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IZM/EE Toolbox

Environmental Assessment

A modular approach for evaluating and optimising the environmental properties of electronic systems will be presented. The first modular stages are based on the material contents of electronic products to avoid the data difficulties encountered with full LCA approaches. A smooth transition from these screening indicators to process estimations and then to product specific process descriptions allows the flexible choice of evaluation principles according to the trade-off between precision and data needs. The concept is suited for different company sizes and for different workflow integration strategies.

Environmental optimisation of electronics is a multidisciplinary and concurrent aim on different levels in companies. It includes the management level with the implementation of suited frameworks such as ISO 14000ff. and all organisational levels concerned with the analysis, evaluation and optimisation of processes and products. For this, different methods and tools were developed all over the world in the past. However, LCAs for complex products such as electronic appliances are still characterised by the time and costs needed for data acquisition. A complete investigation of the processes through all life cycle phases may easily take a few months (sometimes years), and in many cases will still not deliver satisfactory results due to
- incomplete process descriptions,
- different and undocumented data quality,
- open and hidden approximations.

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The demands from the electronics industry (including many SMEs) need to be addressed with custom-tailored solutions for the assessment and the improvement of electronic products and related processes. Especially the direct integration of environmental issues into the product design flow has to be improved and promoted. Such customisation can only be achieved through a modular concept. Table 1 shows an overview of the modules currently included in the so-called Environmental Engineering (EE) Toolbox.

With this approach companies can choose which data and which assessment types to concentrate on first, and then slowly evolve towards the more comprehensive and time-consuming process of gathering, updating and evaluating life cycle data for all their products.

The first screening modules of the EE Toolbox, which are primarily used together with industrial partners, are:
- Toxic Potential Indicator (toxicity based on product contents),
- Recycling Potential Indicator (suitability of product contents for specific recycling paths),
- Energy Intensity ERM based on the raw materials for the product and EPU for the product usage.

Stage 1a:	**Based on Product Material Content**
	TPI (Toxic Potential Indicator)
	RPI (Recycling Potential Indicator)
	E_{RM} (Energy for Raw Materials)
Stage 1b:	**Based on Product Information**
	E_{PU} (Energy for Product Usage)
Stage 2:	**Based on Specific Process Data**
	ProTox (Process Toxicity Screening)
	E_P (Energy for Production Steps)
Stage 3:	**With Further Life Cycle Data**
	LCI/LCA
	LCEE (Life Cycle Energy Efficiency)
	LCC (Life Cycle Costing)

Table 1. Modular approach to the evaluation of electronic systems.

Description of Modules

TPI (Product Toxicity Screening)

The Toxic Potential Indicator or TPI for the analysis and evaluation of products is based on the environmental properties of the materials contained in the product after manufacturing. Different ecological impacts are aggregated into one number, so the numerical result expresses the possibility of harm to both humans and the environment when the substances in the product are released freely. Uncontrolled, fine spread release, e.g. as dust or through ground water, is assumed to be the worst impact case for each substance, even though it might not occur in the real life cycle of the product under investigation.

Each material is attributed one number which describes the relative worst case ecological impact of the material on a scale from 0 to 100. Some materials from the database are presented in Table 2. The material weights for each component are multiplied by this evaluation to achieve the component assessment.

The evaluation model is based on legally defined values like the maximum allowable workplace concentration. While the chosen threshold values are a part of German legislation, the rating behind

Material		**TPI (1/mg)**
Be	beryllium	69.1
Ni	nickel	42.5
Sb_2O_3	antimony oxide	42.3
Hg	mercury	39.5
Co_3O_4	tricobalt tetraoxide	38.0
Ag	silver	37.8
Pb	lead	20.8
$SnPb_{37}$	eutectic tin lead solder	8.4
TBBA	tetrabromobisphenol A	3.0
Cu	copper	1.6
Sn	tin	1.2
Al	aluminum	0.7
Zn	zinc	0.6

Table 2. A section of the material list evaluated with TPI.

