**Environmental aspects of e-waste management**

**Author**

Prakash Kumar Sahoo

Post Graduate Department of Chemistry

Dhenkanal Autonomous College

Dhenkanal, Odisha-759001

Correspondence email- [prakashchemistry1989@gmail.com](mailto:prakashchemistry1989@gmail.com)

**Abstract**

E-waste, or electronic waste, has emerged as a significant environmental and health concern in recent years due to the rapid advancement of technology and increasing consumer demand for electronic devices. As the world becomes increasingly digitalized, the volume of electronic waste generated is projected to escalate. Effective management of e-waste is crucial to mitigate the adverse impacts on the environment and human health. This abstract explores future aspects of e-waste management, considering potential developments and strategies that can be implemented to address this pressing issue. The first aspect revolves around technological advancements aimed at minimizing e-waste generation. This includes the development of modular and upgradeable devices, encouraging reparability and recycling, and designing eco-friendly materials with reduced environmental impact.

Another critical aspect is the establishment of robust and sustainable e-waste collection and recycling systems. Future approaches involve the implementation of extended producer responsibility (EPR) frameworks, where manufacturers are responsible for the entire lifecycle of their products. This includes designing devices for easy disassembly and recycling, setting up efficient collection networks, and ensuring proper treatment of hazardous components. Furthermore, emerging technologies such as artificial intelligence (AI) and the Internet of Things (IoT) offer promising opportunities for improving e-waste management. AI can be utilized for automating the sorting and categorization of e-waste, optimizing recycling processes, and identifying valuable components for recovery. IoT devices can enable better tracking and monitoring of e-waste throughout the supply chain, facilitating efficient collection and recycling. Additionally, public awareness and education play a crucial role in future e-waste management. Promoting responsible consumption, encouraging device longevity, and fostering a culture of recycling are essential for sustainable practices. Collaboration between governments, industry stakeholders, and non-governmental organizations is also vital to drive policy changes, establish standardized regulations, and support research and innovation in e-waste management. While several challenges remain, such as the informal sector, limited infrastructure in certain regions, and complex material recovery processes, future aspects of e-waste management hold great promise. By adopting a comprehensive and holistic approach, integrating technological advancements, sustainable practices, and collaborative efforts, it is possible to mitigate the environmental impact of e-waste and create a more sustainable future.

**Keywords**: e-waste, electronic waste, management, sustainability, technology, extended producer responsibility, recycling, artificial intelligence, Internet of Things, public awareness.

**Introduction**

Electronic waste, commonly known as e-waste, is a growing environmental and public health concern in our technologically driven society. E-waste refers to discarded electronic devices, components, and accessories that have reached the end of their useful life. These items include smartphones, computers, televisions, printers, and various household appliances. The rapid pace of technological advancements, coupled with our increasing reliance on electronic devices, has led to a significant surge in e-waste generation globally. Managing e-waste is a critical challenge due to its complex composition and hazardous nature. Electronic devices often contain toxic substances such as lead, mercury, cadmium, and flame retardants, which can leach into the environment if not handled properly. In addition to the environmental impact, improper e-waste disposal also poses risks to human health, as the toxic components can contaminate air, water, and soil.

To address these challenges, e-waste management has gained prominence as a vital field encompassing various practices aimed at minimizing the adverse effects of e-waste and maximizing resource recovery. Effective e-waste management involves the collection, transportation, recycling, and disposal of electronic waste in a safe and sustainable manner.

The primary goals of e-waste management are:

**Environmental Protection**: Proper management of e-waste aims to prevent the release of hazardous substances into the environment, minimizing soil, water, and air pollution. By implementing appropriate disposal methods, e-waste management strives to safeguard ecosystems and protect human health from the harmful effects of toxic materials.

**Resource Conservation**: Electronic devices contain valuable resources, including precious metals, rare earth elements, and other reusable components. E-waste management focuses on recovering and recycling these resources to reduce the demand for raw materials, conserve energy, and decrease the environmental impact of extraction and manufacturing processes.

