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Editorial

Electronic waste—an emerging risk?

In 2004, more than 180 million personal computers (PCs) were sold worldwide. In the same year, an estimated 100 million obsolete PCs entered waste streams and were either recycled for the recovery of materials or finally disposed of. A PC may contain up to 4 g of gold and other valuable materials that can be recovered at a profit, particularly if the work is done in low-income countries. However, as is the case with almost all present-day electronic products, a PC also contains toxic substances such as lead, mercury, arsenic, cadmium, selenium, and hexavalent chromium. In many parts of the world, both formal and informal recycling industries that deal with the rapidly growing streams of *Waste Electrical and Electronic Equipment (WEEE)*, or *e-waste* for short, have emerged.

For the EU15 (the 15 countries constituting the EU before May 2004), the WEEE generated per capita today is between 4 and 20 kg/a (Widmer et al., in this issue). The range of uncertainty is mainly due to definitional problems, as it is typical for the entire e-waste topic.

Computers are only one type of WEEE. However, given the trend towards *pervasive computing*, which means that more and more everyday commodities will contain microprocessors in the future, the borderlines between ‘classic’ electrical equipment (such as refrigerators) and electronic equipment will become blurred. One can already see today that more and more objects that used to be considered purely ‘electrical’ are now equipped with computer chips, and thus have turned into ‘electronic’ objects. Today, more than 98% of all programmable microprocessors are embedded in commodities that are usually not perceived as computers (e.g., household appliances and toys). Even more relevant from an environmental point of view, many commodities that until recently were considered ‘non-electric’ are now being equipped with microprocessors for extended functionality, or with radiofrequency identification (RFID) transponders for contactless identification (Hilty et al. 2005; Oertel et al. 2005).

Both the old (device-like) and new (embedded) types of information and communication technologies (ICTs) are spreading out rapidly, leaping geopolitical borders and penetrating our everyday lives across traditional categories of basic commodities. Given these trends in ICT diffusion and application, it is likely that the dissipation of valuable and toxic materials due to the distribution and disposal of electronics will continue, unless effective countermeasures are taken. The hope that the continued miniaturization of electronics, according to the so-called Moore’s Law and related technological trends, will

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solve the problem in the long run is neither supported by experience nor by the expectations explicitly stated by ICT manufacturers.

Experience shows that the miniaturization of devices is usually counteracted by the growing numbers of devices produced. For instance, the considerable reduction in the average physical mass of a mobile phone from over 350 g (1990) to about 80 g (2005), which corresponds to a reduction by a factor of 4.4, was accompanied by an increase in the number of subscribers, which in turn led to a rise of the total mass flow by a factor of 8.0 (data for Switzerland; Hilty et al. 2005). In every case of miniaturization in digital electronics thus far, the price per functional unit has fallen and triggered greater demand, which compensates–or even overcompensates–for the miniaturization effect in terms of mass flow. There is no evidence that this rebound effect of miniaturization will no longer apply if the visions called 'pervasive computing,' 'ubiquitous computing,' or 'ambient intelligence' become real.

Quite the contrary, IBM expects that in the next 5–10 years, about 1 billion (10^9) people will be using more than a trillion (10^{12}) networked objects across the world. This would mean that there would be an average of 1000 'smart objects' per person in the richer part of the world, each containing a processor and some communication module. If we assume that the average mass of an electronic component used to make an object 'smart' is about 10 g and that such a component would be in service for about 1 year, the resulting per-capita flow of e-waste amounts to 10 kg/a. This value is on the same order of magnitude as today's e-waste in industrialized countries, as mentioned above. We can conclude that implementing the 'smart objects' vision would not render the mass flows of electronic waste negligible; however, it will certainly change the quality and manageability of these flows.

Taking other technological visions literally can even lead to dramatic results. One example is the vision of 'e-grains'—very small processors that are envisioned to be used as 'intelligent wall paint,' turning walls into large-scale displays and rooms into distributed computers. In a study for the Swiss Center for Technology Assessment, it was hypothetically assumed that this technology would be applied to give every inhabitant of Western Europe, North America, and Japan one 'intelligent room.' Assuming further that nickel will still be used as a constituent of e-grains, it was estimated that more than 40% of the world's annual nickel production (1.2 million tonnes in the year 2000) would be required to produce the wall paint (Hilty et al 2005).

This example shows that the supply of exotic raw materials could become a limiting factor for future electronics production. The temporary shortage of tantalum that occurred in 1999–2001 demonstrated this problem. Only two companies extract tantulum from the mineral coltan in the Democratic Republic of Congo and Australia. This scarcity appreciably slowed the growth of the ICT industry (e.g., in the mobile phone and games console segments) (Horvath 2002).

