REDUCING THE ENVIRONMENTAL AND SOCIAL IMPACTS OF E-WASTE RECOVERY IN DEVELOPING COUNTRIES THROUGH TECHNOLOGY AND POLICY

Jeremy L. Rickli¹, Abigail R. Clarke¹, Karl R. Haapala¹, Millicent Addo², Jaime A. Camello³, and John W. Sutherland¹

¹Department of Mechanical Engineering-Engineering Mechanics, Sustainable Futures Institute, Michigan Technological University, 1400 Townsend Dr., Houghton, MI 49931 USA, jlrickli@mtu.edu, arclarke@mtu.edu, krhaapal@mtu.edu
²Nelson Mandela School of Public Policy and Urban Affairs, Southern University and A&M College, 412 Higgins Hall, Baton Rouge, LA 70813 USA, madjeibe@yahoo.com
³Grado Dept. of Industrial and Systems Engineering, Virginia Polytechnic Institute and State University, 250 Durham Hall, Blacksburg, VA 24060, jcamelio@vt.edu

ABSTRACT
Rapid economic development and technological progress in the past half century has increased the quality of life and standard of living in many nations around the world. At the same time, the volume of production, consumption, and disposal of consumer goods has accelerated to a rate in developed countries, and to a lesser degree in some industrializing countries, that is unsustainable. The global economy relies on the labor and natural resource base of developing countries, leading to economic development in those regions, but at the cost of environmental damage and social change. The past several decades have seen a dramatic increase in the disposal of electronics including computers, cell phones, media players, and televisions, all of which have shortened their life cycles compared to traditional manufactured goods. Inhabitants of developing countries have recognized an economic opportunity in the recovery of materials from consumer e-waste, but infrastructure, worker safety, environmental degradation, and appropriate policy initiatives are substantial concerns. Given these concerns, advanced technologies and safe practices are needed for the recovery and treatment of e-waste to provide a path toward economic development while reducing environmental impacts and social concerns. Success of e-waste recovery programs in developing countries relies on creating viable remanufacturing logistics and infrastructures, and the formulation of domestic and foreign e-waste policies. Appropriate reverse logistical methods, product treatment, and development impacts with regard to e-waste are discussed. In addition, Extended Producer Responsibility (EPR) is explored as a basis to formulate e-waste policies in developing countries. This approach will aid in the improvement of the sustainability of waste electronics and electrical equipment from a life cycle perspective.

KEY WORDS:
Waste Electronics and Electrical Equipment, Extended Producer Responsibility, Developing Countries, Value Recovery

1. INTRODUCTION
It has been reported that the wealthiest 20% of the global population accounts for approximately 86% of global private consumption. In contrast, the poorest 20% account for a mere 1.3% (UN, 1998). The difference is disturbing when considering that though the majority of the wealthy are located in developed countries, and developing countries are striving to transition to similar levels of economic productivity. The transition to developed economies will dramatically increase global consumption and elevate product demand and concomitant wastes to critical levels. Researchers, technology, developers, and policymakers have investigated many strategies to improve product design, reduce consumption, and facilitate end-of-use treatment of consumer products. Imposing limits on consumption is becoming ever more difficult as new and used products become more accessible around the world. Consumption is additionally influenced by advances in product technology and accelerated design cycles, which lead to shortened product life spans, such as for cell phones and computers. As a result, value recovery has attracted attention as a method to reduce the environmental and social impacts of consumer product waste. Value recovery refers to the act of capturing residual value from a product at its end-of-life through remanufacturing, reuse, and recycling activities. Value recovery has the potential to contribute to sustainability as a viable and profitable industry with positive social impacts, such as the creation of new businesses, employment opportunities, and improved waste management infrastructure.

Value recovery has grown in developed countries due to high raw material costs, awareness of the harmful effects of hazardous waste landfilling, and dwindling landfill space. Most notably, recovery programs in the United States have expanded from the household
collection of metals, plastics, newspapers/magazines, and cardboard to include cell phones, vehicle batteries, and used motor oil. However, legislation in the United States, Japan, and the European Union, as well as other nations, is evolving to require increased producer responsibility throughout product life.

In developing countries, value recovery initiatives are needed to address problems associated with the importation of recovered products, particularly e-waste, and the challenges of properly managing the consumer products waste stream (Troschinetz and Miheleic, 2008). Currently, a majority of imported e-waste is unrepairable and thus immediately disposed, often illegally. Products that can be repaired are re-distributed but are likely to be improperly disposed of due to non-existent or insufficient recovery networks and waste management practices (Fig. 1). Mismanagement is augmented by the lack of an original manufacturer presence and importer responsibility, but is also affected by social and political aspects such as governance and policy formation.