**Health and Safety**: E-waste management aims to safeguard the health and well-being of both workers and communities involved in the handling and processing of e-waste. By implementing safe practices, including proper storage, transportation, and dismantling of electronic devices, the risks associated with exposure to hazardous substances are minimized.

**Awareness and Education**: Creating awareness about the hazards of improper e-waste disposal and promoting responsible consumer behavior are essential aspects of e-waste management. Educating the public, businesses, and governments about the importance of recycling and responsible disposal encourages participation in e-waste collection programs and fosters a culture of sustainability.

**Policy and Regulation**: Governments play a crucial role in formulating policies and regulations that govern e-waste management practices. Establishing comprehensive frameworks ensures the proper handling, recycling, and disposal of e-waste and holds manufacturers, importers, and consumers accountable for their roles in the lifecycle of electronic devices.

As far as current situation is concerned, e-waste management is an urgent global challenge that requires sustainable and innovative approaches to mitigate its environmental and health impacts. By adopting responsible practices, raising awareness, implementing effective regulations, and promoting resource recovery, we can ensure the safe and sustainable management of e-waste, contributing to a more environmentally conscious and technologically advanced future. In the rapidly advancing digital age, electronic devices have become an integral part of our lives. From smart-phones and laptops to smart home appliances and wearable gadgets, our reliance on electronics continues to grow. However, this increased reliance also brings forth a significant challenge: electronic waste, or e-waste. E-waste comprises discarded electronic devices, components, and accessories that pose environmental and health hazards if not managed properly.

To tackle this mounting issue, futuristic aspects of e-waste management have emerged, leveraging innovative technologies and sustainable practices. These forward-looking approaches aim to minimize the environmental impact of e-waste while extracting value from discarded electronics. In this discussion, we will explore some key futuristic aspects of e-waste management that hold the promise of a more sustainable and efficient future. Circular Economy and Resource Recovery: One significant aspect of futuristic e-waste management is the adoption of a circular economy model. Instead of the traditional linear approach of "take-make-dispose," a circular economy focuses on extending the lifespan of electronic devices through repair, refurbishment, and recycling. It emphasizes resource recovery by extracting valuable materials from e-waste to be used in the production of new devices, reducing the need for raw material extraction.

Advanced Sorting and Separation Technologies: Efficient sorting and separation of different materials in e-waste are crucial for effective recycling. Futuristic e-waste management incorporates advanced technologies like robotics, artificial intelligence (AI), and machine learning to automate the sorting process. These technologies enable precise identification and separation of various components and materials, improving recycling efficiency and reducing reliance on manual labour. Urban Mining and Recovery of Rare Elements: Electronic devices often contain valuable and scarce resources, including rare earth elements and precious metals. Futuristic e-waste management focuses on urban mining, a process of extracting these valuable materials from discarded electronics. Advanced techniques such as hydrometallurgical processes and bioleaching are employed to recover and recycle these resources, reducing the demand for new mining and minimizing environmental damage.

Design for Disassembly and Recyclability: To facilitate e-waste management, future electronics are designed with disassembly and recyclability in mind. Manufacturers are exploring modular designs, where components can be easily replaced or upgraded, extending the lifespan of devices. Additionally, eco-friendly materials and construction techniques are being adopted to enhance recyclability and reduce the environmental footprint of electronic products. Extended Producer Responsibility (EPR) Programs: Futuristic e-waste management emphasizes the implementation of Extended Producer Responsibility (EPR) programs. EPR holds manufacturers accountable for the entire lifecycle of their products, including their disposal and recycling. This encourages manufacturers to design products that are easier to recycle, invest in e-waste management infrastructure, and take responsibility for the environmental impact of their products. The Futuristic aspects of e-waste management offer innovative solutions to tackle the growing environmental challenge of electronic waste. By adopting a circular economy approach, leveraging advanced sorting technologies, practicing urban mining, focusing on recyclability, and implementing EPR programs, we can move towards a more sustainable and efficient management of e-waste. These futuristic approaches hold the potential to conserve resources, reduce environmental pollution, and create a more sustainable future for electronic devices and the planet as a whole.

