Energy-efficient distribution transformers in industry and commerce

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Keywords

energy efficiency, distribution transformers, amorphous transformers, energy saving potentials, distribution losses, loss reduction, policy-mix, industry, commerce, eco-design, mandatory standard, labelling, LCC calculation

Abstract

There are about 950,000 distribution transformers in Europe's industry and commerce, of which about 780,000 are liquid-filled and 170,000 dry-type transformers. They convert electrical energy supplied at medium voltage level to electrical energy at voltage levels needed in the firms. The distribution transformer fleet in industry and commerce is still dominated by traditional technology, averaging an operating efficiency in Europe of 98.15% (liquid-filled) and 98.40% (dry-type), with totalling electricity losses equal to 11.4 TWh/year in EU-27 in 2004. If all existing distribution transformers in Europe's industry and commerce were replaced by the most energy-efficient ones available today, 51.9% of these electricity losses could be reduced. If current replacement rates and expected economic developments are taken into account, up to 6.1 TWh electricity per year could be saved compared to BAU market behaviour within 15 years. A large part of these electricity saving potentials is economical from the perspective of the whole economy and from the perspective of industry and commerce.

The paper presents a comprehensive and detailed analysis of the technical and economic energy efficiency potentials of distribution transformers in industry and commerce in the EU-27. Based on this, strategies, policies and measures on European, national and company level are presented that can support the realisation of energy saving potentials (e.g. mandatory standards, information and training, labelling, and a calculation tool). The findings result from a recent study within the "Intelligent Energy Europe" programme of the European Commission.

Introduction

Energy losses of distribution transformers account for almost about one third of overall transmission and distribution losses in Europe. While research and policies and measures in the past have focused energy saving potentials in conversion of primary energy to final energy and in energy end-use, the loss reduction potentials in the transmission and distribution sector have been widely neglected so far. However, with increasing decentralised generation, expected large changes in grid infrastructures, and still increasing demand for electricity in several countries, this issue becomes even more relevant. In particular, with the electricity system developing towards "smart grids", the question arises if and how in such an integrated system distribution grid losses could be minimised.

In autumn 2008, the European Commission has commissioned a preparatory study on distribution and power transformers within the framework of the EcoDesign directive (Directive 2005/32/EC of the European Parliament and of the Council Establishing a Framework for the Setting of EcoDesign Requirements for Energy-Using Products and Amending Council Directive 92/42/EEC and Directives 97/57/EC and 2000/55/EC of the European Parliament and of the Council). The study will prepare the ground for implementing measures on European level, e.g. for a mandatory energy efficiency standard for transformers available on the Community market.

This paper will show that energy saving potentials of distribution transformers in industry and commerce in Europe are substantial and largely economical. The findings result from the European study "Strategies for development and diffusion of energy-efficient distribution transformers (SEEDT)", completed in summer 2008 and co-ordinated by the National Technical University of Athens (NTUA) in the framework of the Intelligent Energy Europe programme of the European Commission (Project no. EIE/05/056/SI2.419632). While this study analysed energy efficiency of distribution transformers in all sectors, this paper concentrates on industry and commerce only. For the energy saving potentials of distribution transformers of electricity distribution companies, which are substantial and economical, too, the readers are referred to the papers of the SEEDT project mentioned in the references (cf. also http://seedt.ntua.gr).

The following chapter will give an overview on the distribution transformer fleet and market, market conditions and barriers towards energy efficiency in industry and commerce in the EU-27.

Then, technical solutions to improve energy efficiency of distribution transformers will be presented. A particular focus will be laid on transformers using cores of amorphous steel.

Applying these technical solutions will result in substantial EU-wide technical and economic energy saving potentials which will be summarised afterwards.

In other regions and countries outside Europe, the realisation of these potentials to reduce transformer losses is fostered by mandatory energy efficiency standards, which will be described within an additional chapter.

Finally, based on the analysis of the market, the available technical solutions, and the example of mandatory energy efficiency standards outside Europe, policies and measures for the European level and the national Member States will be proposed that foster the realisation of loss reduction potentials in the EU-27.

The paper concludes with an outlook on further research and monitoring needs.

European transformer fleet and market

Distribution transformers are devices which transform electrical energy supplied at medium voltage level (typically from 10 kV to maximum 36 kV) to electrical energy at voltage levels most appropriate for residential, commercial and partly industrial loads. The European electricity distribution networks include about 4.5 million distribution transformers (cf. Targosz/Topalis/et al. 2008 for this and the following numbers). There are about 950,000 of these units in Europe's industry and commerce, of which about 780,000 are liquid-filled and 170,000 dry-type transformers mainly used for specific applications in industry (Table 1). On average, in recent years, about 137,000 distribution transformers have been sold annually in Europe, of which about 52,000 have been sold to industry and commerce. In industry and commerce, rated power of distribution transformers is in a range between 50 and 2,500 kVA, with an average size of liquid-filled transformers of about 410 kVA and of dry-type ones of about 830 kVA (Figure 1). It should be noted that these and the following numbers have been collected within the SEEDT project on the basis of different materials, interviews with manufacturers and transformer users, associations and energy agencies, as well as available public and grey literature. However, since there are no official statistics which contain this data, some uncertainty remains, and some figures had to be estimated, because data for some countries and particularly for the industry and commerce sector was rather poor. Nevertheless, this data basis might still be the best publicly available one.

The European distribution transformer fleet and market is still dominated by traditional technology, averaging an operating efficiency in Europe's industry and commerce of 98.15% (liquid-filled) and 98.40% (dry-type) in transformer population, and 98.77% (liquid-filled) and 98.40% (dry-type) in transformer market. However, in practice efficiency of transformers differs very much depending on the framework conditions and purchasing routines in the respective country and of the respective market actor, and particularly on the transformer's age. New transformers are either purchased to replace old ones, because of increased demand for electricity, or to connect distributed generation.

Total electricity losses of distribution transformers in industry and commerce in EU-27 in 2004 summed up to 11.4 TWh/year, of which about 7.5 TWh/year are total losses of liquid-filled transformers (Targosz/Topalis/et al. 2008). Energy losses of distribution transformers can be mainly divided into non-load losses, which probably account for about 63% of total losses, and load losses, which sum up to about 24% of total losses. Furthermore, there are additional losses (harmonic losses, reactive power losses), which have the lower share in total losses (about 13%), and can hardly be addressed by specific policies and measures. The tables of the European norms (e.g. the EN 50464-1 of 2007) categorising transformers according to their losses also differentiate between non-load and load losses, only. For the design of policies and measures it is important to know that the share of non-load, load and additional losses in total losses of distribution transformers differs depending on the type of transformer and its application in practice, i.e. on the specific load profile, which is hardly well-known. This in turn leads to the conclusion that any attempt to reduce losses has to address all loss types. Otherwise, concentrating on one part of the losses only could lead to sub-optimal solutions.