the values expresses more general attributes of the substances and is not limited to the German situation. The selected input lists are hazardous material marking with so-called R-values (Gefahrstoffkennzeichnung mit R-Sätzen), maximum workplace concentration (Maximale Arbeitsplatzkonzentration MAK) and water pollution classes (Wassergefährdungklassen WGK).
All these lists are updated by expert commissions and published regularly. The values can also be found on the materials safety data sheets, which have to be supplied by the material producers on request. Thus the screening parameter TPI can be easily generated and maintained for almost all materials used in electronic products.
The TPI evaluation method has been implemented in a database for materials and electronic components. In a server-based workgroup environment different users can simultaneously work on
- material definition & their evaluations,
- component definition & their material contents,
- assembly definition & data export for evaluations.

RPI (Recycling Scenarios)

Evaluating the recyclability of products is one of the basic environmental tasks where many companies manufacturing electronic products seek outside advice. Increasingly, the companies are challenged to calculate future costs which will be incurred taking back their products. Already today they are looking for technological and logistical ways to limit the recycling costs by appropriate product design. The crucial decisions for recycling are made in the design phase. For that reason, in particular the dismantling times of products have been assessed and been optimised in the past.
Assembled printed circuit boards (PCBs) are the essential parts of electronic appliances. The variety and complexity of these parts require a fundamentally different strategy for the assessment of the recyclability and the following optimisation by this. The material content of components, solder systems, the PCB materials and in consequence the complete assembled PCB determines the possible recycling options.
The material content of an assembled PCB is suitable for the determination of the optimal recycling strategy. For this

