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International activities on E-waste and guidelines for future work

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Abstract

The status of knowledge of e-waste issues is surveyed from an international perspective. Existing estimations of domestic generation and international flows of e-waste are reviewed. While initial estimates suggest that there is a substantial and increasing mass of waste to be handled, analysis is clearly in its infancy. The status of international research on green electronics and e-waste is also surveyed. Thus far work has focused more on issues relevant to the developed world, in particular manufacturers. Surprisingly, there is a significant lack of risk assessments addressing leaching of heavy metals from electronics from landfills, despite the fact that this concern has been a major driver of legislative activity around the world to curb the use of landfills as an end-of-life option. NGOs have spearheaded research into the e-waste problem in developing countries, with response emerging from research communities in Europe and Japan. Also, the context for developing future research activities to solve the e-waste problem is discussed. One key issue is the multi-criteria nature of the challenge: it is desirable to maximize reuse of equipment and economic development while minimizing environmental burdens and economic costs. Multi-stakeholder aspects are also important: the issue is politically contentious, both within and between nations. It is argued that, to the extent possible, effective research requires collaboration between different regions and societal sectors, and debate on solutions should be rigorous and take place in a neutral arena.

Keywords

e-waste, materials flows, research needs, environmental impacts

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1. Introduction

Informal recycling of waste electronic goods (e-waste) in developing nations is emerging as a new environmental challenge for the 21st century. Exposés by NGOs such as the Basel Action Network, the Silicon Valley Toxics Coalition and Toxics Link have revealed that home-grown computer recycling systems in China and India are wreaking environmental havoc. It is suspected that similar problems are on the rise elsewhere as well. In these cases, waste electronics is usually processed by "backyard" industries under the most primitive of processes. For example, wires are collected and burned in open piles to recover re-saleable copper. Circuit boards are treated in open acid baths next to rivers to extract copper and precious metals. Volumes of waste equipment needing processing are increasing rapidly in both the industrialized and industrializing worlds. Despite significant attention from the media and enactment of some national level trade bans (most notably China and India), the problem is apparently worsening.

Social responses to this new challenge, such as research and policy development, are starting in various parts of the world. Finding appropriate solutions and achieving consensus and implementation is complex. Unlike many traditional wastes, the main environmental impacts of e-waste mainly arise due to inappropriate processing, rather than inherent toxic content. Also, drawing lines between secondary goods intended for reuse and wastes is difficult. There are social benefits to secondary markets, especially computers, as they make goods available to low income people, raising standards of living. Given that unregulated processing in developing countries generates income, there is a strong economic pull driving the creation of an informal sector, which poses a challenge for enforcement of regulations.

Analyzing and formulating appropriate social response clearly requires efficient, networked activities between researchers, businesspersons, and policy makers around the world. One important aspect is assessing the state of knowledge and activities internationally. The first part of this article attempts to characterize (partly) this status. The second part analyzes outlines a conceptual structure for developing future research and activities to address the e-waste problem.

2. Status of international knowledge and activities addressing e-waste

2.1 E-waste generation and flows

How much e-waste is being generated around the world, and from where and to where is it moving? These questions are crucial, yet very difficult to answer given current systems of gathering information. A primary obstacle is that flows of secondary and waste products are by and large invisible to national statistics on production, sales and trade in goods. Few, if any statistical categories are defined to distinguish new goods from used or waste ones. The first task in this article will be to survey results of studies attempting to characterize generation and flows of e-waste.

E-waste generation

Researchers with the e-waste project based at EMPA in Switzerland (of which more will be said later) have collected results from different efforts to estimate total generation of waste electronics in selected countries. The results are summarized in Table 1. The first question to ask is whether these amounts are significant. As a benchmark, note that US consumption of steel and aluminum are 120 million and 9 million tons respectively. But this comparison begs with questions of significance, as potential environmental impact cannot generally be understood by mass alone. If e-waste is informally recycled in the developing world, it seems that relatively small quantities can cause significant impacts. If this e-waste instead is put in properly managed landfills in the developed world, the impacts are almost certainly much less, but it is not yet clear how much less. More on this will be discussed in section 2.2.