Technical solutions to improve energy efficiency

The principal technical options to reduce losses of single transformers are the following:

- Applying improved cold rolled grain oriented (CGO) steel, with improved cutting technology, and decreased lamination thickness, with CGO sheets minimum thickness of 0.23 mm (or even 0.18 mm; however, the 0.18 mm thickness shown in Figure 2 has not proved to be economically feasible in production yet)
- Optimisation of (aluminium or copper) windings
- Optimisation of core design
- Change from CGO steel technologies (with a crystalline atomic structure) to distribution transformers with amorphous cores (AMDT) (with a non-crystalline, anisotropic

Table 1: European distribution transformer population and market sales in 2004

Transformer type and size		Fleet EU-25		Market EU-25	
		pcs	MVA	pcs	MVA
Electricity distribution companies liquid-filled*	< 400 kVA	2,639,129	307,230	55,099	6,886
	≥ 400 kVA & ≤ 630 kVA	845,107	432,793	22,944	12,129
	> 630 kVA	125,047	153,891	5,884	7,823
	Subtotal	3,609,283	893,913	83,927	26,837
Commerce and industry liquid-filled	< 400 kVA	480,596	64,540	22,887	3,062
	≥ 400 kVA & ≤ 630 kVA	176,119	88,119	8,237	4,140
	> 630 kVA	124,164	168,295	5,893	7,847
	Subtotal	780,879	320,954	37,017	15,049
(Commerce and) Industry dry-type	< 400 kVA	38,416	12,419	2,559	519
	≥ 400 kVA & ≤ 630 kVA	67,084	39,906	5,333	2,863
	> 630 kVA	63,968	87,817	7,818	10,718
	Subtotal	169,468	140,142	15,710	14,100
Total		4,559,630	1,355,010	136,654	55,985

* Dry-type transformer population in electricity distribution companies is estimated at marginally low level (~1% of electricity distribution companies' fleet)
Source: Targosz/Topalis/et al. 2008

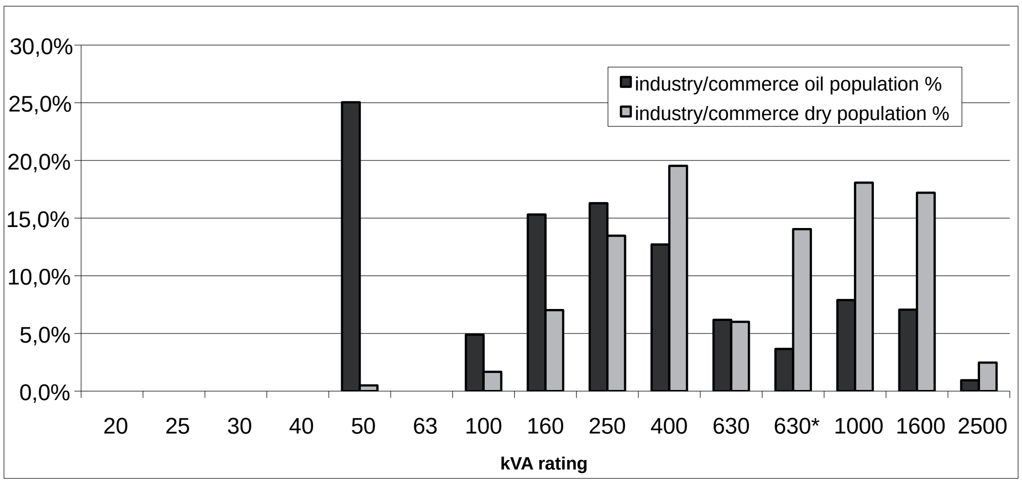

Figure 1: Distribution of ratings of European distribution transformer population in industry and commerce in 2004, with differentiation between liquid-filled and dry-type distribution transformers. Source: Targosz/Topalis/et al. 2008

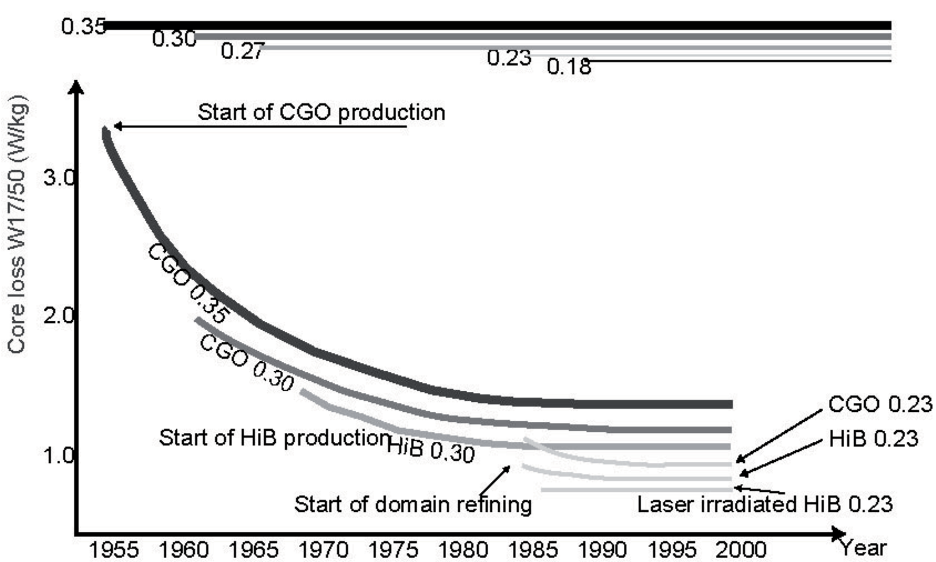

Figure 2: Core loss evolution 1955-2000: Production technology and possible thickness. Source: Targosz/Topalis/et al. 2008

atomic structure) (cf. Frau/Gutierrez 2007 for a comparison of both technologies)

- Using superconducting technology.

These options are only partly applied in European practice yet. While the application of superconducting technology to distribution transformers does not seem to be economically feasible at the moment and its introduction into the European market seems to be far off, the use of the other options could be increased.

Amorphous transformers are working very well abroad Europe (mainly in Asia), but have not found their way into the European market. The energy company ENDESA in Spain is working on this matter. In 2007, ENDESA performed several economic and technical analyses with manufacturers from Asia. In January 2008, ENDESA started an innovative pilot project in Europe, with 20 units of amorphous core transformers (400 kVA) that lead to a reduction of more than 50% of no-load losses compared to the most efficient transformer standardized in Europe (Ao according to EN 50.464-1). With each unit, ENDESA saves 5.5 MWh electricity per year. After 6 months of monitoring these AMDT units in different market environments (urban, rural, and tourism areas), ENDESA is planning to expand the pilot project to South-America in 5 countries (Brasil, Chile, Argentina, Colombia, Perú) installing AMDT transformers.

Another possibility to reduce losses is on the system level by reducing redundancies within the grid system (i.e. reducing the number of transformers in the grid and increasing capacity utilisation of remaining transformers like it is done by some electricity distribution companies in Germany). However, this option might not be feasible for most of industrial and commercial companies.