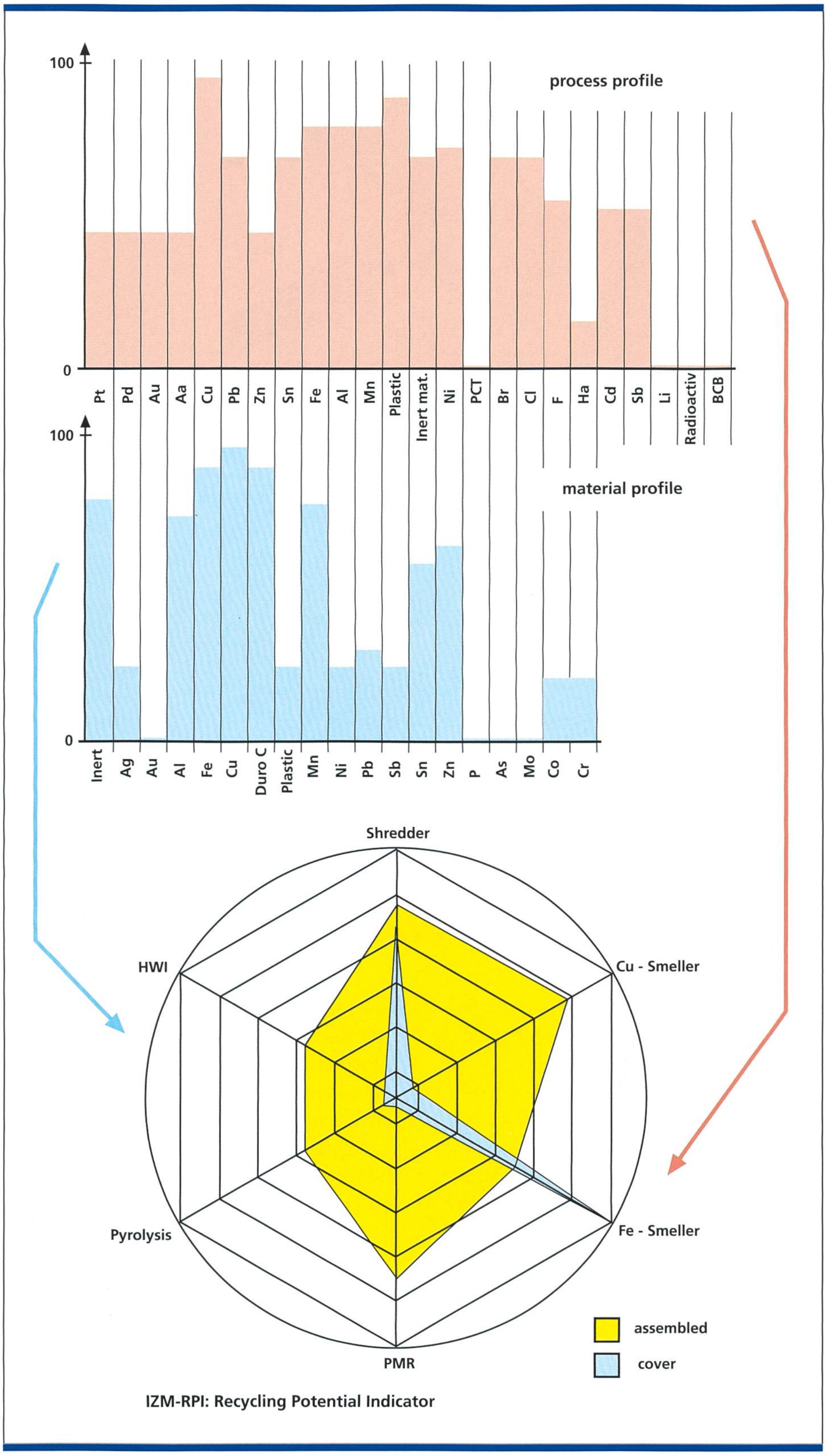

Fig. 1. Principle of the RPI calculation and assessment of two product parts.

the list of materials, as generated for the previous modules, is represented in a product material vector, or graphically expressed as the material profile of the product.
For the characterisation of so-called "process vectors" for the potential disposition paths, the required minimum quantities of valuable materials for standard recycling processes and tolerable maximum quantities of interfering or noxious substances were specified.
This results in assessed lists of all relevant materials for all investigated processes,

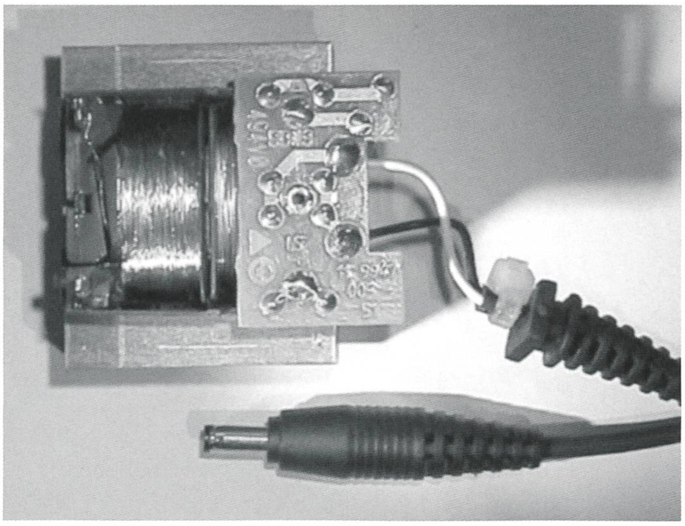

Fig. 2.
Conventional power supply for small appliances (Type C).

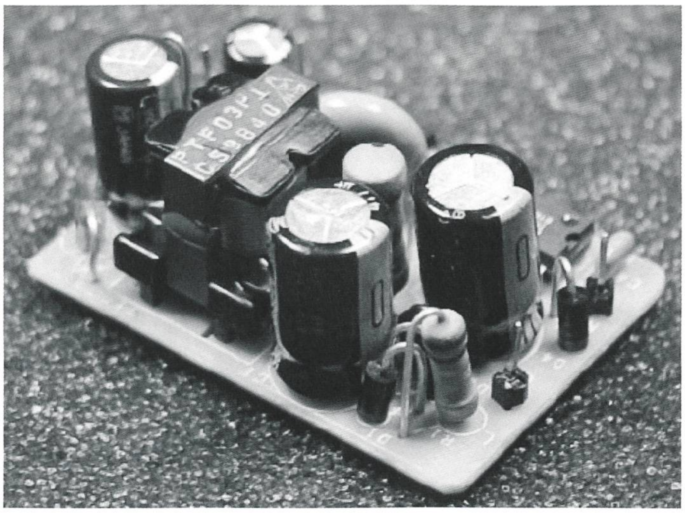

Fig. 3.
Switched power supply for small appliances (Type S).

the process vectors, that can again be graphically represented in material-discrete process profiles.

