Global Perspective on Electronic Waste Management: A Cross-Cultural Analysis

A Research Paper submitted to the Department of Engineering and Society

Presented to the Faculty of the School of Engineering and Applied Science

University of Virginia - Charlottesville, Virginia

In Partial Fulfillment of the Requirements for Degree

Bachelors of Science, School of Engineering

Word Count: 3297

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Spring 2024

On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

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Introduction

To begin my research paper, I would like to ask the readers two introspective questions: Where do you go to dispose of old or broken technology? Do you know where to properly dispose of your digital devices? If you were unable to answer or unsure of the answer to the previous questions - you are not alone: only 42% of households knew how to properly dispose of their digital devices (Nowakowski, 2016). Improper disposal of electronics has made electronic waste, or e-waste, the fastest growing waste stream, producing over 50 million tons of waste annually (Regel-Rosocka, 2018). The issue of e-waste continues to grow as society shifts to be more technologically dependent; it is no longer simply a luxury to own technological devices but a necessity. Additionally, as technology evolves at a breakneck pace, the lifespan of many devices has decreased. Instead of replacing a device once it has died, many are now replacing their devices purely for the upgraded hardware and software. As a result, the average lifespan of computers has decreased from 4.5 years in 1992 to two years in 2005, whereas an average smartphone's life cycle is only one year (Herat, 2007).

In this research paper, I aim to use the Social Construction of Technology (SCOT) framework to examine how the social interactions and interpretations of different groups have impacted the development, design, use, and regulation of technology (Pinch & Bijker, 1984). In particular, I will inspect three major groups: the government, producers, and consumers. By analyzing the distinct contributions of these various groups to e-waste management, I aim to present the evolution of e-waste regulations and highlight the disparity in regulatory frameworks across countries due to their cultural differences. Focusing particularly on the United States, I will emphasize and suggest alternative solutions and strategies utilized by other countries for the United States to adopt, allowing us to confront the growing e-waste problem.

Electronic Waste In the United States

The topic of electronic waste in the United States is largely ignored and has long been viewed as unimportant. Schumacher & Agbemabiese (2019) states that only 25 states have passed legislation promoting e-waste recycling and/or prohibiting e-waste landfilling and incineration. On a federal level, few laws have been passed; with the earliest being the 1984 Hazardous and Solid Waste Amendment and the Resource Conservation and Recovery Act of 1976. These federal legislations however, are dated and ineffective in regulating e-waste due to their "inadequate scope, ineffective regulation, and numerous exemptions and exclusions built into both legislation" (Schumacher & Agbemabiese, 2019, p. 606). The United States currently faces the Collingridge dilemma with e-waste, which illustrates the difficulty in regulating technology during different stages of its development (Genus & Stirling, 2018). In the early stages of development, information about the technology is limited and the impacts are unknown, making it difficult to predict and control the future of technology. This is why the aforementioned federal legislation, which was passed into law nearly 50 years ago, is ineffective. At the time these laws were enacted, the current common household technologies such as computers and cell phones were still at their infancy stages and it was unclear how consequential these technologies would be. On the other hand, the Collingridge dilemma states that late into the development of technology, while the impacts are more understood, the technology has now been deeply embedded into society, making it more difficult and costly to regulate. As we are currently in the 'late' cycle of e-waste, we are witnessing how difficult it is to regulate e-waste with only 50% of states having any kind of regulation/legislation for the issue (Schumacher & Agbemabiese, 2019).

The United States currently handles e-waste in three ways. The first and most popular method of disposing of e-waste is in landfills. Due to the lack of established disposal systems in numerous states, citizens often lack awareness of proper disposal methods for e-waste, leading them to discard it along with regular waste, which ultimately ends up in landfills. However, unlike other streams of waste, e-waste has a unique problem: the presence of rare and dangerous metals, which can be found within many computer chips, circuit boards, etc. The list of toxic metals found within these electronic devices include: zinc, nickel, lithium, lead, copper, cadmium, and many others. These metals have been proven to be highly toxic for humans as they corrode, causing damage to blood, kidneys, and nervous systems (Kiddee et al., 2013). In the United States, the consumer electronics industry accounts for 70% of the heavy metals and 40% of the lead found in landfills (Herat, 2007). Disposing of e-waste in landfills is simply a technological fix, which is defined as a purely technical solution to handle excess e-waste (Oelschlaeger, 1979). It does not fully consider the socio-technical aspects of the e-waste issue such as human and environmental risks and therefore, the United States should view disposing e-waste in landfills only as a temporary solution which we should move away from in the future.