Technical and economic energy saving potentials

If all existing distribution transformers in Europe's industry and commerce were replaced at once by the most energy-efficient ones available today, 51.9% of these electricity losses could be reduced (about 31.3% of dry-type transformer losses, 61.8% of liquid-filled ones) (Figure 3). However, of course, this is not a feasible solution. If current replacement rates and expected economic developments are taken into account, up to 6.1 TWh electricity per year could be saved compared to BAU market behaviour within 15 years (Table 2).

Table 2 presents the loss reductions and economic impacts on industry and commerce of four different energy efficiency scenarios for the period 2010-2025, assuming that the electricity system will develop according to the European PRIMES Trends scenario. The four energy efficiency scenarios assume that every time a distribution transformer in industry or commerce is purchased, an energy-efficient one is bought. The four scenarios differ with regard to the energy efficiency of the new transformers bought:

- **Energy efficiency scenario 1:** This is a **"market leader" scenario**, where quite energy-efficient technology already purchased today is assumed to be widely implemented. In this scenario, liquid-filled transformers are replaced by transformers with category AoBk as defined in the norm EN 50464-1, and dry-type transformers are implemented according to the norm HD 538. In the norm EN 50464-1, 'o' relates to no-load losses and 'k' to load-losses, and A, B, etc., refer to different energy efficiency levels, with 'A' being the most efficient one.

- **Energy efficiency scenario 2:** This scenario assumes that the **best conventional technology available today** is widely implemented. In this scenario, liquid-filled transformers are replaced by transformers with category AoAk as defined in the norm EN 50464-1, and dry-type transformers are implemented with losses 10% below HD 538.

- **Energy efficiency scenario 3:** This scenario **focuses on the decrease in non-load losses by applying best-available non-conventional technology**. In this scenario, liquid-filled transformers are replaced by transformers that have 50% lower non-losses than Ak and 10% higher load losses than Bk, and dry-type transformers are implemented with losses 20% below HD 538.

- **Energy efficiency scenario 4:** This scenario assumes that **best available non-conventional technology to reduce load losses and extremely efficient technology to reduce non-load losses** is used every time a transformer is purchased. In this scenario, liquid-filled transformers are replaced by transformers that have 50% lower non-losses than Ak and load-losses category Bk, and dry-type transformers are implemented with 10% lower load losses and 40% lower non-load losses compared to HD 538.

From the perspective of the whole economy or society, and according to assumptions on prices, costs and discount rates set in the SEEDT project (cf. Rialhe et al. 2008), a large part of the electricity savings potentials is economical. However, sensitivity analysis shows that this result strongly depends on the development of prices for energy-efficient transformers and electricity in the future, and on load-factors assumed and transformer lifetime assumed. The transformer prices, in turn, are strongly influenced by world market price development for steel, aluminium and copper. Furthermore, the discount rate chosen for the calculations has an important influence on the economics of distribution transformers due to their long lifetime.

In particular and as Table 2 shows, the economic results strongly differ between dry-type transformers and liquid-filled ones in industry and commerce. While only energy efficiency scenario 2 is economical for dry-type transformers from the perspective of industrial or commercial customers and will lead to net cost savings for these sectors of 9 Mio. Euro per year, all energy efficiency scenarios for liquid-filled transformers are economical with the price and cost assumptions made. With energy efficiency scenario 4, net cost savings of more than 200 Mio. Euro per year could be achieved in 2025 by the use of energy-efficient liquid-filled transformers in industry and commerce from 2010 onwards.

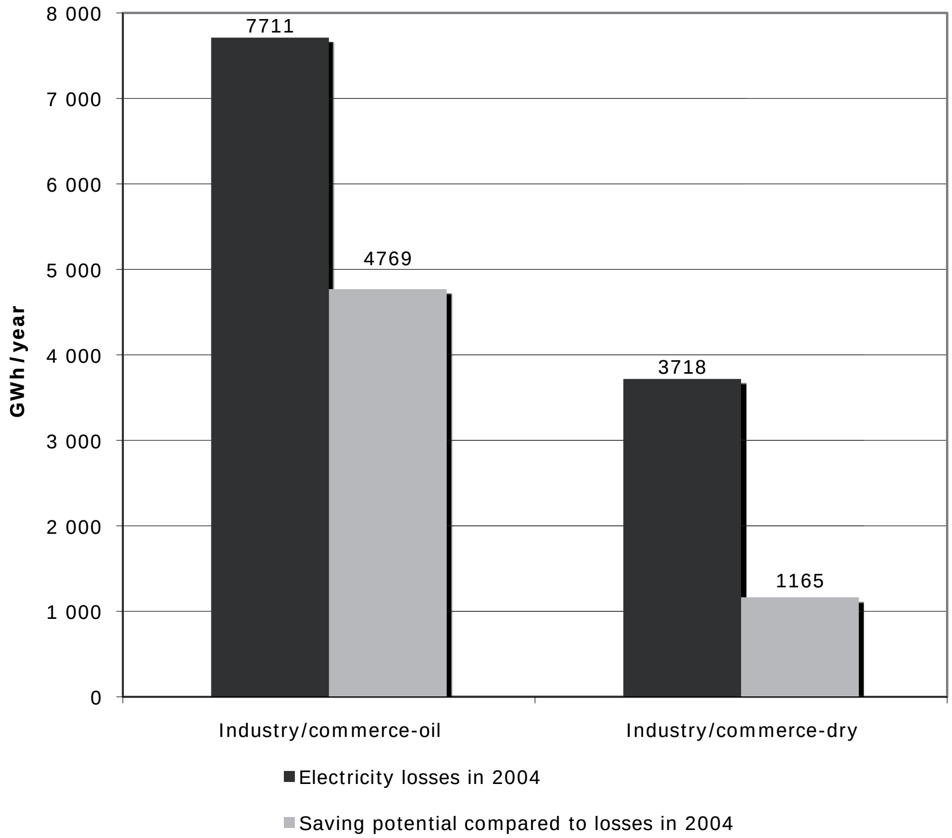

Figure 3: Electricity losses of distribution transformers in 2004 and total static loss reduction potential Source: Rialhe et al. 2008

Table 2: Electricity saving potentials and net cost impacts of different energy efficiency scenarios for distribution transformers in industry and commerce in EU-27 in 2025 for PRIMES trend development of the electricity system

General development of electricity system	**Energy efficiency scenario 1** oil: AoBk / dry: HD 538	**Energy efficiency scenario 2** oil: AoAk / dry: HD538 LL ./. 10%, NLL ./. 10%	**Energy efficiency scenario 3** oil: Ao-50% Bk+10% / dry: HD538 LL ./. 20%, NLL ./. 20%	**Energy efficiency scenario 4** oil: Ao-50% Bk dry: HD538 LL ./. 10%, NLL ./. 40%
Liquid-filled transformers in industry and commerce				
Electricity savings potential [TWh/year]				
PRIMES Trends	3.0	3.2	4.0	4.1
Additional costs (negative values) or cost savings (positive values) of realising the electricity saving potential from the perspective of industry and commerce (8% real discount rate) [Mio. Euro]				
PRIMES Trends	193	137	199	203
Dry-type transformers in industry and commerce				
Electricity savings potential [TWh/year]				
PRIMES Trends	0.3	0.9	1.4	2.0
Additional costs (negative values) or cost savings (positive values) of realising the electricity saving potential from the perspective of industry and commerce (8% real discount rate) [Mio. Euro]				
PRIMES Trends	- 15	9	- 23	- 86