**Quantification of e-waste**

Quantifying e-waste is essential for understanding the scale of the problem and developing effective strategies for its management. The quantification of e-waste involves measuring and analyzing various aspects, including the volume, composition, and generation rates. Here are some common methods and parameters used for quantifying e-waste:

**Volume**: The physical measurement of e-waste in terms of its volume provides an initial assessment of the quantity of discarded electronics. This can be done by weighing the e-waste or estimating its volume in cubic meters or cubic feet. Measurements can be carried out at collection points, recycling facilities, or disposal sites.

**Generation Rates**: Determining the generation rates of e-waste involves estimating the amount of e-waste produced within a specific period. This is usually measured in weight (e.g., kilograms or tons) or units (e.g., number of devices). Generation rates can be calculated based on data from government reports, industry surveys, or waste management facilities.

**Composition Analysis**: Analyzing the composition of e-waste helps identify the types of electronic devices and materials present in the waste stream. This is typically done through waste characterization studies, where representative samples of e-waste are collected and sorted into different categories. The composition analysis provides insights into the types and quantities of materials, such as metals, plastics, glass, and hazardous substances, present in e-waste.

**Global and National Statistics**: Various organizations, including governments, international bodies, and research institutions, compile and publish data on e-waste generation at global, regional, and national levels. These statistics are often based on surveys, data from waste management facilities, and extrapolations from known data sources. They provide a broader perspective on the magnitude of e-waste generation and trends over time.

**Data from Recycling and Disposal Facilities**: Recycling and disposal facilities play a crucial role in e-waste management. They collect, process, and dispose of e-waste, generating valuable data on the quantity and types of e-waste received. Monitoring and analyzing data from these facilities can provide insights into the e-waste stream and its characteristics.

**Surveys and Questionnaires**: Surveys and questionnaires are useful tools for gathering information on e-waste generation and disposal practices from households, businesses, and other stakeholders. These surveys can capture data on the types and quantities of electronic devices owned, disposal methods employed, and awareness of e-waste management practices.

It's important to note that quantifying e-waste can be challenging due to factors such as informal recycling and disposal practices, illegal trade, and data gaps in certain regions. However, efforts are being made to improve data collection and reporting mechanisms to enhance the accuracy and reliability of e-waste quantification. By quantifying e-waste, policymakers, researchers, and waste management professionals can better understand the magnitude of the problem, identify trends, and develop targeted strategies for sustainable e-waste management and resource recovery.

**Environmental impacts of e-waste**

Electronic waste, or e-waste, refers to discarded electrical or electronic devices, such as computers, smartphones, televisions, and other electronic appliances. The improper disposal and management of e-waste can have significant environmental impacts, including:

**Toxic Substances**: Many electronic devices contain hazardous materials such as lead, mercury, cadmium, and brominated flame retardants. When e-waste is improperly handled or disposed of in landfills, these substances can leach into the soil and water, contaminating ecosystems and potentially entering the food chain.

**Air and Water Pollution**: When e-waste is burned or incinerated, it releases toxic gases and particulate matter into the air. These pollutants can contribute to air pollution and respiratory diseases in humans. Additionally, if e-waste is not properly managed, it can contaminate water sources through leaching of hazardous chemicals.

**Resource Depletion:** Electronics manufacturing requires the extraction of various raw materials, including precious metals like gold, silver, and palladium, as well as rare earth elements. Excessive disposal of e-waste without proper recycling means that these valuable resources are lost and need to be extracted from the environment again, leading to resource depletion and environmental degradation.