The RPI vector, calculated from a product material vector and the process vectors by material-discrete correlation, sets the frame for product assessment regarding material-resulting applicability for different recycling processes. Proscription lists of inadmissible interfering materials are integrated in the calculation of RPI as exclusion criteria for certain processes. The RPI vector is a numerical measure for the correlation of product content and recycling processes. The elements of the vector are calculated for all examined processes. The process with the largest corresponding vector element is the most suitable for the given product. The applicability for other processes is also displayed to give sufficient room for the final decision.

Figure 1 illustrates the determination of RPI vectors. For the copper smelter, the relevant profitable minimum Cu-content and the technological maximum of tolerable interfering or noxious substances is specified and from this a process profile is formed.

The correlation of process and material profiles results in one element of the RPI vector. By repeating the calculation for the recycling pathways of precious metal refining (PMR), steel smelting, mechanical conditioning (shredder) and thermal treatment by incineration (household waste incineration HWI) or pyrolysis the whole RPI vector is derived, which can be displayed in a net diagram. With average processing costs and recovery rates, estimates of the worth of the recycled materials can also be calculated. The material prices can either be based on raw material prices or on market data for the recycled material quality.

Energy (Product use Energy and raw Materials Energy)

For electronic products the most important areas of ecological impact are toxicity or energy related. Proper recycling and possible resource depletion are equally pressing problems, but they seem to be of a smaller impact scale in comparison (when evaluated with LCA methodologies, which may be biased of course).

As has been shown in other research, the energy can be dominated either by the product use phase or by the production phase, depending on the product under investigation. A complete energy inventory for all life cycle phases faces the same obstacles as obtaining suitable data for LCA, and is therefore not possible in most (smaller) projects. The use phase can be reasonably estimated from the technical data of the product. One other part of the energy inventory can be estimated sufficiently with moderate data needs, the energy for the product's raw materials. We will call these parts of the energy inventory EPU and ERM. Each material from the toxicity screening (TPI) is attributed with a further number, which expresses the (cumulative) energy needed to generate one weight unit of the material, e.g. in J/mg or MJ/kg. The actual manufacturing of the product is not included at this stage, and neither are the respective processing materials, production yields and other overhead factors.

Table 3.
Example values for cumulated raw material extraction energy ERM.

Material	ERM (MJ/kg)	Comments
Ag	3024	estimate
Al	168	
Au	139944	estimate
Cu	168	40% recycling
Expoy	196	
Ni	300	
Pb	74	
PE, PET, PP	75–82	
PVC	63	
Si (Wafer)	8990	
Sn	240	

Thus ERM is not an indicator for the total production energy, but rather one part of it, which is chosen for practicality, not because it is the most important part of a product's energy budget. For many standard materials these energy data for raw materials can now be obtained from previous LCA groundwork (see table 3). Some important materials for electronics will only have energy estimations, or the sources may be contradicting, which shows the need for further stringent and transferable energy investigations.
The aim of the two simple energy measures ERM and EPU is to determine in which life phase the energy intensity can potentially be reduced. Energy intensive substances may be replaced or – more often – measures should be taken to improve the recyclability of these material fractions.
As has been pointed out, the production steps – which can for many electronic products exceed ERM and EPU in importance – are not investigated at this stage due to concerns over data availability and quality for these processes. Expanding the definition and documentation of exemplary energy data for electronics specific production processes is still a necessary task.

