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Environmental Impact Assessment Review 25 (2005) 436–458
Environmental Impact Assessment Review
www.elsevier.com/locate/eiar

Global perspectives on e-waste

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Received 4 April 2005; received in revised form 21 April 2005; accepted 26 April 2005

Abstract

Electronic waste, or e-waste, is an emerging problem as well as a business opportunity of increasing significance, given the volumes of e-waste being generated and the content of both toxic and valuable materials in them. The fraction including iron, copper, aluminium, gold and other metals in e-waste is over 60%, while pollutants comprise 2.70%. Given the high toxicity of these pollutants especially when burned or recycled in uncontrolled environments, the Basel Convention has identified e-waste as hazardous, and developed a framework for controls on transboundary movement of such waste. The Basel Ban, an amendment to the Basel Convention that has not yet come into force, would go one step further by prohibiting the export of e-waste from developed to industrializing countries.

Section 1 of this paper gives readers an overview on the e-waste topic—how e-waste is defined, what it is composed of and which methods can be applied to estimate the quantity of e-waste generated. Considering only PCs in use, by one estimate, at least 100 million PCs became obsolete in 2004. Not surprisingly, waste electrical and electronic equipment (WEEE) today already constitutes 8% of municipal waste and is one of the fastest growing waste fractions.

Section 2 provides insight into the legislation and initiatives intended to help manage these growing quantities of e-waste. Extended Producer Responsibility (EPR) is being propagated as a new

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doi:10.1016/j.eiar.2005.04.001

paradigm in waste management. The European Union's WEEE Directive, which came into force in August of 2004, makes it incumbent on manufacturers and importers in EU states to take back their products from consumers and ensure environmentally sound disposal.

WEEE management in industrializing countries has its own characteristics and problems, and therefore this paper identifies some problems specific to such countries. The risky process of extracting copper from printed wiring boards is discussed as an example to illustrate the hazards of the e-waste recycling industry in India.

The WEEE Knowledge Partnership programme funded by seco (Swiss State Secretariat for Economic Affairs) and implemented by Empa has developed a methodology to assess the prevailing situation, in order to better understand the opportunities and risks in pilot urban areas of three countries—Beijing-China, Delhi-India and Johannesburg-South Africa. The three countries are compared using an assessment indicator system which takes into account the structural framework, the recycling system and its various impacts. Three key points have emerged from the assessments so far: a) e-waste recycling has developed in all countries as a market based activity, b) in China and India it is based on small to medium-sized enterprises (SME) in the informal sector, whereas in South Africa it is in the formal sector, and c) each country is trying to overcome shortcomings in the current system by developing strategies for improvement.

Keywords: WEEE; E-waste initiatives; Transboundary e-waste movement; E-waste assessment methodology; Extended producer responsibility; Waste management; Informal sector

1. Introduction

The use of electronic devices has proliferated in recent decades, and proportionately, the quantity of electronic devices, such as PCs, mobile telephones and entertainment electronics that are disposed of, is growing rapidly throughout the world. In 1994, it was estimated that approximately 20 million PCs (about 7 million tons) became obsolete. By 2004, this figure was to increase to over 100 million PCs. Cumulatively, about 500 million PCs reached the end of their service lives between 1994 and 2003. 500 million PCs contain approximately 2,872,000 t of plastics, 718,000 t of lead, 1363 t of cadmium and 287 t of mercury (Puckett and Smith, 2002). This fast growing waste stream is accelerating because the global market for PCs is far from saturation and the average lifespan of a PC is decreasing rapidly — for instance for CPUs from 4–6 years in 1997 to 2 years in 2005 (Culver, 2005).

PCs comprise only a fraction of all e-waste. It is estimated that in 2005 approximately 130 million mobile phones will be retired. Similar quantities of electronic waste are expected for all kinds of portable electronic devices such as PDAs, MP3 players, computer games and peripherals (O'Connell, 2002).

In 1991, Larry Summers, then Chief Economist of the World Bank (and now President of Harvard University), spoke of the economic sense of exporting first world waste to developing countries (Summers, 1991). He argued that

- the countries with the lowest wages would lose the least productivity from "increased morbidity and mortality" since the cost to be recouped would be minimal;

- the least developed countries, specifically those in Africa, were seriously under-polluted and thus could stand to benefit from pollution trading schemes as they have air and water to spare; and that
- environmental protection for "health and aesthetic reasons" is essentially a luxury of the rich, as mortality is such a great problem in these developing countries that the relatively minimal effects of increased pollution would pale in comparison to the problems these areas already face.

The most prominent example of an international initiative stemming against this type of thinking is the 1989 Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal (in force since 1992). The Convention puts an onus on exporting countries to ensure that hazardous wastes are managed in an environmentally sound manner in the country of import. Apart from Afghanistan, Haiti, and the United States of America all 164 signatory countries have ratified the convention (Secretariat of the Basel Convention).

The transboundary movement of electronic waste, or e-waste, is regulated by the Basel Convention (UNEP, 1989), as it is considered to be dangerous to humans and the environment under the List A of Annex VIII of the Convention. There are highly toxic substances in e-waste such as cadmium, mercury and lead (EU, 2002b). However, e-waste also contains valuable substances such as gold and copper. Recovering these metals from e-waste has become a profitable business, resulting in global, transboundary trade in e-waste.

Countries such as China and India face a rapidly increasing amount of e-waste, both, from domestic generation and illegal imports. For emerging economies, these material flows from waste imports not only offer a business opportunity, but also satisfy the demand for cheap second-hand electrical and electronic equipment. In addition, the lack of national regulation and/or lax enforcement of existing laws are promoting the growth of a semi-formal or informal economy in industrializing countries. An entire new economic sector is evolving around trading, repairing and recovering materials from redundant electronic devices. While it is a source of livelihood for the urban and rural poor, it often causes severe risks to humans and the local environment. Most of the participants in this sector are not aware of the risks, do not know of better practices, or have no access to investment capital to finance profitable improvements.

1.1. Definitions of electronic waste

'Electronic waste' or 'e-waste' for short is a generic term embracing various forms of electric and electronic equipment that have ceased to be of any value to their owners. There is, as yet, no standard definition. Table 1 lists selected definitions. In this article, we use the terms "WEEE" and "e-waste" synonymously and in accordance to the EU WEEE Directive.