Table 1: e-waste generation in selected countries
(source: http://www.ewaste.ch/facts_and_figures/statistical/quantities/)

Country	Total E-waste Generated tonnes/ year	Categories of Appliances counted in e-waste	Year
Switzerland	66,042	Office & Telecommunications Equipment, Consumer Entertainment Electronics, Large and Small Domestic Appliances, Refrigerators, Fractions	2003
Germany	1,100,000	Office & Telecommunications Equipment, Consumer Entertainment Electronics, Large and Small Domestic Appliances, Refrigerators, Fractions	2005
UK	915,000	Office & Telecommunications Equipment, Consumer Entertainment Electronics, Large and Small Domestic Appliances, Refrigerators, Fractions	1998
USA	2,158,490	Video Products, Audio Products, Computers and Telecommunications Equipment	2000
Taiwan	14,036	Computers, Home electrical appliances (TVs, Washing Machines, Airconditioners, Refrigerators)	2003
Thailand	60,000	Refrigerator, Air Conditioners, Televisions, Washing Machines, Computers	2003
Denmark	118,000	Electronic and Electrical Appliances including Refrigerators	1997
Canada	67,000	Computer Equipment (computers, printers etc) & Consumer Electronics (TVs)	2005

It must be emphasized that comparison of the figures in Table 1 is complicated by lack of standardization both in terms of what products constitute e-waste and in methods for estimation of generation. It is important to question whether these are reliable figures or not. While it is not within the current scope to assess all of the studies, I will consider one case, that of the US, in more detail. This figure for e-waste generation comes from a United States Environmental Protection Agency (USEPA) report from the Office of Solid Waste[1]. Total generation of waste is estimated by combining data on shipments of new electronics with lifetime. Figures for shipments of new electronics come from national statistics and industry associations, and are presumably fairly reliable. Lifetime of different electronic goods, however, is taken from data from a consulting firm, Franklin Associates. It is not clear how these data were obtained or how reliable they might be. It is thus fair to assume a wide error band for this estimation, perhaps even of the order of $\pm$ 50% or more.

How quickly is the e-waste problem growing? While analyses of this issue are scarce, it can be assumed that disposal of obsolete electronics products is fundamentally driven by the production of new ones. In economic terms, global production of electronics grew 4.4% in 2002 and 6.8% in 2003[2]. One might expect that e-waste trends may grow at a similar scale, though in the short term real figures could be lower as newer products are absorbed into economies. It is likely that growth in e-waste amounts is heterogeneous according to product. For personal computers, whose markets in many developed countries are tending towards saturation, one expects continued increase in e-waste over a time scale comparable to the "closet life" and after that stabilization. But for other products such as cell phones still in rapid growth phase, it is expected that amounts of e-waste should continue to rise rapidly in the medium term.

Used product/E-waste flows

Even less is known about international flows of e-waste. Results of researchers in Japan to characterize these are described elsewhere in these proceedings; here the focus is on work done in other nations. The most well-known result is the study of the UK International Council of Electronics Recyclers done for the Environment Ministry, which characterizes in some detail the flows out of the United Kingdom[3]. They estimate that in 2003 160,000 metric tons of secondary and waste electronic equipment was exported. 133,000 tons of this was IT/telecoms equipment. In this category, 110,000 tons were declared exports and properly documented, while 23,000 tons were undeclared or grey-market exports going to non-OECD countries. While detailed breakdowns of exports per destination were not estimated, receiving regions include China, Dubai, Eastern Europe, Hong Kong, India and Jordan. While no studies identifying flows of e-waste from other European were identified, though there is anecdotal evidence of substantial flows from Western to Eastern Europe (e.g. Germany to Poland).

While no published estimates of exports of secondary electronics/e-waste from the US could be identified, a crude estimate is attempted here by using the principle of mass balance. The recycling rate of computers in the US in 1999 has been estimated at 11%[4]. This leaves 1.92 million tons of electronics either entering landfills or being exported. Roughly 2.2% of input to landfills by weight is electronics[5], which suggests a total of 1.7 million tons at the national level[1]. Assuming the remainder is exported, this suggests that 220,000 tons is being shipped overseas. It must be emphasized however, that as margins of uncertainty are large for all figures used, this is a very rough estimate.

2.2 International research activities

Green Electronics

E-waste processing in developing nations has only recently emerged as an important issue, thus relevant research remains scarce. The overarching issue of assessing and managing the environmental impacts of electronics, however, has a history of research and implementation, especially from the 1990's. Terming this field of research "Green Electronics", major areas of research and activity include:

- design for environment,
- recycling processes and systems,
- eco-labeling,
- disassembly,
- greening supply chains,
- life cycle assessment.