Developing countries often have a wealth of natural resources that offer the opportunity to improve economic competitiveness by supplying material and energy to developed countries. Material extraction activities can exacerbate unsustainable development. Implementation of value recovery systems in developing countries institutes an infrastructure that would support sustainability by providing avenues for material reprocessing and post-consumer waste management as consumption levels increase. Specifically, value recovery systems provide improved product management, treatment, and disposal (Fig. 2).

This paper discusses the key issues related to the implementation of value recovery activities in developing countries as a result of electronic waste (e-waste) exportation from developed countries. Focus is placed on reverse logistics, product treatment, and policy measures essential to value recovery. Aspects unique to developing countries that affect the viability of each approach are discussed.

2. E-WASTE EXPORTATION

Importation of Waste Electronics and Electrical Equipment (WEEE) by developing countries will inhibit sustainable development opportunities unless appropriate infrastructure, waste management, and value recovery methods exist for managing the waste. Particular focus has recently been placed on e-waste exportation; however, exportation of other consumer products at end-of-life, e.g., automobiles and clothing, is growing and also must be addressed (Cassells et al., 2005; Morana and Seuring, 2007).

The motivation for exporting used products such as e-waste is apparent from a developed country perspective. Consumer product waste normally destined for landfill is exported, freeing up valuable landfill space. From an importing country perspective, financial gains are attractive through the recovery and resale of reusable products and valuable materials. If the majority of products are beyond repair the financial advantages may not be realized due to high labor and disposal costs.

The Basel Action Network (BAN) has performed extensive studies concerning e-waste exportation from developed countries. The BAN found that 500 containers filled with used computers and electronics from the EU and North America are received each month in Lagos, Africa, for example. If all of the used products were repaired and redistributed, e-waste levels would be reduced and valuable technology would be distributed to the African population. Under the current situation, however, recovery or disposal likely occurs in an unsafe manner or illegally. Complete repair and redistribution is the most attractive situation for extending product use, but local experts have determined that 25-75% of all electronics received are not capable of being repaired and are immediately disposed (BAN, 2005). In effect, e-waste from developed countries is exported to developing countries for disposal due to less restrictive environmental regulations in developing countries (Fig. 1), and value recovery operations for the products are not pursued.

The situation in Asia is similar to that in Africa. Americans reportedly spent $125 billion on new technologies and machines in 2006 (ABC, 2006), 75-80% of the aged, unwanted equipment was exported to Asian countries, most notably to India and China. Compounding the problem in India is their production of 146,180 tons of domestic hazardous e-waste (for 2007), an amount projected to triple over the next five years. In response to this situation, various institutions, including the University of California, have agreed to eliminate exportation of their e-waste (Chopra, 2007). The main drawback of this approach is the elimination of potentially recoverable products and e-waste that could serve as a valuable resource. Without access to used equipment, people in developing countries have limited access to important technologies, including communication technology.

Cell phone communications span all continents due to fewer barriers than with land line networks (Noffsinger, 2004). A resolution to the difficulty of purchasing new cell phones by poorer populations has been reached in part by importing and reselling recovered cell phones from developed countries. Communications capabilities increase dramatically by redistributing cell phones, as does the potential for an e-waste catastrophe. As alluded to previously, the e-waste situation has been compounded by decreasing cell phone life spans. Cell phones are estimated to have an average life span as short as 18 months to 2 years (Noffsinger, 2004). Moreover, rapid technological advances serve to make cell phones obsolete even quicker.
Recovery of cell phones occurs in developing countries, but often via ad hoc approaches. In India, recovered cell phones can be reconditioned at 40-60% of the costs of original manufactured phones with 20% of the work (Mitra, 2007). Increased availability resulted in 54 million total cell phone connections in India in 2005, which may be insignificant compared to its population, but growth has been projected to be 50% annually. As exportation and redistribution of cell phones continues, waste management difficulties loom. In addition, product responsibility is not assigned to manufacturers or dealers. However, dealers often voluntarily take back used cell phones in exchange for new ones due to future resale potential. The dealer-consumer cycle showcases a positive attribute of value recovery systems, but the system fails in the case of cell phone disposal. Lack of dealer and manufacturer responsibility and an effective value recovery system does not discourage illegal disposal of cell phones. It can be seen from this example that the exportation of e-waste represents a significant environmental sustainability concern, but is integral to the future economic sustainability in developing countries. Technology and policy development must attempt to resolve this conundrum to ensure that societal needs are met without undue social, environmental, or economic impacts.