**Energy Consumption:** The production and disposal of electronic devices contribute to significant energy consumption. Energy-intensive manufacturing processes, transportation, and waste management all have associated environmental impacts, including greenhouse gas emissions and contributions to climate change.

**Ecosystem Damage:** Improper disposal of e-waste can lead to the contamination of soil and water, affecting plants, animals, and aquatic life. Ecosystems can be disrupted, and biodiversity can be harmed as a result of exposure to toxic substances.

**Human Health Risks:** E-waste recycling and disposal activities often take place in informal or unregulated settings in many parts of the world. This exposes workers, including children, to hazardous substances and conditions, resulting in health issues such as respiratory problems, skin disorders, and increased risk of certain cancers.

**Global Trade and Environmental Injustice:** E-waste is sometimes exported to developing countries with lax environmental regulations. This practice can result in environmental injustice, as local communities bear the brunt of the negative impacts while others profit from the trade.

To mitigate these environmental impacts, it is crucial to implement responsible e-waste management practices, including proper recycling, refurbishment, and safe disposal. Legislation and regulations aimed at reducing the generation of e-waste, promoting product design for recyclability, and enforcing proper disposal methods are important steps toward addressing these challenges. Additionally, raising awareness among consumers about the importance of responsible e-waste disposal and recycling can help minimize the environmental impacts of electronic waste.

**Human toxicity of hazardous substances in e-waste**

Hazardous substances present in e-waste can pose significant risks to human health, especially when not properly managed during disposal, recycling, or dismantling processes. Here are some of the hazardous substances commonly found in e-waste and their potential human toxicity effects:

**Lead (Pb):** Lead is often used in soldering and coatings in electronic devices. It can affect the nervous system, causing developmental and cognitive impairments, especially in children. Lead exposure can lead to learning disabilities, behavioral issues, and even irreversible brain damage.

**Mercury (Hg):** Mercury is present in some flat-screen monitors, fluorescent lamps, and batteries. It can harm the nervous system, cause respiratory and digestive problems, and have adverse effects on fetal development. Mercury exposure can lead to symptoms such as tremors, memory loss, and difficulty concentrating.

**Cadmium (Cd):** Cadmium is used in batteries and coatings. Inhalation or ingestion of cadmium can damage the lungs and kidneys, leading to severe health problems. Long-term exposure can result in kidney and bone damage, as well as an increased risk of cancer.

**Brominated Flame Retardants (BFRs):** These chemicals are used to reduce the flammability of electronics. BFRs can leach into the environment and accumulate in human tissues. They may disrupt the endocrine system, impact neurological development, and potentially contribute to cancer development.

**Polyvinyl Chloride (PVC):** PVC is commonly used in cables, wires, and casings. When burned, PVC releases toxic chlorine gas and dioxins, which are highly toxic and can cause cancer, reproductive and developmental disorders, and immune system suppression.

**Arsenic (As):** Arsenic is found in some electronic components. Chronic exposure to arsenic can lead to skin lesions, peripheral neuropathy, cardiovascular diseases, and an increased risk of various cancers, including skin, lung, and bladder cancers.

**Beryllium (Be):** Beryllium is used in some connectors and electronic components. Inhalation of beryllium dust or fumes can cause a serious lung condition known as berylliosis, characterized by coughing, difficulty breathing, and fatigue.

**Phthalates:** Phthalates are used in plastics to increase flexibility. They are potential endocrine disruptors and can have negative effects on reproductive and developmental health, including reduced fertility and developmental issues in children.

**Chlorofluorocarbons (CFCs):** CFCs are used in older cooling systems. They can deplete the ozone layer and contribute to global climate change.

**Hexavalent Chromium Cr (VI):** This is used in some electroplating processes. Inhalation or ingestion of hexavalent chromium can lead to respiratory issues, lung cancer, and other adverse health effects. It's important to note that these hazardous substances can impact not only workers in the e-waste recycling industry but also local communities exposed to contaminated air, water, or soil. Proper e-waste management, including safe recycling and disposal practices, is crucial to minimizing human exposure to these toxic substances and reducing associated health risks.