The second method is to send e-waste to recycling centers, where it can be properly disposed of. This solution, however, is not widely implemented, with only 41.7% of waste being recycled (Schumacher & Agbemabiese, 2019). These facilities are primarily used when old or broken technology is disposed of en masse - primarily from organizations and companies looking to upgrade their systems. With only 50% of states having legislation, the availability of recycling centers for common consumers is low and most consumers are completely unaware of such facilities - if it even exists within their state.

The lack of federal regulation and funding towards these recycling facilities leads into the last method - exporting e-waste to developing countries. This ‘out-of-sight, out-of-mind’ mentality held by the United States is due to the influx of e-waste which surpasses the capacity of our recycling centers. Rather than exacerbating the issue locally by dumping e-waste into landfills, the U.S. will send e-waste to other countries such as China, Nigeria, and India - where primitive recycling practices are used. Due to a lack of technological resources, these primitive recycling processes consist of disassembling e-waste by hand, incineration, and acidic decomposition, which can potentially pose greater environmental and human damage (Schumacher & Agbemabiese, 2019). Under the Basel Convention, it is illegal to export waste to other countries; however, by sending both functional and non-functional devices to developing countries, it could be viewed as trade rather than the disposal of broken devices (Robinson, 2009). This practice is yet another example of how old policies fail to perceive the issues and impact of technology, which lead to loopholes that are able to be exploited, rendering early regulation of e-waste unsuccessful.

The United States currently faces the growing problem of e-waste without a clear strategy to scale our operations to control the issue. The three main e-waste disposal methods currently employed by the United States are inadequate for reducing environmental harm. Additionally, the decentralized nature of e-waste legislation due to the lack of federal regulation has made any systematic improvement extremely difficult. Each state is left to decide on their own how to respond to e-waste and to what degree - with many states ignoring the issue all together.

Producer Responsible Organizations and Take-Back Method

One of the newest methods of addressing e-waste is with Producer Responsible Organizations (PRO) which defines an organization designed to manage the collection and end-of-life process for their devices (Herat, 2007). Several countries across the world have put PRO's into action but various organizations have different regulations and methods with their implementation in addition to a different definition of who the 'producer' is. In India, the producers are the companies who create the product such as Acer, Dell, Lenovo, Samsung, etc. The list of producers who take responsibility for their products are small, consisting of only 10 companies who utilize the 'take-back method', which as the name suggests, will take old or broken devices back to be recycled. Companies who agree to become PRO's are likely to use environmentally friendly materials, standardize disassembly, and encourage green procedure and packing options (Narayanan et al. 2010). However, the fact that only 10 companies opted into becoming PRO's is a clear indication that the system is not scalable. Economically, companies would have to invest resources into greener designs, organize locations to take devices back, and invest in R&D teams to find environmentally friendly materials - all while trying to maintain product quality. This eliminates smaller tech companies from being a PRO. Additionally, there is no regulation or requirement for companies to become PROs which leaves the question: how much are these companies 'really' doing and are they claiming greener practices just for 'show'?

That being said, a few of the largest tech companies have established refurbishing and trade-in programs to encourage consumers to upgrade their devices early and aid in e-waste management. Companies like Amazon and Apple have the resources to create entire e-waste recycling centers internally. For these flagship companies, the recycling centers allow them to harvest rare metals found in many devices, lowering the cost of manufacturing future products.

There are, however, limitations to these programs. Each organization will have different mandates on the devices they will take. Generally, the list of devices taken for these programs are limited to small devices (phones, laptops) and must be in working condition (Amazon Recycling Center, n.d). Additionally, the economic demand of creating a recycling center is a privilege only the wealthiest companies can afford and is unsustainable for the vast majority of organizations.

In Europe, the definition of 'producers' is not as intuitive. The organization who manages the take-back method is the government. Understanding that mandating every company to take responsibility for the end-of-life of their products would be next to impossible, the government (in many EU countries), has established their own systems. Analogous to cardboard or plastic recycling in the U.S, Poland has established stationary points where citizens are able to go to discard their e-waste. In a survey conducted by Nowakowski in 2016, citizens in Poland reported that by having collection stations, they increased their use of them by 24% and reduced disposing e-waste with general waste by as much as 35%. It is worth mentioning this study only sampled students attending university/college in Poland. Nowakowski claims that "(a) great majority of daytime students live together with their parents and do not reside in campuses as is more commonly observed in Great Britain or other EU countries. Therefore, the responses to the survey questions are considered as household residential opinions and therefore are extrapolated to the larger population of Poland" (Nowakowski, 2016). With this claim, the survey presumes that the view of younger, educated citizens can be extrapolated to the country as a whole however, there are many other external factors such as education, financial stability, or political view that may not be considered by only surveying students. Regardless, the study does seem to show major improvements in at least one group of citizens, which is still a step forward. Nowakowski's survey shows that when people are provided with a consistent option to dispose of their waste properly, they are likely to do so. Analogously, it would be the same as providing recycling bins for plastic or paper. It may sound obvious however, this method is currently not used in the United States. As mentioned previously, in some states, there are no methods in which a person can properly dispose of e-waste because there is no legislation, regulation, or system in place which allows them to make the correct action. Left with no other option, citizens in the United States are, in a sense, forced to contribute to the e-waste pollution by disposing of e-waste in landfills.