3. VALUE RECOVERY POLICY

3.1 Extended Producer Responsibility

Since the 1991 Ordinance on Avoidance of Packaging Waste was passed in Germany, the concept of extended producer responsibility (EPR) has gained momentum as a policy mechanism for sustainable development (Kibert, 2004). EPR places a legal duty on manufacturers to manage their products over the entire life cycle. This duty requires companies to approach design and manufacturing activities with consideration of potential impacts even after a product reaches the end of its useful life. Such a legal responsibility inherently reduces the potential for human health and environmental impacts. However, much of the cost burden traditionally born by society (e.g., disposal costs) may be placed on individual companies. Moreover, the lack of comprehensive life cycle assessment tools at the design stage makes it time-consuming or even impossible for product manufacturers to anticipate impacts that may not come to fruition for decades in the future. Regardless, numerous EPR policies are being implemented as a means to reduce environmental impacts.

EPR policy approaches include administrative, economic, and informative instruments (Nnorom and Osibanjo, 2008). In terms of e-waste, an EPR policy can take the form of mandated take back (administrative), product taxes (economic), or product material information provided to recyclers (informative). Nnorom and Osibanjo (2008) stated that according to Fishbein an effective EPR program: “1) focuses specifically on the waste generated by end-of-life products, 2) clearly defines what financial responsibility producers have for the collection, transport, and recycling of their products at end-of-life, 3) sets meaningful targets for collection and recycling, 4) differentiates recycling from technologies such as waste-to-energy conversion, 5) includes reporting requirements and enforcement mechanisms, 6) provides producers with incentives to design for reuse/recycling, and 7) provides consumers with incentives to return their used products.”

An example of one the first EPR policies that follows these guidelines is the European Union (EU) directive on end-of-life vehicles (ELVs) that also served as a foundation for the EU WEEE directive (Gerrard and Kandlikar, 2007). Since the EU ELV directive was enacted in 2000, extended producer responsibility policies have been legislated in many countries such as the United States, Japan, and Korea. Korea initially passed legislation requiring manufacturers of packaging materials, batteries, and automotive tires to pay a deposit fee to the government that was refunded upon collection and processing (Wilson, 1996). More recently, the Korean Waste Electronics and Electrical Equipment (WEEE) program established mandatory take-back and recycling requirements (Walls, 2006). Recycling rates exceeded targeted values for televisions and personal computers but were not reached for large scale appliances. Additionally, it has been reported that 60% of large scale equipment is collected by retailers while 30% is collected by local authorities, and a 39% increase in the volume of electronic and electrical equipment recycled occurred (Park, 2005), but perhaps the most prominent EPR policy is the EU ELV directive.

3.2 ELV Directive

In the EU, between 8 and 9 million metric tons of waste originates from ELVs every year. Directive 2000/53/EC on End-of-Life Vehicles (the ELV directive) was passed in the European Union with the purpose of harmonizing the different national ELV measures and keeping the EU market fair and smooth (EU, 2000). The ELV directive contains instructions on the prevention of waste and collection, treatment, and reuse and recovery of end-of-life vehicles as reviewed briefly below.

Specifically, four articles within the directive aim to achieve EPR for vehicles in the EU. The first of these articles, Article 4, demands policies that place direct responsibility on vehicle manufacturers to prevent waste. Particular emphasis is assigned to hazardous material reduction, design for reuse and recovery, and increasing the quantity of recycled materials from ELVs. Lead, mercury, cadmium, and hexavalent chromium were targeted for elimination by July 1, 2003 as well (Gerrard and Kandlikar, 2007). The fifth article requires ELV and component recovery by means of collection systems that utilize certificates of destruction for confirmation. Critical to Article 5 is the attempt to separate any destruction cost from owners by assigning the costs of policy implementation to manufacturers or importers.

Article 6 of the Directive establishes requirements for material and component removal during ELV storage and treatment, and encourages the use of environmental management systems by producers. Article 7 is the final article with a direct impact on EPR and focuses on guidelines for the reuse and recovery of ELVs by manufacturers or importers. A target date for 95% vehicle reuse and recovery was set for January 1, 2015, however, it has been revealed that, “although the Directive has been almost literally transposed into national law, the end-of-life vehicles management system might not be fully operational” (EU, 2007). The statement illustrates the difficulty of implementing broad-reaching EPR policies.