**Strategies to manage e-wastes**

Effective management of e-waste involves a combination of strategies aimed at reducing its generation, promoting responsible disposal, and ensuring proper recycling. Here are some key strategies to manage e-waste:

**Eco-Friendly Design and Product Lifecycle:**

Manufacturers can design electronic products with longevity, repairability, and recyclability in mind. Implement extended producer responsibility (EPR) programs, where manufacturers take responsibility for the end-of-life disposal of their products.

**Reduce, Reuse, And Repair :**

Encourage consumers to extend the lifespan of electronic devices by repairing and upgrading them instead of immediately replacing them. Promote the culture of buying refurbished electronics and support repair services.

**Collection and Segregation:**

Establish collection centres, drop-off points, or collection events for e-waste to ensure proper disposal channels. Implement effective sorting and segregation of e-waste to separate hazardous components from recyclable materials.

**Safe Handling and Disposal:**

Train workers involved in e-waste handling to use proper protective gear and follow safe practices to prevent exposure to hazardous substances.

Develop regulations and guidelines for the safe disposal of e-waste, including prohibiting open burning and uncontrolled dumping.

**Formal Recycling Facilities:**

Invest in and promote the establishment of formal e-waste recycling facilities equipped with proper equipment and processes to extract valuable materials and dispose of hazardous components safely.

**Public Awareness and Education:**

Educate the public about the environmental and health impacts of improper e-waste disposal and the benefits of responsible recycling. Raise awareness about available collection points and recycling options.

**Legislation and Regulation:**

Enact and enforce comprehensive e-waste management laws and regulations that set standards for collection, transportation, recycling, and disposal. Impose penalties for illegal dumping and improper e-waste handling.

**International Cooperation:**

Collaborate with other countries to address the global issue of e-waste, including regulating the export and import of e-waste to prevent environmental and health hazards.

**Innovation and Research:**

Invest in research and development to develop new technologies for more efficient and environmentally friendly e-waste recycling. Explore innovative solutions for extracting valuable materials from e-waste.

**Public-Private Partnerships:**

Foster collaboration between governments, industry, NGOs, and other stakeholders to develop and implement effective e-waste management strategies.

**Circular Economy Approach:**

Promote a circular economy by designing products for durability, repairability, and recycling, and by creating closed-loop systems for the recovery and reuse of materials. By implementing these strategies, communities and governments can work together to minimize the environmental and health impacts of e-waste, promote resource conservation, and create a more sustainable approach to managing electronic waste.

**Conclusion**

In conclusion, the environmental aspects of e-waste management are of paramount importance due to the rapidly growing volume of electronic waste and its potential negative impacts on the environment. It is clear that improper disposal and management of e-waste can lead to severe pollution, resource depletion, and health hazards for both human populations and ecosystems. Effective e-waste management strategies should prioritize the reduction, reuse, and recycling of electronic products to minimize the extraction of raw materials, energy consumption, and the release of hazardous substances into the environment. By implementing comprehensive recycling programs and encouraging responsible consumer behaviour, we can significantly reduce the environmental burden of e-waste.

Furthermore, collaboration among governments, industries, and consumers is essential to establish proper regulations, guidelines, and infrastructure for managing e-waste. This includes designing products with longevity and recyclability in mind, enforcing extended producer responsibility (EPR) programs, and promoting awareness campaigns to educate the public about the importance of responsible e-waste disposal. Ultimately, addressing the environmental challenges of e-waste management requires a holistic and multifaceted approach that considers the entire lifecycle of electronic products. By embracing sustainable practices, fostering innovation in recycling technologies, and promoting a circular economy, we can mitigate the environmental impact of e-waste and work towards a more sustainable future for our planet.