Perhaps the most compelling argument against PROs is the financial burden they incur. As previously discussed, only major corporations with considerable financial resources can independently establish PROs. Alternatively, relying on government funding poses challenges, especially in the United States, where there is often a negative perception around taxes and public expenditures. However, it is worth noting that the United States Environmental Protection Agency released the Recycling Economic Information (ERI) report which assessed the economic implication of material reuse and recycling. The report's key findings revealed several benefits, including the creation of 681,00 jobs, $37.8 billion in wages, and $5.5 billion in tax revenues (United States Environmental Protection Agency, n.d.). These numbers show the economic viability of material reuse and recycling infrastructure. Furthermore, waste management plays a critical role in safeguarding public health and well-being, a priceless aspect that cannot be overlooked.

Electronic Waste in Asia

Asian countries have long struggled with e-waste in a similar fashion as the United States as they have embraced the technological age early and have quickly become the leading manufacturers of technological goods. As a result, their e-waste issue has also grown significantly, with China being the number one country for e-waste production, creating as much as 40% of the total e-waste in Asia (Herat, 2021).

In response to the growing issue, China has specifically taken a strong governmental stance on e-waste. Three key legislative regulations: Law on Promotion of Cleaner Production (2002), Law on Promotion of Circular Energy (2008), and Law on the Prevention of Environmental Pollution from Solid Waste (2004) have all been implemented to regulate the disposal of e-waste and minimize the harm caused by e-waste (Herat, 2021). These laws promote waste prevention, provide guidance on what to do with waste, and lay the framework for handling hazardous components of e-waste. Additionally, several administrative organizations have been formed to enforce licensing and supervision of e-waste facilities. Despite these governmental safeguards, China continues to be outpaced by the growing stream of electronic waste, producing 10 million tons of e-waste in 2019, the most of any country (Herat, 2021). As predicted by the Coolingridge dilemma, these pieces of legislation came into effect too late. The enormous size and production capability of China has made it difficult to regulate these legislations nationwide.

As a result, many small communities across Asia have created an informal sector for e-waste management. Herat (2021) defines the informal sector as smaller employment groups mainly consisting of women and children with minimum safeguards to their health and safety. These workers are tasked with extracting valuable metal components while disposing of the poisonous residue. However, due to their lack of training and knowledge for e-waste, poisonous residue from e-waste recycling is not managed and is left to pollute the local environment and residents. The informal sector extends far beyond recycling of e-waste. Second hand markets are established within these areas for consumers to resell old and broken devices to rural areas. Refurbishing shops are also a popular option given that tech parts are in abundance. The economic value of these informal sectors is staggering high, profoundly impacting the communities they serve. A study conducted by Mehat et al. (2019) found that around 30 percent of citizens in Asia utilized the informal sector, leading to its emergence as one of the most widely practiced methods of e-waste management.