1.2. Composition of WEEE

According to the definitions in the Directive 2002/96/EC of the European Parliament and of the Council (January 2003) on Waste Electrical and Electronic Equipment (EU, 2002a), WEEE consists of the ten categories listed in Table 2.

Table 1
Overview of selected definitions of WEEE or e-waste

Reference	Definition
EU WEEE Directive (EU, 2002a)	"Electrical or electronic equipment which is waste... including all components, sub-assemblies and consumables, which are part of the product at the time of discarding." Directive 75/442/EEC, Article 1(a) defines "waste" as "any substance or object which the holder disposes of or is required to dispose of pursuant to the provisions of national law in force."
Basel Action Network (Puckett and Smith, 2002)	"E-waste encompasses a broad and growing range of electronic devices ranging from large household devices such as refrigerators, air conditioners, cell phones, personal stereos, and consumer electronics to computers which have been discarded by their users."
OECD (2001)	"Any appliance using an electric power supply that has reached its end-of-life."
SINHA (2004)	"An electrically powered appliance that no longer satisfies the current owner for its original purpose."
StEP (2005)	E-waste refers to "...the reverse supply chain which collects products no longer desired by a given consumer and refurbishes for other consumers, recycles, or otherwise processes wastes."

This categorisation seems to be in the process of becoming a widely accepted standard. The Swiss "Ordinance on the Return, the Taking Back and the Disposal of Electrical and Electronic Equipment" (ORDEE) of 1998 differentiates between the following categories of WEEE:

- electronic appliances for entertainment;
- appliances forming part of office, communication and information technology;
- household appliances
- electronic components of the (above) appliances.

Recently the Swiss ordinance has been amended (June 2004) to match the EU Directive's definition (BUWAL, 2004).

Table 2
WEEE categories according to the EU directive on WEEE (EU, 2002a)

No.	Category	Label
1	Large household appliances	Large HH
2	Small household appliances	Small HH
3	IT and telecommunications equipment	ICT
4	Consumer equipment	CE
5	Lighting equipment	Lighting
6	Electrical and electronic tools (with the exception of large-scale stationary industrial tools)	E & E tools
7	Toys, leisure and sports equipment	Toys
8	Medical devices (with the exception of all implanted and infected products)	Medical equipment
9	Monitoring and control instruments	M & C
10	Automatic dispensers	Dispensers

Of the ten categories listed in Table 2, Categories 1–4 account for almost 95% of the WEEE generated (see Fig. 1).

1.3. Quantities and routes of WEEE

Presently, e-waste is mainly generated in countries of the Organization for Economic Cooperation and Development (OECD), which have highly saturated markets for Electrical and Electronic Equipment (EEE), as Fig. 2 shows for the example of PCs. Comparatively, the market penetration of EEE in industrializing countries is not very high. However, these countries show the fastest growing consumption rates for EEE, and thus large quantities of domestically generated e-waste will become part of the waste stream in them as well in the near future.

Numerous methods have been suggested and used to estimate possible global quantities of WEEE. In Lohse et al. (1998) three estimation methods are described:

- the 'consumption and use method', which takes the average equipment of a typical household with electrical and electronic appliances as the basis for a prediction of the potential amount of WEEE (used in the Netherlands to estimate the potential amount of WEEE);

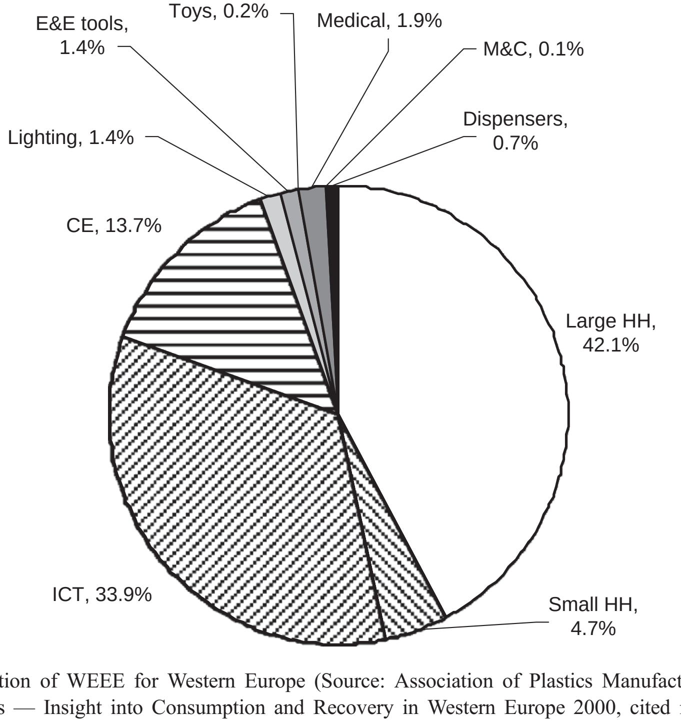

Fig. 1. Composition of WEEE for Western Europe (Source: Association of Plastics Manufacturer in Europe (APME): Plastics — Insight into Consumption and Recovery in Western Europe 2000, cited in International Copper Study Group, 2003).

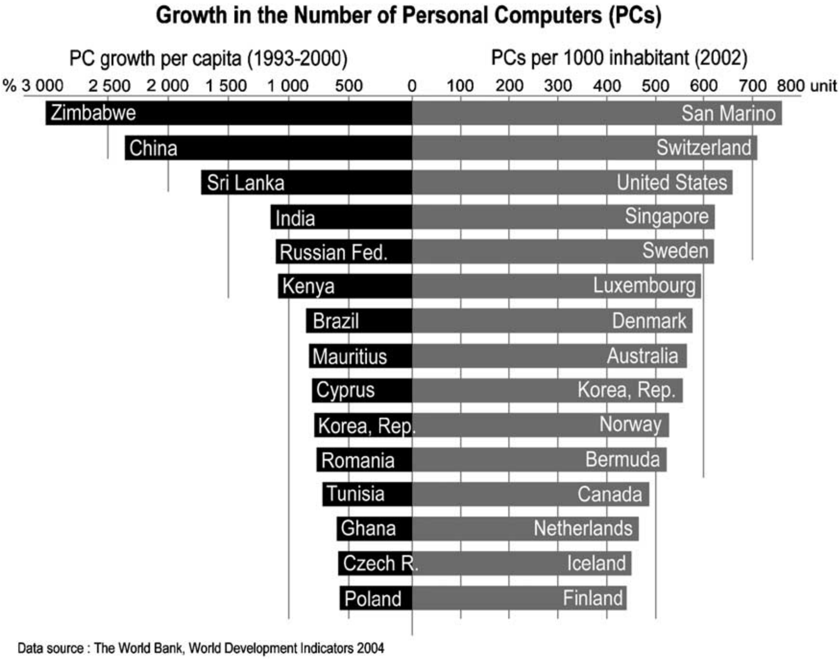

Fig. 2. Top scoring countries in PC growth rates (cumulated 1993 – 2000) and market saturation (2002) (Schwarzer et al., 2005).