3.3 EPR for Domestic and Exported E-Waste

The EU ELV directive, among others mentioned previously, has set a global precedent for EPR policies focused on WEEE that can be formulated and implemented in other developing and developed countries. Effects from the policy have resulted in the establishment of electronic take back policies in approximately thirty countries (Nnorom and Osibanjo, 2008). In addition to mandatory programs, global electronics manufacturers including HP, Nokia, and Dell have voluntarily established individual take back programs.
Several obstacles exist for implementing e-waste recovery efforts in developing countries, which may not be present in developed countries. Governance instability, less strict environmental regulations, and insufficient infrastructure are among the barriers that impact the success of e-waste and product value recovery. Advancing recovery technologies in such areas as reverse logistics and product treatment can make the formation of EPR policies in developing countries more probable by making e-waste recovery more efficient and less costly. Actions to sustainably resolve problems associated with the ability of developing countries to handle e-waste remains a top priority. Sustainably resolving the situation will remain critical as exportation of e-waste and product waste from developed countries continues to occur, according to the EU integrated product policy (IPP) project study on the exportation of cellular phones. The IPP project reported that cellular phone refurbishment and distribution to developing markets “will remain a key driver for the collection of handsets from developed markets” (Lindholm et al., 2008).

4. REVERSE LOGISTICS

Successful implementation of a system for reverse logistics for e-waste and product value recovery is extremely critical. Distribution of products to consumers is relatively simple because products are shipped from one central location to retailers. E-waste and product recovery presents a multitude of problems related to network distribution, retailer involvement, and consumer incentives and responsibilities. The importance of reverse logistics is highlighted in a recycling program instituted in the state of Minnesota in the United States. Program members included the Minnesota Office of Environmental Assistance, Sony, Panasonic, Waste Management’s Asset Recovery Group, and the American Plastics Council. The program estimated that approximately 75% of the cost of recovery is due to product collection and transportation (Walls, 2003).

4.1 E-Waste Recovery Networks

The reverse distribution network is complicated since products to be recovered are highly dispersed, especially in the case of household goods. Hence, product collectors must work against system entropy by taking small amounts of unwanted products from many locations and conglomerating these products in one location (Fleischmann et al., 2000). The difficulty in bringing products to a centralized location has significant financial and environmental impacts. Accordingly, logistics make up a substantial portion of costs for a reverse supply chain network (Krikkie et al., 1999). Because of differences in transportation costs between forward and reverse distribution networks, reverse network design is key to economic feasibility of product remanufacturing (Fleischmann et al., 2001).

Reverse logistics hold challenges for any nation, however, logistics within developing countries can be difficult, regardless of the direction of product flow. Many developing countries lack the transportation infrastructure required for smooth logistics. Infrastructure problems include poor facilities for storage, loading and unloading, as well as subpar roads, runways, and train tracks (Razzaque, 1997). In addition, developing countries may have more significant political hurdles, from increased paperwork to expected bribes or general corruption (Razzaque, 1997). Governmental institutions may be unable to enforce compliance with regulations due to lack of funding or training. Recovery network costs are further influenced by the level of EPR instituted.

4.2 Consumer Involvement

Consumers are critical to the recovery of e-waste and used consumer products as a result of the ownership role they assume upon purchasing. The opportunity to illegally dispose of a product is ever-present and requires logistical incentives for product return or retention within established recovery systems. Techniques such as user pays and deposit-refund can have differing effects in developed and developing countries.

User pays incentives include deposit-refund, volume based fees, fee incorporation into product price, and pay for disposal (Hanafiah et al., 2003). The most widely used technique is deposit-refund (Wilson, 1996), popularly used for aluminum cans in the United States, but Fridgen (1990) considers volume based fees to be the most sustainable. Volume based fees directly relate the cost of disposal to the amount of material/products to be disposed of or treated. Each technique is highly applicable to developed countries that have higher income levels, but developing countries do not exhibit the necessary income levels, at the national scale, to support a user-pays philosophy, possibly resulting in increases in illegal dumping. A potentially successful approach is a manufacturer deposit-refund method that was utilized in Korea (Wilson, 1996). Manufacturers pay a deposit to the government during the manufacturing of a product, which is then refunded upon collection and treatment. However, instability and corrupt governance can inhibit a government-manufacturer deposit-refund approach.

5. RECOVERED PRODUCT TREATMENT

For electronics, like other products, multiple value recovery options are available with varying degrees of processing and complexity. Three primary actions are reuse, recycling, and remanufacturing (Fig. 3). Reuse consists of transferring product ownership to another consumer for use of the product in its existing condition; recycling involves the breakdown of a product into different materials that are then processed into material feedstocks (Thierry et al., 1995), and remanufacturing is completed through the repair and refurbishment of used products and components to the same standards as new product/components (Jayaraman et al., 1999). Disposal is another option at end-of-life, but can result in harmful environmental and social impacts and is a lost opportunity for value recovery.