Remarks: Baseline: 2004 market behaviour. Policies and measures beginning to have an impact in 2010. No change in replacement rates. LL = Load losses; NLL = No-load losses. Oil = Liquid-filled transformers with categories AoBk, AoAk, etc. as defined in EN50464-1; Dry = dry-type transformers with regard to HD 538

Table 3: Policies and measures supporting energy efficiency of distribution transformers in the world

Country	Labelling	BAT	Efficiency standard		Test standard
			Mandatory	Voluntary	
Australia			x		
Canada	x		x (dry-type)	x	
China			x		
EU				x (single companies)	
India				x	x
Japan	x	x		x	
Mexico			x		x
Taiwan	x	x			
USA	x	x	x		x

BAT = orientation towards Best Available Technology

Source: Irrek et al. 2008

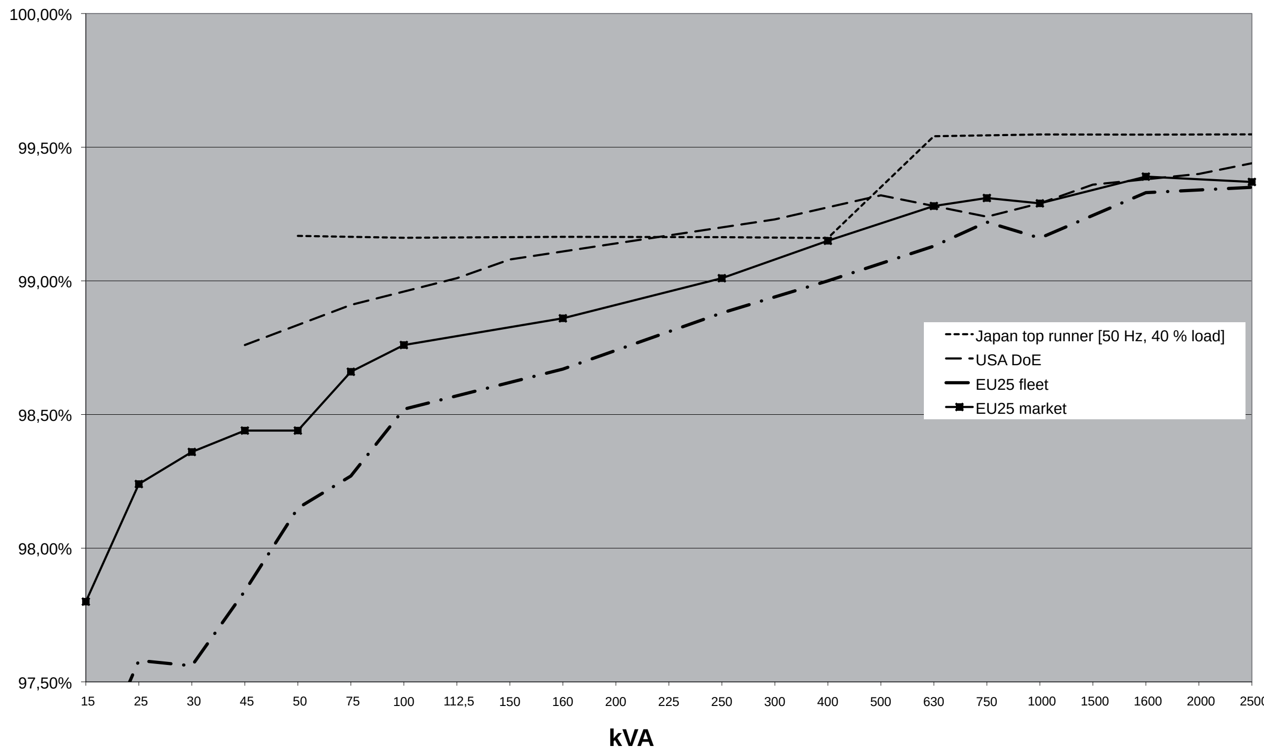

Figure 4: Comparison of selected standards and efficiency levels of distribution transformers. Source: Irrek et al. 2008

Transformer standards addressing energy efficiency

Unlike in many countries around the world, there is no mandatory European standard on energy efficiency of distribution transformers which could foster the realisation of these cost saving potentials. Still the two main documents which describe losses in transformers are Harmonised Documents; HD 428 for oil cooled transformers and HD 538 for dry type transformers (or their different country equivalents, e.g. DIN).

CENELEC Technical Committee 14 (Work Group 21) "Power Transformers" has prepared and concluded on a norm which supersedes the HD 428 document. This standard has already received the status of a European Standard EN 50464-1 in 2007 and has been reviewed and accepted by member countries committees. Also IEC 60076 – Power Transformers - Application Guide is widely referred to in the context of losses measurement. Lately, CENELEC has started the work to update HD 538 standard for dry-type transformers and draft results are expected within 2009.

Table 3 summarises existing international policy instruments supporting energy efficiency of distribution transformers. In particular, the recent development in the USA is remarkable. A new standard has been introduced, which practically means that all transformers manufactured for sale in the USA and imported to USA on or after January 1, 2010 will have a minimum efficiency, which is very close to the transformer categories CC' -30% or >AoBk as defined by the norms mentioned above. Figure 4 shows the ambitiousness of this standard compared to the Japanese one and to Europe's stock and market. Next to this new US standard, transformers also are part of the broader EnergyStar labelling programme, and thus are part of campaigns to measure the efficiency of industrial transformers

Table 4: Barriers and obstacles towards increasing energy efficiency of distribution transformers in industry and commerce in the European Union

<table>
<tr><th>Market actor</th><th colspan="2">Most important market barriers and obstacles</th></tr>
<tr><td>Large industry</td><td>Need for high flexibility and adaptability with regard to possible changes in the production process, usually expressed as maximum payback period required
Investment priority for core elements of the production process; energy efficiency investments have lower priority</td><td rowspan="4">Insufficient competition among amorphous metal manufacturers; no producer of amorphous transformers in Europe

Lack of competences in economic calculation of investment in energy-efficient distribution transformers, particularly with regard to the estimate of the load profile (assumed, e.g., in „A“ and „B“ price factors given by customers or their advisors (planners, engineering firms) to transformer manufacturers in the course of a tender as an input to the capitalisation formula)</td></tr>
<tr><td>Small and medium industry and commerce</td><td>Lack of information / knowledge
Too small to build up own knowledge in this field: Outsourcing of investment planning to engineering firms, ESCOs, energy companies or consultants
Investment priority for core elements of the production or service process; energy efficiency investments have lower priority</td></tr>
<tr><td>Engineering firms, ESCOs, energy consultants, planners</td><td>Lack of information / knowledge
Disincentives or no incentive from tariff systems for planners; no incentive for optimisation of whole system
No incentive to change routines: One-to-one replacement of old transformers following traditional lay out of transformer design (often oversized)</td></tr>
<tr><td>Transformer manufacturers (and their suppliers)</td><td>Risks of high investment in building up an amorphous production line
Limited production areas for extending or shifting production to amorphous metals
Hardly any demand for amorphous technology in Europe yet
Increasing prices for steel, aluminium and copper
Existing procurement routines: Customers specify their demand traditionally and very differently between countries and between companies</td></tr>
</table>

Source: Irrek et al. 2008

and to stimulate companies to upgrade their transformers to the best available in the market.