- the ‘market supply method’, which uses data about production and sales figures in a given geographical region (used by the German Electrical and Electronic Industries Association to estimate WEEE) and
- the Swiss Environmental Agency’s estimates based on the assumption that private households are already saturated and for each new appliance bought, an old one reaches its end-of-life.

In the first two methods, assumptions need to be made about the average life-time of EEE products as well as their average weight (from which to derive WEEE generation in tons). Under the third method, however, the assumption of the average life-time of the appliances is irrelevant, as it assumes a completely saturated market.

Another method of estimation developed at Carnegie Mellon University by Matthews et al. (1997) is also based on sales data. Although it focuses only on computers, it includes the reuse and storage parameters for obsolete machines, which in reality delay their entry into the waste stream. However, the model is only for the US and cannot be universally applied. An adapted model for WEEE estimation based on Matthews’ model is shown in Fig. 3.

The results of WEEE estimation studies vary widely and comparisons of the studies are difficult because both the methods used and basic assumptions made differ from one study to another.

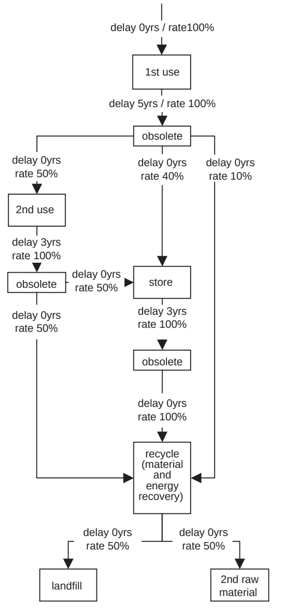

Fig. 3. A simple model adapted from Matthews et al. (1997) to calculate expected e-waste at recyclers and/or landfills. It mainly describes usage patterns of PCs ('1st use', '2nd use' and 'store') followed by a final destruction to recover materials and energy. Some of the material is landfilled and the rest is returned as secondary raw materials. The transfer from one stage to the next is described with a delay in years and a transfer rate in percent of the total volume at this stage in any year.

The following considerations are based on a simple model to estimate only scrap PC quantities. Fig. 4 displays timelines of global quantities of drop-out PCs, calculated as the difference between annual new PC sales and the annual growth of the installed PC base. The average drop-out rate for PCs over the period 1991–2004 is then calculated as the ratio between the drop-out PCs and the installed PC base, which turns out to be approximately 11%. This corresponds to a total life span of approximately 9 years — assuming a linear decay — which is considerably longer than the useful life of a PC and hence indicates quite a long storage time.

In the former 15 European member countries (EU15) the amount of WEEE generated varies between 3.3 and 3.6 kg per capita for the period 1990–1999, and is projected to rise to 3.9–4.3 kg per capita for the period 2000–2010 (EEA, 2003). According to the study (which assessed only five appliances: refrigerators, personal computers, televisions, photocopiers and small household appliances), this amount covers only 25% of the whole WEEE stream of the EU15. Hence, these numbers correspond to other estimates of total WEEE amounts, which range from 14 to 20 kg per capita (estimated by AEA, cited in Enviros, 2002). Nevertheless, the quantity of WEEE generated constitutes one of the fastest growing waste fractions, accounting for 8% of all municipal waste (The Economist, 2005).

Although the *per-capita* waste production in populous countries such as China and India is still relatively small and estimated to be less than 1kg e-waste per capita per year, the total *absolute* volume of WEEE generated in these countries is huge.

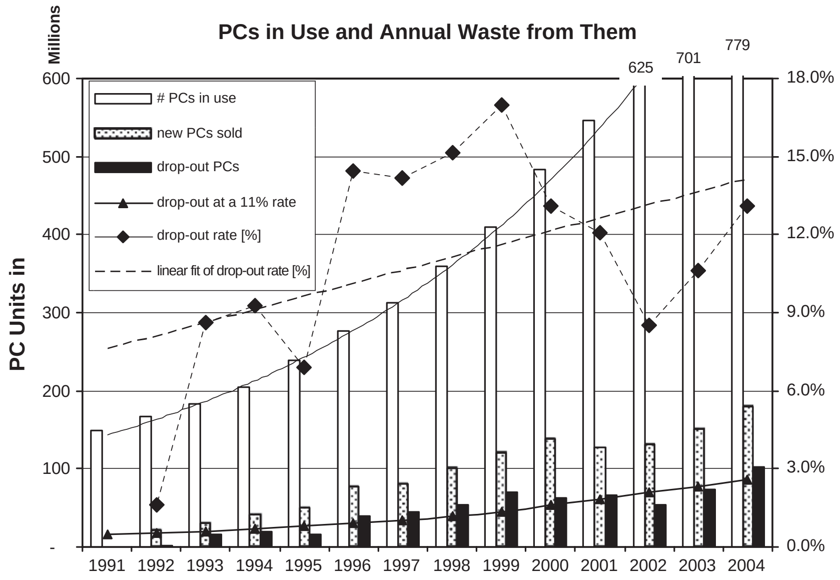

Fig. 4. Some facts and trends of the PC market over the last decade (all input data from The World Bank online statistics www.worldbank.org). The globally installed base of PCs [# PCs in use] increases exponentially. The sales of new PCs [new PCs sold] also grew substantially from 20 million (1992) to 180 million (2004). However, there is a considerable drop in new PC sales in the years 2001 and 2002, reflecting the technology bubble burst in 2000, followed by a quick recovery in the last 2 years. About half of the new PCs replace obsolete ones [drop-out PCs]. The rest adds to the installed base which results in the present growth. Comparing the number of dropped-out PCs with the totally installed base a drop-out rate between a 2% and 17% results. A trend to an increased drop out rate can be observed [linear fit of drop-out rate], clearly indicating a decreasing life span of PCs. However, this trend is overrun by the market developments in the past years: the rate was highest (17%) in 1999 at the peak of the ICT boom. The average drop-out rate over the entire period is approximately 11% which turns out to be a life span (assuming linear decay) of approximately 9 years. This in turn indicates quite a long storage time, which was confirmed by sampling tests done for SWICO in Switzerland. If we assume a constant drop-out rate of 11% (which represents the average drop-out rate over the period 1991–2004) the number of PCs which would drop out every year from the installed base [# PCs in use] gives a conservative estimate of PC scrap occurring [drop-out at a 11% rate] if extrapolated into the future.