In the project 'The Future Impact of ICT on Environmental Sustainability' for the European Commission, a socio-economic simulation study with a time horizon running up to 2020 was carried out for three different policy scenarios (Hilty et al. 2004). Even in the scenario which assumed that environmental regulation would be put into force to internalize external costs (e.g., accounting for the externalities of extracting and processing raw materials, supplying energy, and disposing of waste), the total EU15 WEEE mass flow increased by a factor of 2.7 (compared to the level of 2000) in the best case and by 4.0 in the worst case. In the two scenarios without additional environmental regulation, the WEEE flow increased by a factor of 3.1–7.0. The large spans between best-case and worst-case results are due to parameter uncertainties.

Irrespective of the many details that may be debatable, the considerations set out above suggest that the life cycle of electronics has to be improved significantly if we are to avoid an accelerated loss of scarce raw materials and emission of toxics into the environment. When e-waste is disposed of, recycled, or put into a landfill with domestic waste without any controls, there are predictable negative consequences for the environment and for human health.

The rapidly increasing WEEE mass flow, combined with the trend towards embedded electronics, makes WEEE an emerging risk for society. Reinsurance companies use the term 'emerging risk' in cases where a high potential for damage has to be assumed, but the traditional quantification of the risk as the extent of damage weighted by the probability of occurrence is not or not yet applicable because the type of risk is novel and has evolved gradually (Spuehler 2003).

This special issue of *Environmental Impact Assessment Review* is an attempt to collect the existing knowledge on the emerging risk of growing e-waste streams. Some of the contributions are outcomes of the first international knowledge management project on the electronic waste problem, 'Knowledge Partnerships in E-Waste Recycling,' funded by the Swiss State Secretariat of Economic Affairs (seco) and carried out by the Technology and Society Laboratory at Empa, the Swiss Federal Laboratories for Materials Testing and Research (Empa, 2005).

Rolf Widmer and his co-authors first give an overview of the quantities and composition of e-waste, the hazards, as well as the economic value of discarded electrical and electronic appliances. They also provide insight into the legislation and approaches being taken to manage these growing quantities of e-waste, with a special focus on the situation in transition and developing countries.

Charlotte Hicks, Rolf Dietmar, and Martin Eugster focus on the situation in China, where a large recycling industry has emerged in the informal sector, processing both domestic and imported WEEE. They focus on legislative issues in the context of the environmental, human health, and economic impacts of e-waste recycling.

Martin Streicher-Porte and his co-authors have assessed the management and recycling of WEEE in the city of Delhi, India. The personal computer was defined as a tracer for which a model was designed, depicting the life cycle of the PC, from production through sale and consumption–including reuse and refurbishment–to the material recovery in the mainly informal recycling industry.

Deepali Sinha-Khetrival, Philipp Kraeuchi, and Markus Schwaninger compare the e-waste recycling systems of the informal type, as they have emerged in India, with the system that has been implemented in Switzerland and discuss their economic, social, and environmental aspects.

Mario Schmidt introduces and discusses a methodology for the analysis of WEEE recycling systems based on a production theory approach. In transformation processes such as those that occur in production or recycling, this approach makes it possible to distinguish stringently between the economic revenue from a process, on one hand, and the economic and ecological expenditures for it, on the other hand. This approach can be transferred to systems of processes (e.g., recycling networks) in order to determine the system revenue and system expenditure. With the aid of an example developed jointly with Hewlett Packard Europe, the paper outlines how this approach can be employed in the field of e-waste management.

Roland Hischier, Patrick Waeger, and Johannes Gauglhofer pose the question of whether the recycling of e-waste under the conditions of industrialized countries pays off in environmental terms. Using the Swiss WEEE take-back and recycling systems as an example, they show that within the complete recycling chain, the sorting and dismantling activities of the companies are of minor environmental relevance—the main load is to be found in the treatment needed to upgrade the products from those processes into secondary raw materials. When comparing the environmental loads from WEEE recycling with those due to the baseline scenario (incineration of all WEEE and primary production of the raw materials), recycling definitely proves to be preferable from an environmental perspective.

Wolfram Scharnhorst and his co-authors present a life cycle assessment (LCA) study of mobile phone network components. They assess the relative environmental relevance of the production, use, and end-of-life phases using the IMPACT2002+ method. Focusing on the end-of-life treatment options, the authors show that recycling network materials leads to a reduction in environmental impacts both in the end-of-life phase itself as well as in terms of the avoided primary production of materials that are recovered.

Patrick Waeger and his co-authors finally analyse the implications of the disposal and recycling of packaging materials containing 'smart labels' for radiofrequency identification (RFID), and discuss the results from the perspective of the precautionary principle. They argue that a broad application of 'smart labels' bears the risk of dissipating both toxic and valuable substances and of disrupting established recycling processes, and show how these risks can be minimized by precautionary measures.

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