**References**

1. Aizawa H, Yoshida H, Sakai SI. Current results and future perspectives for Japanese recycling of home electrical appliances. Res Conserv Recycle 2008;52:1399–410.
2. Andreola F, Barbieri L, Corradi A, Ferrari AM, Lancellotti I, Neri P. Recycling of EOL CRT glass into ceramic glaze formulations and its environmental impact by LCA approach. Int J Life Cycle Assess 2007;12:448–54.
3. Babu BR, Parande AK, Basha CA. Electrical and electronic waste: a global environmental problem. Waste Manag Res 2007;25:307–18.
4. Barba-Gutierrez Y, Adenso-Diaz B, Hopp M. An analysis of some environmental consequences of European electrical and electronic waste regulation. Res Conserv Recycl 2008;52:481–95.
5. Bergendahl CG, Lichtenvort K, Johansson G, Zackrisson M, Nyyssonen J. Environmental and economic implications of a shift to halogen-free printed wiring boards. Electronics Goes Green 2004 (Plus): Driving Forces for Future Electronics Proceedings; 2004. p. 783–8.
6. B.H. Robinson / Science of the Total Environment 408 (2009) 183–191 189 Berkhout F, Hertin J. De-materialising and re-materialising: digital technologies and the environment. Futures 2004;36:903–20.
7. Bertram M, Graedel TE, Rechberger H, Spatari S. The contemporary European copper cycle: waste management subsystem. Ecol Econ 2002;42:43–57.
8. Betts K. Producing usable materials from e-waste. Environ Sci Technol 2008a;42:6782–3. Betts K. Reducing the global impact of e-waste. Environ Sci Technol 2008b;42: 1393-1393.
9. Binder CR, Quirici R, Domnitcheva S, Staubli B. Smart labels for waste and resource management — an integrated assessment. J Ind Ecol 2008;12:207–28.
10. Bradley E. Lead-free solder assembly: impact and opportunity. 53rd Electronic Components & Technology Conference, 2003 Proceedings; 2003. p. 41–6.
11. Brandl H, Bosshard R, Wegmann M. Computer-munching microbes: metal leaching from electronic scrap by bacteria and fungi. Hydrometallurgy 2001;59:319–26.
12. Cai ZW, Jiang GB. Determination of polybrominated diphenyl ethers in soil from e-waste recycling site. Talanta 2006;70:88–90.
13. Chan JKY, Xing GH, Xu Y, Liang Y, Chen LX, Wu SC, et al. Body loadings and health risk assessment of polychlorinated dibenzo-p-dioxins and dibenzofurans at an intensive electronic waste recycling site in China. Environ Sci Technol 2007;41:7668–74.
14. Chatterjee R. E-waste recycling spews dioxins into the air. Environ Sci Technol 2007;41: 5577-5577. Chen DH, Bi XH, Zhao JP, Chen LG, Tan JH, Mai BX, et al. Pollution characterization and diurnal variation of PBDEs in the atmosphere of an E-waste dismantling region. Environ Pollut 2009a;157:1051–7.
15. Chen SJ, Ma YJ, Wang J, Chen D, Luo XJ, Mai BX. Brominated flame retardants in children's toys: concentration, composition, and children's exposure and risk assessment. Environ Sci Technol 2009b;43:4200–6.
16. CIA. Country Comparison: GDP — per capita (PPP). Cent Intel Agency 2009a. CIA. Country Comparison: GDP (purchasing power parity). Cent Intel Agency 2009b.
17. Cobbing M. Toxic Tech: Not in Our Backyard. Uncovering the Hidden Flows of e-waste. Report from Greenpeace International. http://www.greenpeace.org/raw/content/ belgium/fr/press/reports/toxic-tech.pdf, Amsterdam, 2008.