Substance	Applied in e-waste	Health impact
Antimony (Sb)	a melting agent in CRT glass, plastic computer housings and a solder alloy in cabling	Antimony has been classified as a carcinogen. It can cause stomach pain, vomiting, diarrhoea and stomach ulcers through inhalation of high antimony levels over a long time period
Arsenic (As)	Gallium arsenide is used in light emitting diodes	It has chronic effects that cause skin disease and lung cancer and impaired nerve signalling
Barium (Ba)	Sparkplugs, fluorescent lamps and CRT gutters in vacuum tubes	Causes brain swelling, muscle weakness, damage to the heart, liver and spleen though short-term exposure
Beryllium (Be)	Power supply boxes, motherboards, relays and finger clips	Exposure to beryllium can lead to beryllicosis, lung cancer and skin disease. Beryllium is a carcinogen
Brominated flame retardants (BFRs): (polybrominated biphenyls (PBBs), polybrominated diphenyl ethers (PBDEs) and tetrabromobisphenol (TBBPA))	BFRs are used to reduce flammability in printed circuit boards and plastic housings, keyboards and cable insulation	During combustion printed circuit boards and plastic housings emit toxic vapours known to cause hormonal disorders
Cadmium (Cd)	Rechargeable NiCd batteries, semiconductor chips, infrared detectors, printer inks and toners	Cadmium compounds pose a risk of irreversible impacts on human health, particularly the kidneys
Chlorofluorocarbons (CFCs)	Cooling units and insulation foam	These substances impact on the ozone layer which can lead to greater incidence of skin cancer.
Hexavalent chromium/chromium VI (Cr VI)	Plastic computer housing, cabling, hard discs and as a colourant in pigments	Is extremely toxic in the environment, causing DNA damage and permanent eye impairment
Lead (Pb)	Solder, lead-acid batteries, cathode ray tubes, cabling, printed circuit boards and fluorescent tubes	Can damage the brain, nervous system, kidney and reproductive system and cause blood disorders. Low concentrations of lead can damage the brain and nervous system in foetuses and young children. The accumulation of lead in the environment results in both acute and chronic effects on human health
Mercury (Hg)	Batteries, backlight bulbs or lamps, flat panel displays, switches and thermostats	Mercury can damage the brain, kidneys and foetuses
Nickel (Ni)	Batteries, computer housing, cathode ray tube and printed circuit boards	Can cause allergic reaction, bronchitis and reduced lung function and lung cancers
Polychlorinated biphenyls (PCBs)	Condensers, transformers and heat transfer fluids.	PCBs cause cancer in animals and can lead to liver damage in humans
Polyvinyl chloride (PVC)	Monitors, keyboards, cabling and plastic computer housing	PVC has the potential for hazardous substances and toxic air contaminants. The incomplete combustion of PVC release huge amounts of hydrogen chloride gas which form hydrochloric acid after combination with moisture. Hydrochloric acid can cause respiratory problems
Selenium (Se)	Older photocopy machines	High concentrations cause selenosis

Figure 1: Hazardous E-waste Materials (Kiddee et al., 2013)

The impacts of informal e-waste management is depicted with the city of Guiyu, China. Guiyu hosts one of the largest informal sector e-waste recycling centers in the world and a study conducted by Kiddie et al., (2013) surveyed the people living around the area and examined the local environment. Figure 1 above provides an oversight into what types of metals are commonly found in electronic goods, where it is used, and the potential impacts it has on human health. According to Kiddie et al., (2013) drinking water contained levels of lead which was eight times higher than the drinking water standard in China and the air samples contained cadmium, lead, tin, and other toxic chemicals at a concentration five times higher than nearby Hong Kong. As a result, humans have accumulated the pollution found in their nearby environment which has caused serious health effects. In addition to the list of health impacts shown in the figure above, Kiddee et al., (2013) report that children in Ginyu have significantly higher levels of lead and tin in their blood, resulting in lower cognitive abilities and mothers had similar elevated levels of contaminants in their breast milk.

The informal sector, in addition to environmental and health hazards, presents another significant drawback by hindering the development of the formal e-waste sector. Figure 2 depicts the distinct benefits and drawbacks associated with both sectors. The central issue lies in their direct competition, making it difficult to coexist together. This competition is analogous to rivalry between a chain store and locally owned businesses. If the formal sector dominated, anyone aiming to open a refurbishing shop or second hand market would face resource constraints, making it difficult to compete effectively. Conversely, if the informal sector dominated, the local community may not support development of formal e-waste recycling centers as it directly damages their economy.

Formal	**Informal**
+ Safe recycling practices	- Unsafe recycling practices
+ Regulated	- Unregulated
+ Investment in advanced recycling technology	+ No initial investment necessary
+ Long-term efficiency	+ Short-term efficiency
- Expensive	+ Cheap
- Potentially devastating for local economy	+ Essential to local economy

Figure 2: Comparison of Formal and Informal E-waste Sector

Conclusion

The issue of electronic waste is a complex and multifaceted challenge, as explored in this research paper. Improper disposal of e-waste poses significant environmental and health risks whilst exacerbating the already severe issue of waste pollution. With the rapid advancement of technology it is imperative that the United State adopt a sustainable and effective strategy to address the growing e-waste problem.