Example Product Screening

As an example two variants of a small power supply will be investigated. The conventional product uses a transformer and a simple diode rectifier circuit on a small FR2 assembly (see fig. 2). This will be identified as Type C for conventional. The same functionality actually, even with improved technical properties, can be achieved with a switched mode AC/DC converter. The compared electronic assembly with a much smaller transformer but a larger number of other electronic components will be called Type S (for switched), and is shown in fig. 3. The material contents of both variants are shown in table. 4. As the cable and the casing are identical they are not included in the comparisons. Type C is therefore solely dominated by the transformer, consisting of copper, iron nickel and some plastic insulation. In contrast, the switched type contains a much greater variety of materials.
Apart from the copper and the ferrite core of the smaller transformer the largest weight contributions are from the printed circuit board and the electrolytic capacitors.

When evaluated with the Toxic Potential Indicator, the conventional assembly is dominated by the nickel content and to a smaller part by the copper. In comparison, the switched supply shows a large contribution by the tin lead solder. The total TPI evaluation decreases significantly (see table 5).
The Recycling Potential in figure 4 shows that the conventional transformer is most suited for either mechanical separation or the iron smelting, since the amount of iron is much higher than the copper content. However, the copper may deteriorate the quality of the recycled iron, leaving the shre dder as the first plausible treatment step.
The Type S assembly is more oriented towards copper recycling, but again this is no clear indication. Due to the relatively high percentage of plastics, incineration and pyrolysis are favoured. The high lead content would not allow the processing of such electronic parts as household waste, but legal restrictions were ignored for the calculations.
The raw materials energy in table 6 demonstrates that the smaller variant is not automatically an improvement in all environmental aspects. The total estimated materials energy stays roughly the same.
Both assemblies are quite untypical, as they contain almost no silicon and no gold and silver. The energy inventory of electronic products will quite often be dominated by the precious metal extraction and by the energy-intensive fabrication of the silicon wafers.

Type C: 139943 mg	Weight (mg)
$FeNi_{39}MnO_4$	68%
Cu	21%
PP	9%
$CuZn_{15}$	1%
Others	1.7%
Paper	0.5%
$BaTiO_3$	0.38%
Phenolic Resin	0.21%
PVC	0.17%
SiO_2	0.16%
Epoxy Resin	0.07%
Fe	0.06%
Sn	0.03%
$SnPb_{37}$	0.06%
Si	0.01%
Pb	0.01%
TBBA	0.01%
Sb_2O_3	0.01%
Type Sm: 22038 mg	**Weight (mg)**
E-Glass	15%
Cu	14%
Fe_2O_3	13%
Al	9%
Epoxy Resin	7%
Rubber	5%
Fe	4%
PP	4%
MnO	4%
$SnPb_{37}$	4%
Ethyleneglycol	4%
PET	3%
PBT	3%
SiO_2	3%
Others	9%
Sn	0.2%
$SnPb_{28}$	0.1%
Sb_2O_3	0.1%
$SnPb_{20}$	0.3%
Acrylic	0.2%
Zn	0.7%
Pb-Glass	0.5%
Ni	0.1%
Si	0.04%
TBBA	1%
$FeNi_{42}$	1%
Paper	1%
$SnZn_{20}$	1%
Al_2O_3	1%
PVC	1%
ZnO	1%

Table 4. Material contents of both variants.

Type C: 211000 TPI	Weight (mg)
$FeNi_{xx}$	76%
Cu	22%
Sb_2O_3	0.27%
Phenolic Resin	0.28%
$BaTiO_3$	0.75%
TBBA	0.13%
CuZn15	1.26%
$SnPb_{xx}$	0.48%
Others	0.09%
Type S: 31000 TPI	**Weight (mg)**
$FeNi_{xx}$	3.8%
Ethyleneglycol	1.5%
TBBA	1.5%
Sb_2O_3	4.1%
E-Glass	3.5%
Al	4.6%
$SnPb_{xx}$	24%
Cu	26%
Ferrite	28%
Others	2.9%