18. Creamer NJ, Baxter-Plant VS, Henderson J, Potter M, Macaskie LE. Palladium and gold removal and recovery from precious metal solutions and electronic scrap leachates by Desulfovibrio desulfuricans. Biotechnol Lett 2006;28:1475–84.
19. Cui JR, Zhang LF. Metallurgical recovery of metals from electronic waste: a review. J Hazard Mater 2008;158:228–56.
20. Dagan R, Dubey B, Bitton G, Townsend T. Aquatic toxicity of leachates generated from electronic devices. Arch Environ Contam Toxicol 2007;53:168–73.
21. Deng WJ, Louie PKK, Liu WK, Bi XH, Fu JM, Wong MH. Atmospheric levels and cytotoxicity of PAHs and heavy metals in TSP and PM2.5 at an electronic waste recycling site in southeast China. Atmos Environ 2006;40:6945–55.
22. Deng WJ, Zheng JS, Bi XH, Fu JM, Wong MH. Distribution of PBDEs in air particles from an electronic waste recycling site compared with Guangzhou and Hong Kong, South China. Environ Int 2007;33:1063–9.
23. Dietz M, Horold S, Nass B, Schacker O, Schmitt E, Wanzke W. New environmentally friendly phosphorus based flame retardants for printed circuit boards as well as polyamides and polyesters in E&E applications. Electronics Goes Green 2004 (Plus): Driving Forces for Future Electronics Proceedings; 2004. p. 771–6. e-waste.
24. Ernst T, Popp R, Wolf M, van Eldik R. Analysis of eco-relevant elements and noble metals in printed wiring boards using AAS, ICP-AES and EDXRF. Anal Bioanal Chem 2003;375:805–14.
25. Fu JJ, Zhou QF, Liu JM, Liu W, Wang T, Zhang QH, et al. High levels of heavy metals in rice (Oryza sativa L.) from a typical E-waste recycling area in southeast China and its potential risk to human health. Chemosphere 2008;71:1269–75.
26. Goosey M. End-of-life electronics legislation — an industry perspective. Circuit World 2004;30:41–5.
27. Gullett BK, Linak WP, Touati A, Wasson SJ, Gatica S, King CJ. Characterization of air emissions and residual ash from open burning of electronic wastes during simulated rudimentary recycling operations. J Mater Cycl Waste Manag 2007;9:69–79.
28. Ha NN, Agusa T, Ramu K, Tu NPC, Murata S, Bulbule KA, et al. Contamination by trace elements at e-waste recycling sites in Bangalore, India. Chemosphere 2009;76: 9-15.
29. He WZ, Li GM, Ma XF, Wang H, Huang JW, Xu M, et al. WEEE recovery strategies and the WEEE treatment status in China. J Hazard Mater 2006;136:502–12.
30. Herat S. Green electronics through legislation and lead free soldering. Clean-Soil Air Water 2008;36:145–51.
31. Hilty LM. Electronic waste — an emerging risk? Environ Impact Assess Rev 2005;25:431–5.
32. Hischier R, Wager P, Gauglhofer J. Environ Impact Assess Rev 2005; 25:525–39.
33. Hoffmann JE. Recovering precious metals from electronic scrap. J-J Mines Met Mater Soc 1992;44:43–8.
34. Huisman J, Magalini F. Where are WEEE now? Lessons from WEEE: Will EPR work for the US? Proceedings of the 2007 IEEE International Symposium on Electronics & the Environment, Conference Record; 2007. p. 149–54.
35. Huo X, Peng L, Xu XJ, Zheng LK, Qiu B, Qi ZL, et al. Elevated blood lead levels of children in Guiyu, an electronic waste recycling town in China. Environ Health Perspect 2007;115:1113–7.
36. Jang YC, Townsend TG. Leaching of lead from computer printed wire boards and cathode ray tubes by municipal solid waste landfill leachates. Environ Sci Technol 2003;37:4778–84.
37. Kang HY, Schoenung JM. Electronic waste recycling: a review of US infrastructure and technology options. Res Conserv Recycl 2005;45:368–400.