Additionally some developing and industrializing countries import considerable quantities of e-waste, even though the Basel Convention restricts transboundary trade of it. Fig. 5 indicates the main e-waste traffic routes in Asia. There are, however, no confirmed figures available on how substantial these transboundary e-waste streams are. From non-ratifying countries, such as the USA, estimates have been made that 50–80% of the collected domestic e-waste is not recycled domestically but rather shipped to destinations such as China (Puckett and Smith, 2002).

China, India and other countries have recently adjusted their laws to fight e-waste imports. However, being large producers of EEE (China manufactures for instance 90% of the global CRT production), these countries should recognize their inherent interest in closing material cycles and obtaining access to the raw materials in the e-waste streams.

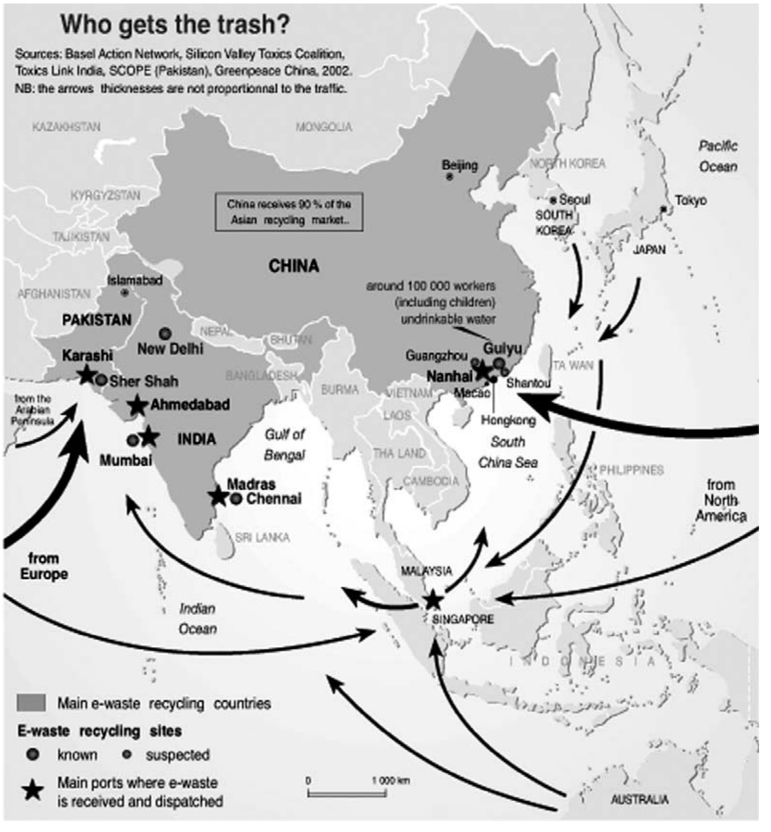

Fig. 5. Asian e-waste traffic (Schwarzer et al., 2005).

1.4. Content of WEEE

When e-waste is disposed of or recycled without any controls, there are predictable negative impacts on the environment and human health. E-waste contains more than 1000 different substances, many of which are toxic, such as lead, mercury, arsenic, cadmium, selenium, hexavalent chromium, and flame retardants that create dioxins emissions when burned. About 70 % of the heavy metals (mercury and cadmium) in US landfills come from electronic waste. Consumer electronics make up 40 % of the lead in landfills. These toxins can cause brain damage, allergic reactions and cancer (Puckett and Smith, 2002).

E-waste contains considerable quantities of valuable materials such as precious metals. Early generation PCs used to contain up to 4 g of gold each; however this has decreased to about 1 g today[1]. The value of ordinary metals contained in e-waste is also very high: 1 ton of e-waste contains up to 0.2 tons of copper, which can be sold for about 500 Euros at the current world price (Soderstrom, 2004). Recycling e-waste has the potential therefore to be

[1] Personal communication with e-waste recyclers.

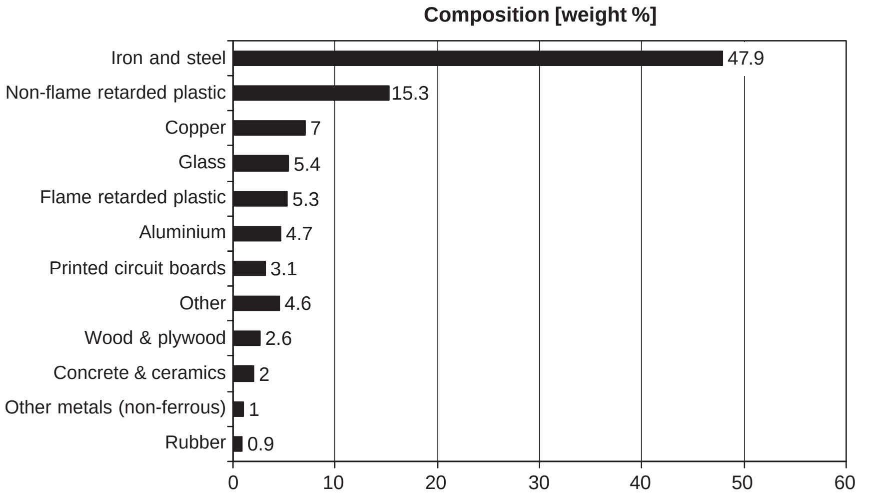

Fig. 6. WEEE material composition. (European Topic Centre on Resource and Waste Management).

an attractive business and companies such as Boliden (Sweden), WEEE AS (Norway) and Citiraya (UK) are investing in the area.

Given the diverse range of materials found in WEEE, it is difficult to give a generalised material composition for the entire waste stream. However, most studies examine five categories of materials: ferrous metals, non-ferrous metals, glass, plastics and "other".