In conclusion, mandatory energy efficiency standards and labels seem to be appropriate options used in other countries to foster energy efficiency of distribution transformers. In order to catch up with the developments in North America, Asia and Australia, they should be developed for Europe, too.

Policies and measures

With regard to the technical and economic potentials presented, an ambitious policy target would be to realise most of the loss reduction potentials of liquid-filled distribution transformers in industry and commerce, for example, 4 TWh/year by 2025, with policies and measures starting in 2010. This could be a medium- to long-term policy target.

In order to identify how much of this potential will be realised anyway by BAU market developments and what could be the role for additional policies and measures, the market chain and market actors involved have to be analysed first. The most relevant market actors relevant for this potential in industry and commerce, and the market barriers and obstacles they face are summarised in Table 4.

In order to overcome these barriers and obstacles, and with regard to the cultural and organisation-institutional setting of the different market actors, the following policies and measures are proposed (cf. Irrek et al. 2008 for more details):

Mandatory minimum energy efficiency standard

Standards help to avoid that the least efficient transformers will be bought. In addition, dynamic standards will give a signal to suppliers in which direction the market will develop.

The SEEDT project team has run various life-cycle cost calculations as a basis for proposing a concrete mandatory standard. Figure 5 presents some results of life-cycle cost calculations for typical liquid-filled transformer types. A conclusion from this figure would be to set the maximum allowable level of losses of liquid-filled distribution transformers at the level of Co for no-load losses (excluding Do and Eo levels), and at Ck (level Dk to be excluded) for load losses, with regard to EN 50464-1 classifications. This is the proposal made by the SEEDT project team.

For dry-type transformers the economic optimum of today is particularly at a reduction of no-load losses according to HD 538 level. However, reducing losses too far (up to the full use of the technical potential) would increase “cost / losses reduction” ratio by roughly factor of 3. CENELEC TC 14 Committee has recently started a process of HD 538 standard update – evolution as done for HD 428. It is recommended to wait for work results of this group to help in better referencing of a proposed standard for dry-type transformers.

Financial or fiscal incentives

Financial (rebates or cheap credits) or fiscal (deduction from taxes) incentives could be a temporary option to be included into a policy package aimed at overcoming the already described barriers and obstacles which hinder the implementation of least-cost optimal solutions in industry and commerce, e.g., if included in anyway existing support schemes.. The ex-

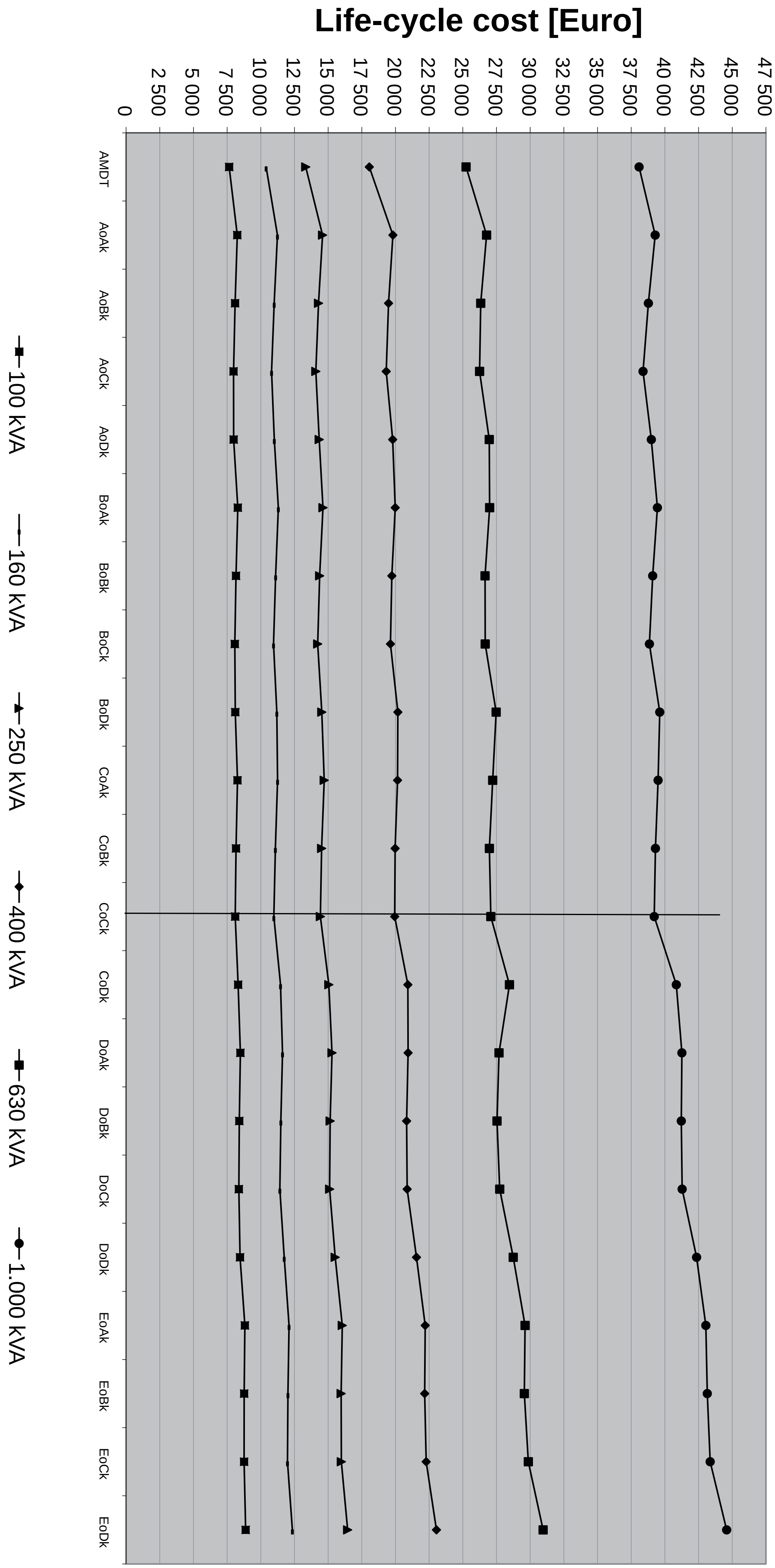

Figure 5: Life-cycle cost for six typical transformer kVA values for different energy efficiency classifications of liquid-filled transformers. Source: Irrek et al. 2008