Throughout this paper, various strategies for treating e-waste pollution have been examined through the lens of three key groups; the government, the producers, and the consumers. Governmental agencies have attempted to regulate e-waste in a myriad of different ways but most are ineffective since these regulations were enacted after the development and widespread use of technology had matured. The Collingridge dilemma underscores the challenges associated with regulating technology which is applicable to their end-of-life processes as well. On the producer side, the establishment of Producer Responsible Organizations (PROs) has shown promise in shifting the responsibility of end-of-life processes of digital devices to specific organizations. The implementation of PROs varies as different organizations take responsibility but has still proven its ability to encourage greener e-waste practices. In areas where government regulations are difficult to enforce, consumers have taken initiative by establishing the informal sector, where e-waste becomes a business opportunity, such as through repair shops or refurbished/resale stores. The informal sector is the backbone of many communities and whilst there are a few advantages, the practices utilized by the informal sector continue to be primitive and cause environmental and human harm.

My suggestion for the United States would be to invest in Producer Responsible Organizations, similar to how many European countries have done. E-waste at its core is just another stream of waste. Like trash, paper, and plastic, e-waste requires governmentally supported infrastructure to facilitate proper disposal and recycling without harming the environment or humans. With proper collection methods and recycling centers, citizens are provided with an opportunity to dispose of e-waste, filling a gap that previously existed. With this new opportunity, federal and local governments could then invest in several incentives to encourage the use of e-waste recycling and change the perception of e-waste management. One method that has been utilized in the past is ‘cash-back recycling’. The cash-back recycling program incentivizes consumers to recycle by offering a financial compensation for returning certain items for recycling or proper disposal. Fundamentally, the strategy for e-waste management in the United States should shift away from attempting to regulate e-waste, as it has been ineffective thus far and move towards constructing and promoting the use of a standardized e-waste recycling program.

References

Amazon Recycling Program. Amazon. (n.d.). https://www.amazon.com/b?node=23883609011&ref=ti_d_v2_ti_recin

Genus, A., & Stirling, A. (2018). Collingridge and the dilemma of control: Towards responsible and accountable innovation. *Research Policy*, *47*(1), 61–69. https://doi.org/10.1016/j.respol.2017.09.012

Herat, S. (2007, September 24). Sustainable Management of Electronic Waste (e-Waste). *Clean Soil Air Water, Vol 35, Issue 4, Page 305-310.* https://doi.org/10.1002/clen.200700022

Herat, S. (2021). E-waste management in Asia Pacific region: Review of issues, challenges and solutions. *Nature Environment and Pollution Technology*, *20*(1), 45–53. https://doi.org/10.46488/nept.2021.v20i01.005

Kiddee P., Naidu R., Wong MH. (2013, May). Electronic waste management approaches: an overview. *Waste Manag. Vol. 33 Issue 5.* doi: 10.1016/j.wasman.2013.01.006

Mahat, H., Hashim, M., Nayan, N., Saleh, Y., & Norkhaidi, S. B. (2019). E-waste disposal awareness among the Malaysian community [Review of *E-waste disposal awareness among the Malaysian community*]. *Knowledge Management & E-Learning*, *11*(3), 393–408. https://doi.org/10.34105/j.kmel.2019.11.021

Narayanan, S., Kumar, K. R., Patel, R. B., & Singh, B. P. (2010). E-waste management and challenges. *AIP Conference Proceedings*. https://doi.org/10.1063/1.3526198

Nowakowski, P. (2016, October 5). The influence of residents' behavior on waste electrical and electronic equipment collection effectiveness. *Waste Management & Research Vol 34, Issue 11*. *doi:10.1177/0734242X16669997*

Oelschlaeger, M. (1979). The Myth of the Technological Fix. *The Southwestern Journal of Philosophy*, *10*(1), 43–53. http://www.jstor.org/stable/43155445

Pinch, T. J., & Bijker, W. E. (1984). The Social Construction of Facts and Artefacts: Or How the Sociology of Science and the Sociology of Technology Might Benefit Each Other. *Social Studies of Science*, *14*(3), 399–441. http://www.jstor.org/stable/285355

Regel-Rosocka, M. (2018). Electronic wastes. *Physical Sciences Review Vol 3 Issue 5*. https://doi.org/10.1515/9783110547061-001

Robinson, B. (2009, December 20). E-waste: An assessment of global production and environmental impacts. *Science of The Total Environment Vol 408, Issue 2.* https://doi.org/10.1016/j.scitotenv.2009.09.044

Schumacher, K. A., & Agbemabiese, L. (2019). Towards comprehensive e-waste legislation in the United States: Design considerations based on quantitative and qualitative assessments. *Resources, Conservation and Recycling*, *149*, 605–621. https://doi.org/10.1016/j.resconrec.2019.06.033

United States Environmental Protection Agency. (n.d.). Recycling Economic Information (REI) Report. https://www.epa.gov/smm/recycling-economic-information-rei-report