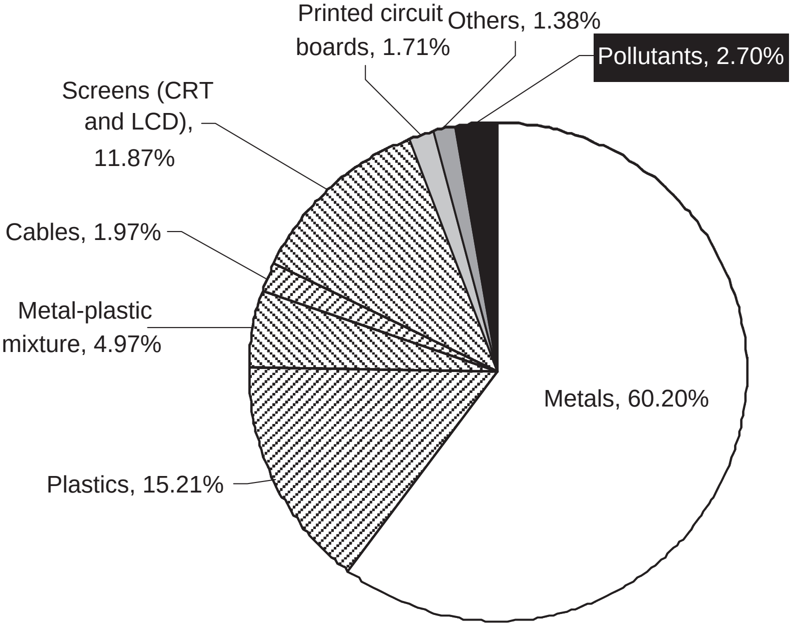

Fig. 7. Material Fractions in e-Waste (Source: Empa, 2005).

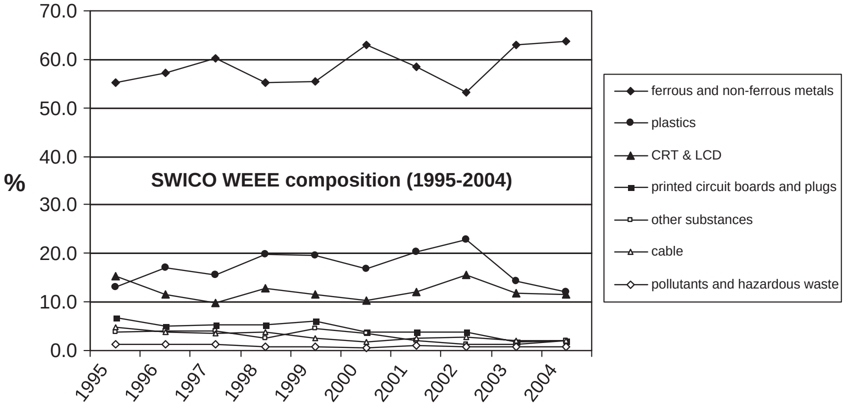

Fig. 8. Time series of SWICO (Switzerland) WEEE composition. (Empa, 2005).

According to the European Topic Centre on Resource and Waste Management (ETC/RWM), iron and steel are the most common materials found in electrical and electronic equipment and account for almost half of the total weight of WEEE (Fig. 6). Plastics are the second largest component by weight representing approximately 21% of WEEE. Non-ferrous metals, including precious metals, represent approximately 13% of the total weight of WEEE (with copper accounting for 7%).

A similar composition is found in the e-waste recycled by the SWICO/S.EN.S recycling system in Switzerland (Fig. 7).

It is interesting to see that over time, the metal content has remained the dominant fraction, well over 50%, as compared to pollutants and hazardous components which have seen a steady decline (Fig. 8).

2. E-waste management approaches and initiatives

2.1. Extended producer responsibility (EPR)

Extended Producer Responsibility (EPR) is being propagated as a new paradigm in waste management. The OECD defines EPR as an environmental policy approach in which a producer's responsibility for a product is extended to the post consumer stage of the product's life cycle, including its final disposal (OECD, 2001). Keeping in line with the Polluter-pays Principle, an EPR policy is characterised by the shifting of responsibility away from the municipalities to include the costs of treatment and disposal into the price of the product, reflecting the environmental impacts of the product. Legislators are increasingly adopting EPR policies to manage various kinds of wastes, such as discarded cars, electrical and electronic appliances and batteries, which require special handling and treatment. The EU, in 1991, designated e-waste as a priority waste stream and in August 2004 the legislation on Waste from Electrical and Electronic Equipment (WEEE) came into force (EU, 2002a), making it incumbent on manufacturers and distributors in EU member states to take back their products from consumers and recycle them.

Legally, and from an administrative perspective, there is a range of approaches for implementing the instruments of EPR—from fully voluntary to mandatory (OECD, 2001) (Table 3). Voluntary approaches are the preferred form of implementing EPR strategies, mainly to avoid the promulgation of national regulations. The degree of producer involvement can vary from totally private to a publicly required one, with shared operations, shared control and public consultative options between the two extremes (OECD, 2001). Producer Responsibility Organisations (PROs) are often instituted as a cooperative industry effort to collectively shoulder the responsibilities of its member companies to meet their EPR obligations.

The Swiss system, started voluntarily in the early 1990s for refrigerators and finding a formal system in 1994 for ICT and CE (consumer electronics) equipment, is operated by two PROs—SWICO and S.EN.S. In Sweden as well, the El-Kresten is a PRO which manages the entire chain from collection to the recycling of WEEE (El-Kresten, 2004). However, in Germany, the EAR project (Elektro-Altgeräte Register Projektgesellschaft b.R., the German WEEE Clearing House) acts only as a clearing house between producers and municipalities, ensuring compliance and monitoring so that producers fulfil their obligations under the German Elektro Geräte Act.

Designing an EPR system with clear and well defined roles is essential for all actors–producers, users, authorities and waste managers (Lindhqvist, 2000). Five broad parameters have been identified which need to be considered when designing or characterising a WEEE management system:

1. Legal Regulation: How elaborate is the legislation, i.e. how much detail does it specify for the operational management of system?
2. System Coverage: One aspect of the coverage of a system is whether it is collective (all inclusive for any brand) or brand-specific (each brand owner is individually

Table 3
Possible approaches to EPR and examples

Type of EPR approach	Examples
Product take-back programs	• Mandatory take-back • Voluntary or negotiated take-back programs
Regulatory approaches	• Minimum product standards • Prohibitions of certain hazardous materials or products. • Disposal bans • Mandated recycling
Voluntary industry practices	• Voluntary codes of practice • Public/private partnerships • Leasing and “servicizing” • Labelling
Economic instruments	• Deposit–refund schemes • Advance recycling fees • Fees on disposal • Material taxes/ Subsidies

(OECD, 2001).

accountable). The other aspect would be whether to have a system that caters to all the product categories or have different systems for different kinds of products under the WEEE umbrella.