Table 5: Proposed labelling classes for liquid-filled transformers

Label	Definition
A	Empty class today
B	[(NLL + 0.16 LL) / REF] ≤ 0,75
C	0,75< [(NLL + 0.16 LL) / REF] ≤ 0,85
D	0,85< [(NLL + 0.16 LL) / REF] ≤ 0,95
E	<0,95 [(NLL + 0.16 LL) / REF] ≤ 1,05
F	1,05< [(NLL + 0.16 LL) / REF] ≤ 1,2
G	[(NLL + 0.16 LL) / REF] > 1,2

with
NLL = no load losses, LL = load losses;
REF is Watt loss calculated from the formula REF=Co+0,16·Bk where
Co – is Co class of no load losses as per EN 50464
Bk – is Bk class of load losses as per EN 50464 (CoBk = CC' of HD428)
Source: Irrek et al. 2008

perience from other fields of application shows, that financial or fiscal incentive programmes are effective and efficient to attract attention from the target groups, because they signal that it will be worth to invest in this efficient technology. However, they need to be accompanied by information, qualification and training in order to pave the way from attracting customers and gaining their interest into the subject to demand for and implementation of energy-efficient transformers. ESCOs, energy consultants and planners, giving advice to industry and commerce, and being involved in planning and/or implementation should be well-informed about the financial or fiscal incentives, and therefore addressed by such comprehensive programmes, too. Moreover, ESCOs should be allowed to receive the incentive if they own the transformer.

Labelling

Small and medium electricity distribution companies and companies in industry and commerce often do not pay enough attention to the efficiency and to the life cycle costs of distribution transformers. A labelling scheme could direct their attention to the more efficient transformers. Furthermore, it might support suppliers in selling the more energy-efficient transformers. Among three alternatives, the SEEDT project team has proposed a specific energy label for liquid-filled distribution transformers, which is based on a simplified combination of no-load and load losses and with the labelling classes depicted in Table 5.

Information and motivation

A lack of information and motivation to deal with the subject can be identified particularly in small or medium companies in the electricity distribution sector and in industry and commerce. Policies and measures could be designed to overcome this barrier. An information campaign will also be needed to inform about a labelling scheme, if such a scheme is introduced.

Energy advice / Audits

Initial energy advice and audit schemes in place or to be introduced to generally support industry and commerce should include the subject of electricity distribution transformers as an additional cross-sectoral technology.

Tool-kits for buyers

From the discussions with electricity distribution companies, suppliers and their clients in industry and commerce as well as planners it can be learnt, that particularly several small or medium companies in all sectors (industry and commerce and electricity distribution) often do not base their investment decision on sound life cycle cost calculations. Sometimes, just a transformer type is bought which has been always bought in the past (stable purchasing habit). Tool-kits might help them to identify more cost-effective solutions, which often are the more energy-efficient ones.

TLCalc (Transformer Losses Calculator) is an interactive tool developed by SEEDT. The aim of this tool is to compare two distribution transformers regarding both economical and environmental point of view. The comparison is achieved after calculations using financial, electrical and environmental parameters. The result is a side-by-side presentation of calculations of each transformer. The TLCalc tool indents to help distribution transformer users, buyers and others to see the benefits of a low losses distribution transformer compared with other old or normal-to-high losses transformer.

TLCalc can be found on SEEDT website (http://seedt.ntua.gr) at the main menu with the title "TLCalc". It can be downloaded or used online.

Co-operative procurement

Large buyers or several medium-sized buyers (e.g. ESCOS, retail chains, or within an industry sector) bundling their purchasing volumes together can influence the supply and the development and introduction of even more energy-efficient distribution transformer types.

Support to R&D and pilot or demonstration projects

This kind of support might be needed to generally lead to further technical improvements and to ease the introduction of more energy-efficient transformer types. For example, financial support to pilot or demonstration projects with amorphous transformers could be a way to overcoming existing barriers and obstacles towards testing this technology. If tests are successful, the introduction of amorphous technology into the European market and further dissemination of this energy-efficient technology could be the

Table 6: Overview on policies and measures for increasing energy efficiency of distribution transformers in industry and commerce

Market actor	Mandatory standard	Labelling	Financial or fiscal incentives	Information, motivation, qualification	Inclusion into energy advice / audit programmes	Toolkit for buyers	Co-operative procurement	R&D, pilot / demonstration projects
Large industry	(X)	(X)	(X)	(X)		X	(X)	**X**
Small and medium industry and commerce	**X**	**X**	X	**X**	**X**	X	(X)	X
Engineering firms, ESCOs, energy consultants, planners	**X**	**X**	(X)	**X**	**Service provider**	X	(X)	(X)
Transformer manufacturers (and their suppliers)	**Compliance required**					Can include it in marketing		**X**

bold = main focus within policy mix for this market actor
brackets = only partly relevant for this market actor, or just addressing small part within this target group
Source: Irrek et al. 2008

consequence. This, in turn, might also move the market for CGO technology towards more efficient units.

Moreover, such test will also help to better evaluate to which extent problems of noise and size of AMDT are still a problem today in practice, and how such possible problems can be solved where this is needed.

Table 6 gives an overview of the respective policy mix proposed for increasing energy efficiency of distribution transformers in industry and commerce.

Figure 6 and Figure 7 give an idea how these policies and measures might address the different market actors to overcome the existing barriers and obstacles in the market.

Conclusions and outlook

Compared to saving potentials in other areas, the electricity saving potentials of distribution transformers in industry and commerce seem to be small. Nevertheless, every contribution to climate change mitigation and energy security is necessary, particularly if it is economical. Since particularly energy-efficient transformers are just on the edge of competitiveness and since a large part of the electricity saving potential is economical from the perspectives of the buyers in industry and commerce following the assumptions set in the SEEDT project, it is recommended to implement the policies and measures proposed. Moreover, if avoided external costs were included, or if electricity prices increase compared to the assumptions taken in the SEEDT project, the economic results would be even more favourable for energy-efficient distribution transformers. Furthermore, combined with the loss reduction potentials of energy-efficient distribution transformers in electricity distribution companies (up to 57.4% in total, respectively up to 5.5 TWh/year realisable within 15 years) and with the not yet calculated energy savings potential of energy-efficient power transformers and small transformers, total loss reduction potential of transformers in EU-27 will be quite large. Finally, and in contrast to energy end-use saving measures, there are no direct rebound effects that could reduce such increase in the energy efficiency of the grid system.