Figure 3 Value recovery product treatment flow chart showing remanufacturing, recycling, and reuse
Additional treatment options can be considered as subsets of the primary recovery options described above. For instance, cannibalization removes a few specific components from a product for reuse, and discards the rest. Repair fixes a product to a level where it will still function (Thierry et al., 1995), and refurbishing improves the condition of the product in addition to fixing product functionality (Thierry et al., 1995).

Though recovery options are available in developing and industrialized countries, the manner in which electronic product recovery occurs in each is very different. Waste not, want not is an idiom that is fitting of electronics product recovery in developing countries. If an electronic product is still functioning, it is likely to find a second or third life with a new user through reuse. Hence, the useful lifetime of products is often longer in developing countries than industrialized countries.

Unlike many industrialized countries, in developing countries users are paid for parting with their WEEE instead of paying to dispose of electronic products (Sinha-Khetriwal, 2005). Manual labor is used to reclaim products and for materials recovery (Hicks et al., 2005). As a result, this industry is informal, small-scale, and highly dependent on labor costs (Widmer et al., 2005). These factors contribute to a lack of understanding by product recovery facilities concerning worker and environmental safety best practices. Additionally, workers are extremely likely to carry out recovery operations for more dangerous materials (e.g., copper and other heavy metals) with hand tools and little to no protective equipment. Hence, informal electronics waste reclamation in some areas of developing countries results in contamination of local water sources and poisoning of workers (Hicks et al., 2005). Fortunately, governing bodies and actors in developing countries are aware of human and environmental health and safety problems with e-waste treatment and are interested in resolving these issues. A possible outcome is that processing steps that involve greater human and environmental health risks needs to take place in a formal, regulated industrial sector.

6. SOCIAL IMPACTS

A significant impact of electronics and product recovery is the creation of employment opportunities. Product recovery efforts collect consumer waste products from multiple manufacturers. Consequently, variation in the characteristics of recovered e-waste (producer, model, year, etc.) is substantial and reduces process standardization capabilities. Less standardization requires more labor intensive recovery processes. As a result, more direct and indirect employment is created by product value recovery and remanufacturing industries than original equipment manufacturing (Ferrer and Ayres, 2000). Developing countries have a large, lower-wage work force; however, workers may have a relatively low skill level and require additional training. Conversely, developed countries have a more-highly skilled work force that demands higher wages (Steinhilper and Brent, 2003).

Increasing work opportunities by instituting product or e-waste recovery can result in negative health impacts unless current worker protection regulations are upgraded. For example, the use of little or no protective equipment in the handling of e-waste through improper disposal or burning (to reduce waste volume/recycle or recover metals) exposes workers to high toxic levels of lead and cadmium (a carcinogen) from the gaseous emissions. Respiratory tract infections and kidney stones have increased in Guiyu town, a province in China faced with the problems of e-waste. Further, the rate of occurrence of these health problems is higher among migrant workers (Hicks et al., 2005 Liu et al., 2006). Ensuring safe and environmentally conscious recovery requires the implementation of EPR-type policies, as well as international collaboration between exporters and importers.

7. CONCLUSION

E-waste and consumer product exports provide the distinct advantage of distributing technology worldwide. However, without appropriate measures, the positive impacts of global connectivity and information expansion are offset by environmental pollution and deleterious health effects. Appropriate policy measures and end-of-life product recovery systems are necessary to reduce negative environmental and social impacts, and to provide a platform for sustainable development.

The recognized need for the recovery of consumer products has resulted in the formulation of a policy approach known as extended producer responsibility (EPR) that has been implemented in various forms in developed countries. Instituting the principles associated with EPR policy in developing countries requires international collaboration and communication among governments, industries, and people. Communication focuses on the introduction of sustainability and product recovery principles at all education levels. Additionally, constructing a profitable and functioning e-waste or product value recovery system with positive environmental and social impacts requires that product treatment and reverse logistics technology be integrated with public policies to address this issue of global concern.

An important aspect of the debate is whether value recovery activities should take place in developed countries or in developing countries. Original manufacturers in developed countries certainly have the means to instigate product recovery, but acquiring a cost effective labor force may be difficult with minimal legislative and financial incentives. Conversely, developing countries often have low cost labor available but minimal capabilities for product recovery. The decision of where to perform recovery is integral to the success of product value recovery systems, but is also affected by the type of product in question. Product worth, remaining life, ease of disassembly, and relevant recovery policies must be considered in identifying an optimal product value recovery location. In short, there is no easy or single answer as to where e-waste or product recovery should be located.

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