3. System Financing: This parameter asks the question who pays, how much and for what. On one extreme of the scale is an entirely externally financed system—where the financial burden of the collection and recycling is borne by the product user or producer or municipality by providing additional funds meant specifically for the end-of-life treatment of the product. On the other hand, an internal system would be one in which the collection and recycling are paid for by the product itself.
4. Producer Responsibility: While designing the system, it is important to consider how much responsibility the producer shoulders, at which points, and how the responsibility is shouldered in practice. While each producer may be individually responsible for its products, several manufacturers can come together to form a collective WEEE management system. Flexible systems allow for both individual and collective implementation of producer responsibility.
5. Ensuring Compliance: The system design needs to be such that there are checks and balances, especially to prevent free riders. Penalties for non-compliance and targets for collection or recycling are often used to ensure compliance. A system may have a high density of such measures, or a relatively few, or even none in extreme cases.

With these key parameters, it is possible to characterise a WEEE management system. For example, the Swiss system would be characterised as one of relatively little regulatory control, with the legal framework, the ORDEE (BUWAL, 2004) giving only the broad guidelines for WEEE management. Here, the producers bear full responsibility of the implementation and operation, covering the entire spectrum of WEEE without being brand-or product-specific, and the entire system is financed

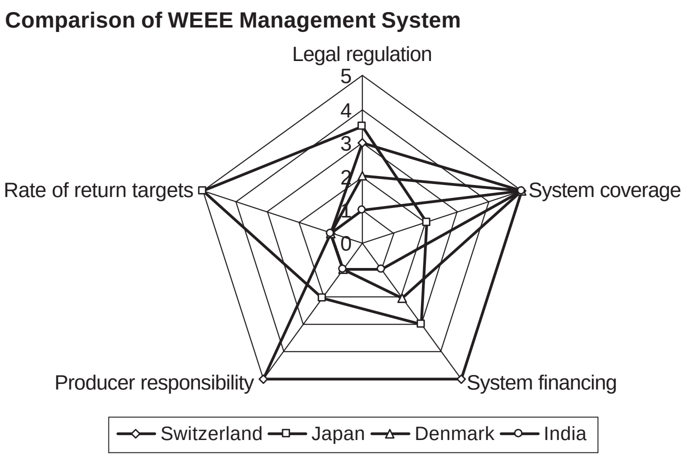

Fig. 9. Characteristics of WEEE management systems in selected countries. See also Table 4.

Table 4
Scale definition for the indicators used in Fig. 9

Comparison indicator	Low (value=0)	Medium (value=3)	High (value=5)
Legal regulation	No existing legal regulation	Existing regulation giving operational flexibility	Existing regulation with no operational flexibility
System coverage	No WEEE handled by system	Few, specific WEEE handled by system	All WEEE handled by system
System financing	No external financing	Partly externally financed system	Fully externally financed system
Producer responsibility	Producer responsibility non-existent	Selective producer responsibility	Strong producer responsibility
Rate of return targets	No legal collection and/or recycling targets	Few collection and/or recycling targets	Preset, legally binding targets for all processes

through product based recycling fees. In comparison, the Japanese Specified Home Appliances Recycling Act, which has been in force since 2001, stipulates specifically the collection, transportation and recycling mechanism of WEEE (Raymond Communications, 2003). It is both product-and brand-specific in its coverage, with only TVs, Refrigerators, Washing Machines and Air Conditioners being covered under it, and the recycling being a producer-specific responsibility. The law also specifies recycling rate targets and imposes heavy penalties for non-compliance.

Fig. 9 shows a graphical comparison of the WEEE management systems in four countries. The chart aims to illustrate the fact that different countries have different configurations of the above mentioned parameters. The grading was done on a subjective basis, with high or low values given to a system not indicating a 'better' or 'worse' performance on the parameter, but merely to illustrate that countries with comparable economic indicators (for instance Switzerland and Japan) can have remarkably different WEEE management systems.

2.2. Selected WEEE initiatives

Selected WEEE initiatives are represented in Table 5.

3. WEEE management in industrializing countries: assessment results from China, India and South Africa

3.1. Problems specific to developing and transition countries

Some of the difficulties specific to developing and transition countries have been mentioned above and are summarized here:

- Although the quantity of indigenous e-waste per capita is still relatively small, populous countries such as China and India are already huge producers of e-waste in absolute terms (Empa, 2005)

Table 5
Initiatives tackling the WEEE issues from various perspectives

Initiatives	Description
Basel Convention and Basel Ban	A global agreement regulating movements of hazardous wastes, including WEEE, between countries, in force since 1992. However, an Amendment to the Convention, commonly known as the Basel Ban, which calls for prohibiting the export of hazardous waste from OECD to non-OECD countries, is still to come into force.
StEP initiative (solving the e-waste problem)	A UN-led initiative started in 2004 at the 'Electronic Goes Green' Conference in Berlin to build an international platform to exchange and develop knowledge on WEEE systems among countries to enhance and coordinate various efforts around the world on the reverse supply chain (StEP 2005).
Basel Action Network (BAN), Silicon Valley Toxics Coalition (SVTC) and computer take back campaign	A network of non-governmental organisations (NGOs) in the US working together on WEEE issues, including international advocacy for the Basel Ban, domestic collection and recycling events as well as investigative research to promote national solutions for hazardous waste management.
WEEE Forum	Founded in 2002, the WEEE Forum is a group of representatives of voluntary collective WEEE take-back systems in Europe, taking care of individual producers' responsibility in Europe.
National Electronics Product Stewardship Initiative (NEPSI)	A multi-stakeholder dialogue to develop the framework of a national WEEE management system in the USA. The NEPSI dialogue includes representatives from electronics manufacturers, retailers, state and local governments, recyclers, environmental groups, and others.
Electronics Product Stewardship Canada (EPS Canada)	EPS Canada was created to work with both industry and government to develop a flexible, workable Canadian solution. An industry-led organization, the founding members are 16 leading electronics manufacturers.
ERP (European Recycling Platform)	Set up at the end of 2002 by Hewlett Packard, Sony, Braun and Electrolux to enable the producers to comply with the WEEE directive. It aims to evaluate, plan and operate a pan-European platform for recycling and waste management services.
Seco/Empa e-waste programme	A project set up in 2003 by seco (Swiss State Secretariat for Economic Affairs) and implemented by Empa (Swiss Federal Laboratories for Materials Testing and Research) in cooperation with a number of local partners and authorities, to assess and improve WEEE recycling systems in different parts of the world by analysing the systems and by exchanging knowledge on recycling techniques and frameworks.