In principle, the transformer industry seems to be in favour of efforts taken to reducing the level of losses of transformers to optimise energy efficiency (T&D Europe 2008). This might be a good starting point for the development of an effective and efficient policy-mix. Mandatory standards and labelling schemes might be developed within the framework of the EcoDesign directive. A preparatory study on distribution and power transformers has just been initiated.

The need for further research and monitoring can be summarised as follows:

- Since the SEEDT project has just analysed the usage phase of distribution transformers, it has neglected possible impacts of different transformer design in other phases of the transformer life cycle. A more efficient transformer will need more copper or aluminium than a less efficient one (trade-off between energy efficiency and material efficiency). Furthermore, the switch from grain oriented steel to amorphous metals has an impact on energy use, the environment and the economy, particularly in the production phase, during transport of materials and final product, but also in the recycling and waste disposal phase, too (cf. e.g. Berti 2006). Furthermore, how raw materials like copper are produced matters, too (cf. e.g. Schüller/Estrada/Bringezu 2008 for a recent analysis of material flows and CO_2 emissions with regard to copper). Nevertheless, the impacts during the operation of the transformer remain by far the most important ones during the whole life cycle. Therefore, the total environmental impact of amorphous transformers over the whole life cycle will be less than the impact of conventional ones (cf. e.g. Berti 2006). However, for further studies, it is recommended to take such aspects into account, particularly within the started preparatory study within the framework of the EcoDesign directive.
- The analysis of existing situation and the calculation of electricity and cost saving potentials in the different Member States have shown that publicly available data and information on energy efficiency of transformer population and market, on loading factors in practice and on investment

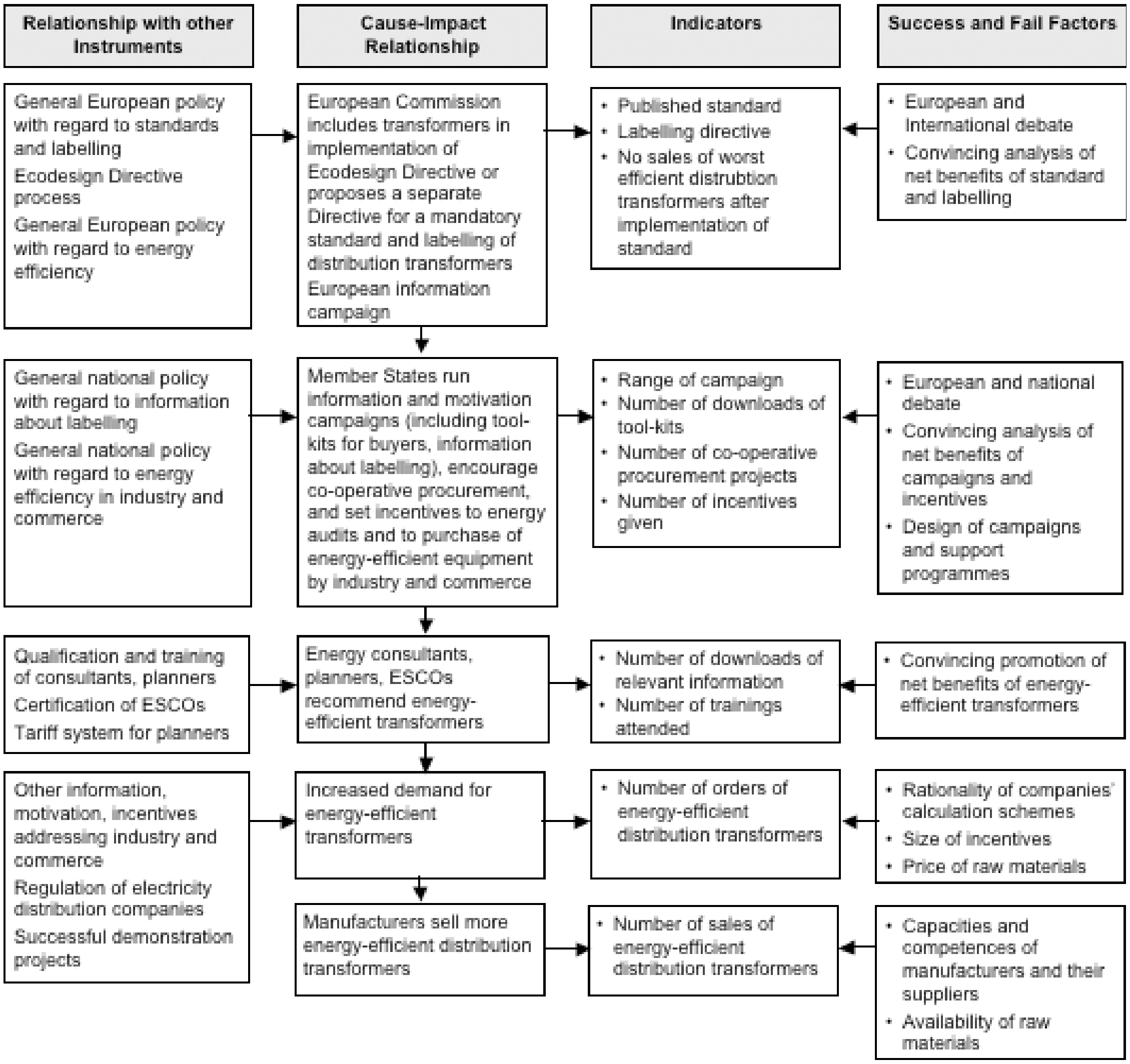

Figure 6: Policy model for information and motivation policy, mandatory standards and labelling on energy-efficient distribution transformers. Source: Irrek at al. 2008.

costs of different transformer types is very limited. This is even more true for industry and commerce than for electricity distribution companies. Therefore, effort should be taken to improve the database. For the mentioned preparatory study within the Ecodesign Directive process, it is recommended to focus on data collection from the beginning, particularly trying to collect more data from industry and commerce on loading factors and energy efficiency of transformer population, and to receive more data from manufacturers on the transformer market and transformer prices than it was possible within the SEEDT project.

- Finally, it should be analysed, which role energy-efficient distribution transformers might play in "smart grids" or "efficiency plants", that combine, integrate and optimise distributed generation (renewables and CHP), centralised generation, load reduction potentials, energy storage facilities and energy end-use efficiency measures so that CO_2 emissions can be further reduced at least cost. The research question would be if and how in such an integrated system distribution grid losses could be minimised.

References

Berti, R.: Confronto degli impatti ambientali di trasformatori di distribuzione a nucleo tradizionale ed amorfo attraverso l'uso della metodologia LCA. Presentation of Cesi Ricerca – TTD at the first Italian SEEDT workshop, Milano, 20 November 2006

CENELEC: EN50464-1, Three phase oil immersed distribution transformers 50 Hz, 2007

CENELEC: HD-428 S1, Three phase oil immersed distribution transformers 50 Hz, Part 1, 1992 with later changes.