In recent years, meeting the requirements of the European Union's Waste Electronic and Electronical Equipment (WEEE) and Restriction on Hazardous Substances (RoHS) Directives have dominated. For stance, the challenge of finding economically and performance alternatives for lead-based solders has becomes a major target in design for environment.

While an overview of research is beyond the scope of this article, I survey major events that have developed to service the research and implementation community concerned with Green Electronics. In the US, the flagship event is the "International Symposium on Electronics and the Environment", sponsored by IEEE, and has been held annually since 1993 (www.iseesummit.org). International participation in previous years was mainly from Europe, but more recently presentations from Japan and other Asian countries have been on the increase. This is an academic conference, with an open call for papers, peer-reviewing of abstracts and publication of proceedings by IEEE. From 2003, a new annual event, "E-Scrap", has emerged as a new player in the field (www.resource-recycling.com). It is more targeted towards industry and policymakers, and the organizers plan the agenda without issue of a call for papers. In Europe, the main event in the field is "Electronics Goes Green", which has been held in 2000 and 2004 in Berlin. While there has been no regular event in Japan focuses on electronics and the environment specifically, the "International Conference on Ecobalance" (www.sntt.or.jp/ecobalance), held biannually since 1994, and "International Symposium on Environmentally Conscious Design and Inverse Manufacturing" (www.ecodenet.com/ed2005), held biannually since 1999, include much content related to electronics. These are academic style conferences, with open calls for papers.

Research on E-waste vis a vis developing nations

Without a doubt the landmark work in e-waste is the report by the Silicon Valley Toxics Coalition and the Basel Action Network. These two US NGOs published "Exporting harm: the high tech trashing of Asia" in 2002, which showcases the Chinese town of

Guiyu as an example of the severe environmental impacts that can be caused by informal recycling of electronics[6]. The challenge posed by backyard recycling of e-waste has much less attention. 2002 SVTC report by US NGOs. Toxics Link, an Indian NGO, published a report in 2003 arguing that similar problems are occurring in Delhi and other areas of India[7]. A recent study from the Competitive Enterprise Institute in Washington takes a diametrically opposed view on the e-waste[8]. The report asserts that dumping of e-waste into landfills poses essentially environmental risk and that regulating e-waste flows away from landfills induces export to developing countries. Although this position, in particular the latter point, is not backed up with substantive analysis, the report does present a position worth investigating. At the writing for this report, no major research project specifically addressing the e-waste problem in developing countries could be identified in the US or Canada

Though not directly concerned with the issue of e-waste processing in the developing world, a few university groups in North America are investigating the possible environmental effects of leaching of heavy metals from electronics in landfills. Most prominent of these is a University of Florida group led by Timothy Townsend. Empirical results show that while circuit boards and CRT monitors routinely failed TCLP laboratory tests, leaching from actual equipment in landfills seems to be much lower than those indicated by the lab tests[9].

In Europe, the main research project addressing e-waste is based at EMPA in Switzerland (www.ewaste.ch). "Knowledge Partnerships with Developing and Transition Countries in e-waste Recycling" was launched in 2003 and is primarily supported by SECO, the Swiss economics agency. One aspect of the project involves undertaking case studies in India, China and South Africa to characterize e-waste processing practices and conditions in these areas. The conceptual basis of the project follows the "double dividend" approach, which has gained popularity in recent years. This is the idea that enhanced knowledge and management can improve environmental and economic performance simultaneously. Thus major goals are to do to identify best practices and to communicate this knowledge and train practitioners.

Despite the fact that Europe is the birthplace of the WEEE and RoHS directives, there do not seem to be a corresponding level of research activity assessing the impacts of e-waste in landfills. Even those much involved in policymaking could not indicate a particular risk assessment or set of assessments that formed the basis of Directives. As a caveat, the literature search was limited only to English (and Japanese) sources.

3. Developing future activities to address e-waste

3.1 Background

This section is concerned with exploring conceptual frameworks to support future development of research and projects to address the e-waste problem.