Type C: ERM ca. 2,1 MJ	Weight (mg)
$CuZn_{15}$	1.3%
PP	4%
Cu	23%
FeNixx	72%
Others	1.0%
SnPbxx	0.1%
Paper	0.1%
PVC	0.1%
Ep. Resin	0.1%
Ph. Resin	0.2%
Si	0.5%
$BaTiO_3$, SiO_2, Fe, Sb_2O_3, TBBA	< 0,1%
Type S: ERM ca. 2 MJ	**Weight (mg)**
E-Glass	4%
Ferrite	5%
$SnPb_{xx}$	7%
PET	3%
PBT	2%
$FeNi_{xx}$	2%
Fe	3%
PP	3%
Si	4%
Rubber	4%
Ep. Resin	15%
Al	17%
Cu	26%
Others	5%
Acrylic	0.2%
Sb_2O_3	0.1%
Paper	0.3%
Zn	0.4%
Al_2O_3	0.2%
TBBA	0.5%
PVC	0.8%
Ethyleneglycol	1.1%
$SnZn_{20}$	1.3%

Table 6. ERM Comparison.

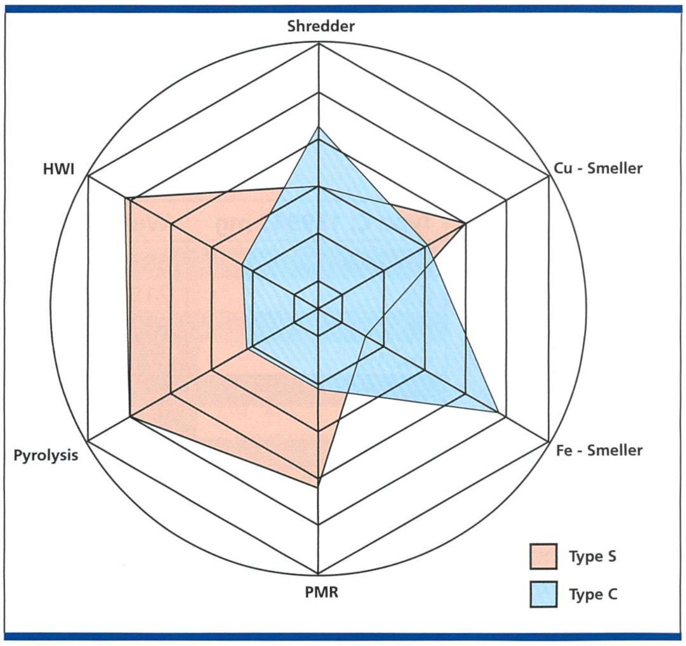

Fig. 4. RPI Comparison.

For recycling purposes the assemblies represent distinctive profiles, but in the absence of precious metals the reclaim of the copper will have priority. The plastic contents will not realistically be recycled. In this way electronic products can be investigated quickly and efficiently. The material contents will be a part of the product documentation, which can be assessed directly or stored for further investigations. Then, based on the first screening results the more complex assessment stages including general process estimations and real product specific process data can be tackled. 8

Conclusions

Basic environmental checks can be performed from the material contents of electronic systems. As in this comparison, trade-offs between smaller weight and a more complex circuitry have to be observed. In this case the raw materials energy is not decreased significantly even though the weight is reduced by a factor of six. With the weight minimisation the Toxic Potential decreases as well. However, the amount of tin lead solder and smaller amounts of other materials poses new concerns. To reduce the solder, surface mount components should be considered, and then possibly lead-free solder pastes in the future.

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Zusammenfassung

Beurteilung der Umwelteinflüsse mit Hilfe von IZM/EE Toolbox

Hier wird ein modularer Ansatz zur Ermittlung und Optimierung der Umwelteinflüsse elektronischer Systeme vorgestellt. Hierbei ist man von der stofflichen Zusammensetzung der Produkte ausgegangen, weil man den Schwierigkeiten, die die Datenbeschaffung bei einem integralen LCA-Ansatz macht, aus dem Weg gehen wollte. An sie schliessen sich Prozesskalkulationen und produktspezifische Prozessbeschreibungen an. Damit wird es möglich, exakt die Beurteilungskriterien zu wählen, die der jeweiligen Wechselbeziehung zwischen Genauigkeit und Datenbedarf angemessen sind. Das Konzept eignet sich für Firmen verschiedener Grösse und für verschiedene Strategien der Workflow-Integration.