- These countries also *display the fastest growing* markets for electrical and electronic equipment.
- Some developing and transition countries are *importing considerable quantities of e-waste*. Some of them arrive as donations meant to help 'the poor', while others are simply mislabelled.

In certain developing and transition countries these difficulties are amplified by a *lack of regulations and/or lax enforcement in the recycling and disposal sector*. Combined with the existence of a very creative and low-income informal sector, the lack permits a profitable e-waste recycling business thriving on uncontrolled and risky low-cost techniques (examples are shown in Fig. 10 and described in Agarwal et al., 2003). Most of the participants in this sector are not aware of environmental and health risks and either do not know better practices or have no access to investment capital to finance even profitable improvements or implement safety measures.

3.2. Developing WEEE knowledge partnerships

In the expectation of having the EU's WEEE and RoHS Directives transposed and enforced soon, many export oriented countries have started to move towards solving their domestic e-waste issues. China drafted a piece of legislation in 2004 and identified the Zhejiang province to enforce the legislation as a pilot for later replication in other provinces. India and South Africa have set up 'WEEE Strategy Groups' to develop a comprehensive WEEE management system. These strategy groups consist of delegates from varies key stakeholders i.e., government agencies, EEE producers' and importers' associations, recyclers and NGOs. The groups have set up committees which look into specific issues such as the formulation of policies and legislation, the creation of a national

Fig. 10. The extraction of copper from printed wiring boards (PWB): (1) manually removing varnish, (2) recovering copper-sulphate after submerging PWBs for 12 h in sulphuric acid followed by boiling off H_2O using PWB residues as a fuel, (3) manually segregating the copper layer and glass fibres after burning multi layer PWBs which are resistant to acid, (4) scrap iron is added to the remaining liquid to react with the dissolved copper, (5) fallen out copper slime is a third product bringing the total to 1 to 2 t of copper per month, (6) such an SME creates about 12 jobs, however at high external costs. (Empa Survey, 2004).

WEEE baseline, the restructuring of the WEEE recycling sector, the implementation of producer responsibility (EPR) and the creation of public awareness.

In 2003, Switzerland initiated a knowledge partnership programme with industrializing countries. The ongoing project is funded by seco (Swiss State Secretariat for Economic Affairs) and implemented by Empa (Swiss Federal Laboratories for Materials Testing and Research) in cooperation with a number of local partners and authorities. The aim of the first phase was to identify and document the current e-waste handling situation in three urban areas—Delhi (India), Beijing (China) and Johannesburg (South Africa)—and to develop a knowledge base to mitigate the hazards without reducing the attractiveness of this business. Currently, this programme is instrumental in supporting the national WEEE strategy groups, in the establishment of national WEEE baselines and assisting in implementing WEEE pilot projects.

3.3. Methodology for assessing informal WEEE management systems

Assessing WEEE recycling systems requires a comprehensive understanding of the prevailing situation. In an environment with a large number of small informal actors handling a complex waste stream, assessing quantities, job and business opportunities as well as risks to the health and the environment is a demanding task requiring a well structured methodology. In the framework of the seco e-waste programme Empa developed a comprehensive assessment methodology, combining qualitative and quantitative methods and tools (Fig. 11).

It has consisted of the following activities:

- Examine the processes used for e-waste recycling both in a specific technical and geographical context. This makes it possible to describe and understand recycling processes, although they are broken up into many minute steps and dispersed over large areas in a manner similar to a 'virtual factory'. The formal description is done with common methods such as material flow analysis (using the material flow networks approach supported by the Umberto® software tool) and the use of Geographic Information Systems (GIS).
- Compare different e-waste recycling systems, thus developing a simplified three shell model, which consists of the outermost layer being the framework conditions, the

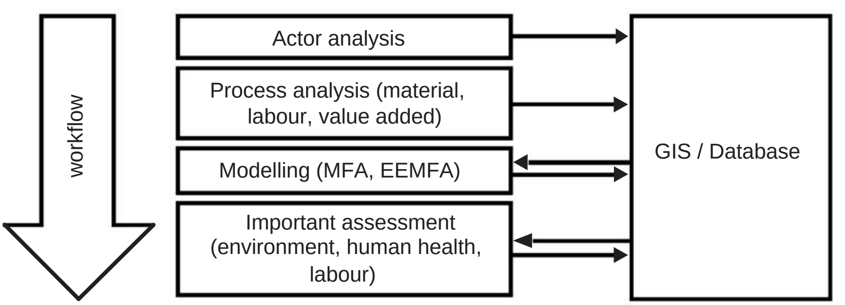

Fig. 11. Overview Assessment methodology (Empa, 2005).

Table 6
Assessment indicator system to measure and compare WEEE management systems

Aspect	Criterion	Indicator
Structural framework	Politics and legislation	Ratification of Basel Convention and Ban Amendment
		Status of a national waste legislation
		Status of a national e-waste legislation
		Corruption perception index
	Economy	Capital cost (industrial investments)
		Secondary raw material market
	Society and culture	Civil and political liberties
		NGO activities
		Recycling culture
		Environmental awareness in society
	Science and technology	Knowledge in WEEE recycling technologies
		Research in WEEE management / recycling technologies
Recycling system	Material flow	WEEE generation per capita
		Closed loop recycling management
	Technologies	Efficiency of material recovery
		Quality of recovered material
	Financial flow	Financial coverage
		Externalities coverage
		Financial incentives for eco-design
Impacts	Environment	Final disposal of WEEE in unsave landfills
		Emissions of hazardous substances
	Human health	Health and safety implementation at workplaces
		Exposure of neighbouring population to hazardous substances
	Labour	Number of jobs generated
		Income distribution

middle layer being the recycling system and the core layer consisting of the impacts on environment and health. This provides a description of the complex inter-relationships between e-waste recycling systems, society and the environment.