Existing research that has been carried out on green electronics has some useful lessons for how the e-waste problem could be addressed. One example is a hybrid life cycle assessment of energy use in manufacturing personal computers from the Information Technology and Environment project at United Nations University (www.it-environment.org). The results are that 260 kg of fossil fuels (or 6,400 megajoules of energy) are required by the network of manufacturing processes producing a desktop system[10]. The hybrid nature of the assessment accounts for processes for which specific data was unavailable by using national economic input/output tables. Adding these "missing processes" doubles the result for manufacturing energy requirements compared to previous studies. This relatively high energy use, combined with typically short lifespans of actual use, implies that computers are more energy intensive that refrigerators, with 80% of life cycle energy use associated with manufacturing. This suggests that extension of life span is a key strategy in managing the gamut of environmental impacts (energy use, chemical use, waste treatment, etc.) associated with computers. Another way to state this is that for computers, the conventional 3R (reduce, reuse, recycle) hierarchy of waste management is tilted even more towards reduce and reuse compared to most other goods[11]. Despite this, nearly all effort thus far in the electronics sector focuses on recycling materials, the environmental "payback" of which is relatively tiny.

International trade in quality used equipment represents an opportunity to bridge the digital divide by making computers more affordable. The raises the issue of opportunities lost by the approach of creating blanket bans on imports of all "end-of-life" electronics. Regardless of whether e-waste being processed in developing countries is domestic or imported, there is a clear need for environmentally and economically effective systems for reuse and recycling.

There is an urgent need for solid analysis exploring different options for meeting the twin objectives of mitigating e-waste recycling impacts and promoting reuse. From the perspective of trade, one end of the spectrum is a free international market in used electronics and e-waste, but with strong investment and regulation mechanisms to ensure it is appropriately handled wherever it lands. While this solution goes far towards meeting multiple social and environmental objectives, it is clearly complex to implement safely. At the other end of the spectrum, one can imagine a complete ban on international flows of non-new equipment, but with effective reuse systems in the developed world. While simple in concept and clearly absolves the developed countries of direct culpability, this it also leaves the developing world without any help to deal with domestic e-waste streams. It also impairs the used market, which has potential social benefit to developing countries. Currently, it is difficult to recommend one option over another, versus a middle ground: Too little is known about environmental and economic implications of different choices.

3.2 Needs : research and otherwise

There are many open and important topics for research relevant to addressing the e-waste problem. Generally speaking, informal economic sectors attract little analysis from either economic or environmental perspectives. Backyard recycling of e-waste is no exception. Outstanding questions include:

- What are the real scale and nature of environmental risks associated with informal recycling?

- Are there alternative low-capital means to achieve reuse and recycling in an environmental safe way appropriate to developing countries?
- Are there instruments, such as finder's fees, that can be used to effect a shift from informal to the formal sector?

Little is known regarding the answers to any of these.

At a more general level, reverse supply chains in general have received far less attention and investment compared to their forward counterparts. Here, the term forward supply chain is being used to refer to the network of firms and activities that produce and deliver goods to consumers starting from raw materials. The reverse supply chain that which collects products no longer desired by a given consumer and refurbishes for other consumers, recycles, or otherwise processes wastes.

There are many factors behind the lack of knowledge and research done to support management of informal sectors. One is that lack of human and knowledge capital to undertake analysis and planning. Generally speaking this increases as with higher consolidation and value-added of an industry. An informal sector clearly at the lowest end of this spectrum. The best-planned recycling systems are generally designed in the developed world given constraints of high wages and low demand for used machines and parts. Solution for the developing world may look quite different, but remain unknown due to lack of appropriate analysis and planning. Another is lack of an information infrastructure supporting analysis. Problems without data sources to inform analysis are often neglected.

Research alone will clearly not be sufficient to solve the problem. Even armed with appropriate knowledge, those in the informal sector have limited capacity to safely implement all processes. A new system of regulations, incentives, standards and/or investment flows is needed. For example, enforcing regulation of the informal sector is likely impractical, thus risky parts of the reverse supply chain (such as recovery of copper from wires) at least ought to be handled by a formal, regulated sector. Achieving this clearly requires some kind of policy to ensure this, call by NGOs for a complete ban on exports of e-waste is one approach. Though it is not clear how enforceable this is and would only help for the non-domestic portion of the e-waste stream. Another possibility is an incentive system in which a domestic formal sector is given responsibility for implementing risky processes, and is obliged to pay the informal sector an attractive price to pass on equipment/parts. Another example of an organizational need is standards for certifying equipment for the secondary market. While the Basel Convention creates a clear exemption for equipment intended for reuse, it is not yet clear how in practice to properly distinguish these from waste. These are but two examples of the kinds of organizational developments that could address the problem. Analysis and implementation of appropriate choices is needed.