CENELEC: HD 538-1 S1: Three-phase dry-type distribution transformers 50 Hz, from 100 to 2500 KVA with highest voltage for equipment not exceeds 24 KV, 1992

Frau, J.; Gutierrez, J.: Energy-efficient distribution transformers in Spain: New trends. Paper 0141, Session 5, 19th International Conference on Electricity Distribution (CIRED), Vienna, 21-24 May 2007

Hasegawa, R.; Azuma, D.: Impacts of amorphous metal-based transformers on energy efficiency and enviroment, Journal of Magnetism and Magnetic Materials, 2004

Irrek, Wolfgang; et al.; Policies and Measures Fostering Energy-Efficient Distribution Transformers, Report (Final

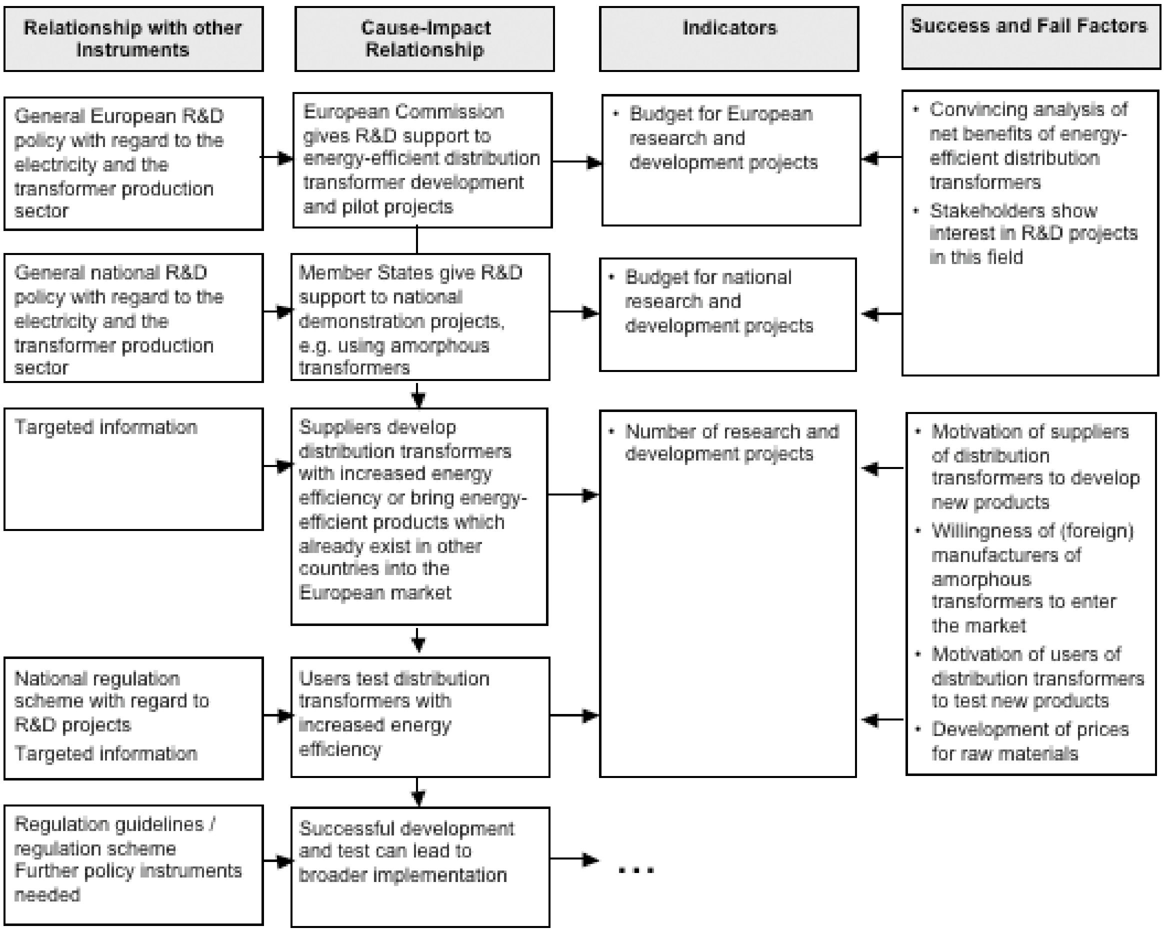

Figure 7: Policy model for R&D policy on energy-efficient distribution transformers. Source: Irrek at al. 2008.

Version of Deliverable No. 6) from the EU-IEE Project "Strategies for Development and Diffusion of Energy-Efficient Distribution Transformers – SEEDT", Project No. EIE/05/056/SI2.419632; Wuppertal, et al.; 2008 [http://seedt.ntua.gr/]

Rialhe, Anne; et al.; Analysis of Potential for Energy Savings, Report (Final Version of Deliverable No. 9) from the EU-IEE Project "Strategies for Development and Diffusion of Energy-Efficient Distribution Transformers – SEEDT", Project No. EIE/05/056/SI2.419632; Aix-les-Bains, et al.; 2008 [http://seedt.ntua.gr/]

Schüller, M.; Estrada, A.; Bringezu, S. (2008): Mapping of Environmental Performance of International Raw Material Production Flows: a Comparative Case Study for the Copper Industry of Chile and Germany. Minerals & Energy - Raw Materials Report, 23:1, 29-45

T&D Europe: Position paper on a study for preparing the first Working Plan of the EcoDesign Directive Report for tender No.: ENTR/06/026 of 22 November 2007, Brussels, 2008

Targosz, Roman; et al.; Selecting Energy-Efficient Distrubtion Transformers, A Guide for Achieving Least-Cost Solutions, Brochure from the EU-IEE Project "Strategies for Development and Diffusion of Energy-Efficient Distribution Transformers – SEEDT", Project No. EIE/05/056/SI2.419632; Wroclaw, et al.; 2008 [http://seedt.ntua.gr/]

Targosz, Roman; Topalis, Frangiskos; et al.; Analysis of Existing Situation of Energy-Efficient Transformers – Technical and Non-Technical Solutions, Report (Final Version of Deliverable No.1) from the EU-IEE Project "Strategies for Development and Diffusion of Energy-Efficient Distribution Transformers – SEEDT", Project No. EIE/05/056/SI2.419632; Wroclaw, Athens, et al.; 2008 [http://seedt.ntua.gr/]

Acknowledgements

The findings in this paper result from the European study "Strategies for development and diffusion of energy-efficient distribution transformers (SEEDT)", completed in summer 2008 and co-ordinated by the National Technical University of Athens (NTUA) in the framework of the Intelligent Energy Europe programme of the European Commission (Project no. EIE/05/056/SI2.419632). Wuppertal Institute's work in this project has been co-financed by the State of North Rhine-Westphalia.

The authors would particularly like to thank all SEEDT project team members for their intensive and fruitful contributions to the SEEDT project results, on which this paper is based.

Furthermore, the authors are particularly thankful to all the stakeholders from industry, energy agencies, science and ministries for any data provided and for their feedback on preliminary results of the SEEDT project and for their contribution to discussions at national and European workshops and in further bilateral meetings.