Datensicherheit

Kampf gegen Hacker und Viren

Der europäische Markt für Datensicherheit wird in den nächsten Jahren massiv zulegen. Nach einer neuen Studie[1] der Unternehmensberatung Frost & Sullivan soll der Gesamtumsatz von 524,6 Mio. US-$ im Jahr 2000 auf 3,13 Mia. US-$ im Jahr 2007 ansteigen. Wichtigste Wachstumsfaktoren sind die zunehmende Nutzung von Internet und E-Mail in Unternehmen sowie ein höheres Sicherheitsbewusstsein.

Die Bereitschaft, in Datensicherheit zu investieren, steigt mit dem Risiko, dass Computernetze in Unternehmen lahmgelegt oder sensible Daten gestohlen und dadurch erhebliche Schäden verursacht werden können.

Antiviren-Software und Inhaltsfilterung

Stark nachgefragt wird zurzeit vor allem Antiviren-Software, deren Notwendigkeit bereits allgemein anerkannt ist. Auf dieses Produktsegment entfiel im Jahr 2000 ein Umsatzanteil von 80%. Dieser Markt wird auch im Prognosezeitraum weiter kräftig wachsen – nicht zuletzt deshalb, weil Computerviren wie «Melissa» und «I love you» immer wieder grosses Medieninteresse hervorrufen. Weil Antiviren-Programme aber zunehmend in andere Lösungen integriert werden, soll sich der Anteil des Sektors am Gesamtmarkt bis zum Jahr 2007 auf 38,5% verringern. Gleichzeitig werden sich Inhaltsfilterung (Content Filtering) und Verschlüsselung zu wichtigen Aspekten einer umfassenden Sicherheitslösung entwickeln.

Das stärkste Wachstum wird laut Frost & Sullivan bei Produkten zur Inhaltsfilterung zu verzeichnen sein. Für eine kräftige Nachfrage sorgt die zunehmende Nutzung von E-Mail und Internet durch Unternehmen und nicht zuletzt deren Interesse, die Internetnutzung ihrer Mitarbeiter stärker zu kontrollieren. Der Sektor für Inhaltsfilterung wird daher seine schnelle Expansion noch beschleunigen und gegen Ende des Prognosezeitraums mit 43,4% den Gesamtmarkt dominieren.

Strengere Datenschutzvorschriften tragen zum Umsatzanstieg bei. Der Einsatz von Verschlüsselungssoftware wird kräftig zunehmen. Dieser Marktanteil betrug im Jahr 2000 7,2%. Zum Umsatzanstieg von 38 Mio. US-$ im Jahr 2000 auf 1,36 Mia. US-$ im Jahr 2007 tragen nicht zuletzt strengere Datenschutzvorschriften bei.

Marktführer

Das Gewicht der einzelnen Ländermärkte wird durch verschiedene Faktoren wie der Grad der Internetnutzung durch Unternehmen und die gesetzlichen Vorgaben bei Verschlüsselung, Datensicherheit und Datenschutz beeinflusst. Hinzu kommt die Präsenz grosser Unternehmen, da diese die wichtigsten Investoren auf diesem Markt sind. Deshalb entfallen die grössten Anteile am Gesamtmarkt auf Grossbritannien mit derzeit 21,7% Marktanteil, gefolgt von Deutschland mit 21,1% und Frankreich mit 14,5%.

Die Marktführer bei Antiviren-Software, Network Associates und Symantec, haben den europäischen Markt für Datensicherheit fest im Griff. Zusammen mit den anderen führenden Anbietern dringen sie erfolgreich in die anderen Teilmärkte vor.

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[1] Report 3935: The European Market for Content Security. Preis der Studie: 4980.– Euro.