In addition to the research and organizational issues outlined above, politics (in the broad sense of the word) is also important. E-waste is a contentious issue, with complicated interfaces of the interests and perceptions of industrializing and industrialized countries governments, manufacturers, recyclers, and NGOs. How to achieve an appropriate balance of interests in the discourse leading to social response is important. For example, original equipment manufacturers (OEMs), under current market conditions, have limited incentive to promote reuse. Yet they possess far more economic and political clout compared to the reuse industry, which is both smaller and more diverse. Also, is it appropriate for environmental NGOs in rich countries to dominate the discourse? These organizations generally place the environment above all other considerations, such as the economic livelihood of workers in the informal sector. The interests of the developing world should clearly be represented in the discourse, but exactly whose interests? Governments and workers are not always on the same side.

3.3 Guidelines for development of future activities

I argue that it is appropriate to develop activities for social response to the e-waste considering the issues outlined above. In this section a set of guidelines for future projects and activities is suggested.

A. Multi-criteria objectives

It is important that activities explicitly recognize that the e-waste issue in developing countries is a multi-criteria challenge. There are no doubt trade-offs between objectives, and the implications of proposed solutions on different issues should be analyzed and debated when considering adoption.

The following is a proposal for objectives to consider in enhancing the reverse supply chain for electronics:

1. Mitigation of environmental harm from e-waste processing in the industrializing world,
2. Increased utilization of resources and increasing reuse of equipment when appropriate,
3. Improving economic and social development, particularly in the industrializing world.

B. International and multi-stakeholder collaboration

Given the lack of background data and analysis existing to inform solutions, a great deal of research is needed. It seems clear that this analysis will require information from firms, developing countries, expertise from academia, etc. Thus the research process should be by necessity be multi-stakeholder, a collaboration between different sectors of society. It is also important to build North-South cooperation, respective sources and sinks of e-waste under current system. Also, there is a need for education and capacity building for stakeholders involved in planning business and policy systems.

C. An open data/analysis infrastructure

Given the newness of the field, research will require building of a new infrastructure for related data and analysis. In this process, it is key that the infrastructure follow, to the extent possible, be open source, transparent, and widely disseminated. One implication is that analyses and underlying data should be open to the public as possible. This may seem a trivial point, but in point of fact much environmental related research is to a large degree "black box", meaning that underlying data and assumptions are not properly reported. The explanation of this lack of reporting has substantive reasons, but partly it is simply custom. On one hand, analysis of industry often requires firm-level data, which companies are understandably reluctant to release for general use. However, there is always a degree of information which can be considered "safe" and it is important to try to push the boundary towards public release to the extent feasible. Also, limited space on the printed page has traditionally limited the degree to which researchers could practically report underlying data and assumptions. With the advent of the Internet, there is no longer any obstacle, but research communities have not yet substantially reformed traditional reporting requirements.

There are two main reasons why an open source model is important. One is that research resources are limited, thus synergy is key. Proper reporting of analysis and data allows research works to better build on previous ones, instead of standing alone. The other reason is that the solutions suggested by research have substantial potential implications for the environment and lives of workers. It is not reasonable to expect society to pick solutions which are based on analysis for which underlying data and assumptions are not publicly available.

It is also important that all relevant information should be easily accessible; the Internet will clearly play a major role in this. In addition to commitments from individual groups to put results on the Web whenever possible, there is a need for web-based meta-indexes to serve as information clearinghouses for results and data from different groups and regions.

D. Neutral arena for discourse on solutions

Given the contentious aspects of the e-waste problem, it is important that the future discourse be pluralistic, allowing representation of the interests of key actors. In particular, workers in developing countries and more diverse industry sectors should also have a voice. It is thus important to have a neutral arena where this discourse can occur. While there is no completely neutral organization, the United Nations system seems a relatively appropriate forum for such an arena. As a caveat, the objective of plurality must be balanced with practical considerations. "Too many cooks spoil the broth", as the saying goes, and nearly everyone has experience with a group or committee that became paralyzed to inaction due to the inability to achieve consensus. Thus the discourse needs to be fair, but also lead to actual implementation of solutions. This is certainly a challenge, but it is exactly the kind of challenge we increasingly face in a interconnected and globalized world.

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