomes non-linear and is given by the formula:

$R=R20\ (1+\alpha\ 20\ \Delta T+\beta_{20}\ \Delta T^2)$

where:

$\beta_{20} = 6.0 \times 10^{-7}\ K^{-2}$

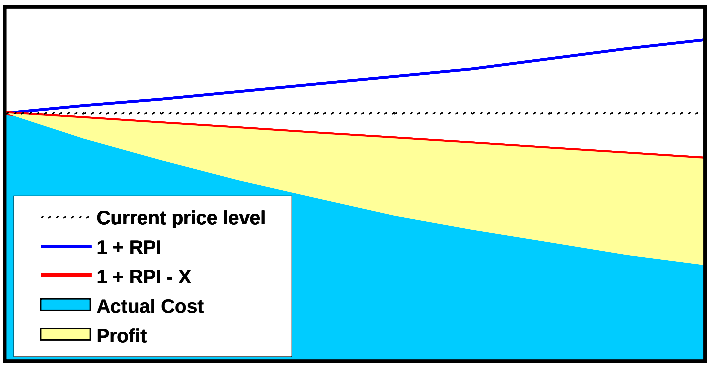
Below is the chart describing this relation between temperature and resistance (directly proportional to load losses I^2R



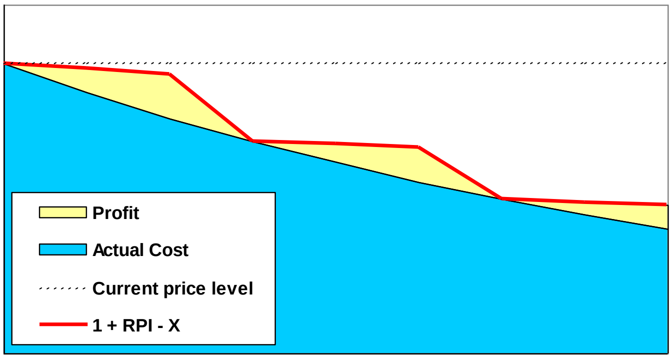
As consequence the resistance and associated load loss at 250°C is about to triple compared to 75°C .

REGULATORY FRAMEWORKS FOR ELECTRICITY IN THE EU

Most European regulators apply incentive regulation, i.e. price or revenue cap. This scheme decouples the profits of the regulated operator from its costs by setting a price ceiling. For each regulatory period, normally between three to five years, the price cap for each year is set based on the Retail Price Index (RPI, a measure of inflation) and an efficiency factor (X). Since prices remain fixed during the period, the utility keeps or shares the achieved cost savings.



At the end of the regulatory period, a new path is set for the next three to five years.



It is important to allow sufficient time to network operators to recover profits derived from extra-investments for efficiency. Giving enough time allows network operator to make decisions in terms of lowest life cycle cost instead of lowest investment cost.

An alternative way for regulator is to compensate upfront the extra-investments for efficiency. In this case the benefits of reduced losses can then be directly transferred to consumers (price trajectory can then be lowered).

Addressing extra-investments for efficiency

As introduced here above, there are two main schemes:

- **Output based schemes**
    - Network operators are encouraged to reduce losses by incentives placed on a recorded reduction in their loss rate relative to a target. Such a scheme can be viewed as internalizing the benefits for the network operators of reducing their losses and often involves giving a benefit per unit that losses are reduced.
    - This scheme leaves the network operators to develop and decide on ways to reduce losses, making it likely that loss reductions will be achieved at minimum cost. However, as presented in the previous chapters, increasing the efficiency of transformers makes

    economic sense. Harmonizing efficiency levels rather than the current variation in specification, could be cost efficient, in particular for distribution transformers.
    - Revision of target losses and incentives by regulator should be adjusted to allow at least the recovery of extra-investments. Otherwise, network operator would opt for the lower investment cost equipment.

- **Input based schemes**
    - The incentive for network operators to reduce losses is placed on inputs rather than outputs. For example, by estimating the contribution to loss reduction from a particular piece of equipment compared to the one most commonly installed, operators could be given this sum upfront to encourage the installation of such equipment. All the benefits from reductions in losses are provided in the same year as the equipment is installed.
    - A regulation on efficiency for transformers would lead to extra-costs faced by the network operators, that could be recognized by the regulator and compensated upfront.

Great Britain combines input and output schemes. The current distribution price control (April 2010 to March 2015) includes an incentive mechanism to reduce losses. Target losses are set by the regulator Ofgem as a fixed loss percentage for each distribution company. The percentage is determined based on an average of performance over the last five years. The price of losses is set by Ofgem (£60/MWh pre-tax, 2010-11 prices) on the basis of the wholesale price of electricity less the EU Emissions Trading Scheme (ETS) cost of carbon plus the shadow price of carbon (as set by the Department for Environment, Food and Rural Affairs). There is cap and collar on the total incentive amount, i.e. companies are not allowed to earn or lose more than 97 basic points (pre-tax) in shareholder returns through the losses incentive. In addition, companies are provided with a pre-determined amount of upfront funding (£16m in the current price control) for low loss investments where they have made a business case using the electricity wholesale price including the Government's shadow price of carbon. This should allow DNOs to finance these investments while ensuring that customers only pay for schemes that have a robust investment case.

Portugal uses an input scheme. An incentive mechanism to reduce network losses in the distribution networks allows the network company to be rewarded / penalized if it has achieved actual distribution losses lower than / above a target value set by the regulator for each year