- Characterize and visualize an e-waste recycling system using four aspects, which may be represented as separate layers on a map: (1) the material flow; (2) the value added chain; (3) the labour resources required; and (4) the risks involved.

An indicator system was developed in order to structure, analyze and compare WEEE management systems from different countries. The indicators were weighted[2] and rated on a three point scale. The system considers the prevailing structural framework (politics and legislation, economy, society and culture, science and technology), the quality of the existing recycling system and its impacts on environment, human health and labour (see Table 6). This method is based on a utility analysis, which enables the multi-dimensionality of complex evaluation problems to be taken into account.

[2] Weighting was carried out on the basis of 1) findings from the survey reports, 2) according expert opinions, 3) global databases (i.e., www.nationmaster.com) and 4) assumptions in the case no reliable information sources could be identified.

The assessments in the three countries confirmed the relevance of the e-waste issue and the need for support in e-waste management in all assessed countries. Three key issues emerged.

- First, in all three assessed urban areas purely business-driven e-waste recycling systems have come about without any government intervention. Any development in these e-waste sectors will have to be built on the existing set-up.
- Second, in China and India, a complex e-waste handling infrastructure based on and executed by a very entrepreneurial informal sector has developed, reflecting a long tradition in waste recycling. Rag pickers and waste dealers easily adapted to the new waste stream and a large number of new businesses were created in re-using components or extracting secondary raw materials. In South Africa with its important (gold) mining sector and state of the art metal recycling, the existing industry had no difficulty integrating the new waste stream.
- Third, the relevant stakeholders in each country are aware of the shortcomings of the current e-waste handling systems. They have declared e-waste management as a priority issue and have started to formulate strategies for improvement. In India, metropolises are facing rapidly growing e-waste quantities, for instance, in the 'Cyber City' of Bangalore. Low risk processes, such as the manual dismantling of WEEE, offer good job opportunities for low and medium skilled labour if given proper training and access to the necessary and affordable technologies. However, some of the recycling processes are extremely harmful and need to be transferred to formal industries. China is facing similar difficulties aggravated by having illegal imports exceed their existing recycling capacities. The central government has designated Zheijiang (one of the most affected areas) as the e-waste pilot province to test solutions for transposing and implementing the new WEEE legislation. Upon successful implementation, the developed WEEE management system should serve as a model for replication to the other provinces. South Africa is relying on its efficient and large recycling industry, expecting it will not encounter difficulty in managing the recovery of materials from e-waste. However it currently lacks an efficient take back scheme for consumers and therefore only a fraction of the discarded EEE (estimated 10%) finds its way to recyclers. Currently the WEEE strategy group and private initiatives in Cape Town and Johannesburg are organizing "Green e-Waste Channels" which guarantee users minimum risk, but optimum value-added disposal of certain WEEE.

4. Conclusions

E-waste is an emerging issue, driven by the rapidly increasing quantities of complex end-of-life electronic equipment. The global level of production, consumption and recycling induces large flows of both toxic and valuable substances.

The international regulations mainly developed under the Basel Convention, focusing on a global ban for transboundary movements of e-waste, seem to face difficulties in being implemented effectively; however, a conclusive account of the situation and trends is not yet possible. On a global scale some attempts have been made to identify past, present and future e-waste streams. The focus has been laid on quantities and in some cases on routes and spatial distribution, but a global perspective is still lacking.

The introduction of a comprehensive legal framework by several OECD countries and notably by the European Union and its member states is not only intended to forward elaborate WEEE management systems but also better product designs. The development of these legal frameworks is starting to transform perceptions and production in non-OECD countries. Exports to the EU are at stake both due the restrictions on hazardous substances (RoHS Directive) and the required compliance with the WEEE Directive, foremost due to the financial implications it brings with it of guaranteeing that all EEE imported into the EU is recycled.

Non-OECD countries are rapidly becoming major EEE producers and are interested in closed loop material cycles to access urgently needed raw materials. At the same time this could offer business opportunities for labour intensive dismantling and recycling operations in low income economies. However assessments have shown that severe shortcomings in capacities, skills and technologies put workers and the environment at considerable risk.

Although awareness and readiness for implementing improvements is increasing rapidly, there are many *obstacles* to manage end-of-life products safely and effectively in industrializing countries:

- *The lack of reliable data* poses a challenge to policy makers wishing to design an e-waste management strategy and to an industry wishing to make rational investment decisions.
- *The lack of a safe WEEE recycling infrastructure in the formal sector* and thus reliance on the capacities of the informal sector may pose severe risks to the environment and human health. However, c*ollecting and pre-processing* can be handled efficiently by the informal sector and — at the same time — can offer numerous job opportunities.
- *The lack of international standards* for simple but efficient WEEE management systems delays their implementation. As a first step, the collection of 'best practice' examples or 'lessons learnt' from carefully designed pilot implementations in industrializing countries would help to accelerate the mitigation process.

Empa's assessments in Delhi, Beijing and Johannesburg have revealed deficits and suggest the following recommendations:

- *Technology and skills:* Support (in)formal SMEs and larger smelting industries (processing metal, glass and plastic wastes) through specific training and consultancy in cleaner technologies and process handling to improve current e-waste processes by introducing best affordable technologies (BAT) and by upgrading and qualifying low- and medium-skilled labor.
- *Policy and legislation:* Support municipalities and/or provincial governments in the drafting, the (public) consultation and the implementation of legislation on e-waste handling by offering advice and exposure and by testing pilot management schemes.
- *Business and finance:* Support securing economic efficiency and sustainability of e-waste management systems by optimizing the value added and improve the effectiveness of collection and recycling systems (e.g., public–private-partnerships in

setting up buy-back or drop-off centers) and by designing-in additional funding e.g., advance recycling fees (ARF).

Although each of the assessed countries needs to develop expertise in all three areas to tackle its potential e-waste management problems, most countries already have specific expertise, which can be used and shared. To optimize learning and maximize the efficiency of support for implementing improvements, a knowledge partnership in e-waste management is proposed in the form of an international WEEE Competence Centre. Partnerships among developing and developed countries offer the possibility to develop new models for e-waste management that will benefit users, manufacturers, and recyclers in all countries.

Acknowledgements

The work reported here was funded by the Swiss State Secretariat for Economic Affairs (seco). The authors would also like to thank Thomas Ruddy, Empa, and the three anonymous reviewers for their helpful comments.

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