38. Kogo T, Kanamori H, Onishi M, Miyajima Y, Nakazawa M. Lead-containing fluoride glass, optical fiber and process for producing it. United States Patent office 1995; Patent Number 5432131.
39. Kohler A, Erdmann L. Expected environmental impacts of pervasive computing. Hu Ecol Risk Assess 2004;10:831–52. LaDou J. Printed circuit board industry. Int J Hyg Environ Health 2006;209:211–9.
40. Ladou J, Lovegrove S. Export of electronics equipment waste. Int J Occup Environ Health 2008;14:1-10. Leung AOW, Duzgoren-Aydin NS, Cheung KC, Wong MH. Heavy metals concentrations of surface dust from e-waste recycling and its human health implications in southeast China. Environ Sci Technol 2008;42:2674–80.
41. Leung AOW, Luksemburg WJ, Wong AS, Wong MH. Spatial distribution of polybrominated diphenyl ethers and polychlorinated dibenzo-p-dioxins and dibenzofurans in soil and combusted residue at Guiyu, an electronic waste recycling site in southeast China. Environ Sci Technol 2007;41:2730–7.
42. Li HR, Yu LP, Sheng GY, Fu JM, Peng PA. Severe PCDD/F and PBDQ/F pollution in air around an electronic waste dismantling area in China. Environ Sci Technol 2007;41: 5641–6.
43. Li JH, Gao S, Duan HB, Liu LL. Recovery of valuable materials from waste liquid crystal display panel. Waste Manag 2009;29:2033–9. Li Y, Xu XJ, Liu JX, Wu KS, Gu CW, Shao G, et al. The hazard of chromium exposure to neonates in Guiyu of China. Sci Total Environ 2008a;403:99-104.
44. Li Y, Xu XJ, Wu KS, Chen GJ, Liu JX, Chen SJ, et al. Monitoring of lead load and its effect on neonatal behavioral neurological assessment scores in Guiyu, an electronic waste recycling town in China. J Environ Monitor 2008b;10:1233–8.
45. Liang SX, Zhao Q, Qin ZF, Zhao XR, Yang ZZ, Xu XB. Levels and distribution of polybrominated diphenyl ethers in various tissues of foraging hens from an electronic waste recycling area in South China. Environ Toxicol Chem 2008;27:1279–83.
46. Liu HX, Zhou QF, Wang YW, Zhang QH, Cai ZW, Jiang GB. E-waste recycling induced polybrominated diphenyl ethers, polychlorinated biphenyls, polychlorinated dibenzo-p-dioxins and dibenzo-furans pollution in the ambient environment. Environ Int 2008;34:67–72.
47. Liu Q, Cao J, Li KQ, Miao XH, Li G, Fan FY, et al. Chromosomal aberrations and DNA damage in human populations exposed to the processing of electronics waste. Environ Sci Pollut Res Int 2009;16:329–38.
48. Liu XB, Tanaka M, Matsui Y. Generation amount prediction and material flow analysis of electronic waste: a case study in Beijing, China. Waste Manag Res 2006;24:434–45.
49. Luo Q, Cai ZW, Wong MH. Polybrominated diphenyl ethers in fish and sediment from river polluted by electronic waste. Sci Total Environ 2007a;383:115–27.
50. Luo Q, Wong MH, Cai ZW. Determination of polybrominated diphenyl ethers in freshwater fishes from a river polluted by e-wastes. Talanta 2007 b;72:1644–9.
51. Luo XJ, Zhang XL, Liu J, Wu JP, Luo Y, Chen SJ, et al. Persistent halogenated compounds in waterbirds from an e-waste recycling region in South China. Environ Sci Technol 2009a;43:306–11.
52. Luo Y, Luo XJ, Lin Z, Chen SJ, Liu J, Mai BX, et al. Polybrominated diphenyl ethers in road and farmland soils from an e-waste recycling region in Southern China: Concentrations, source profiles, and potential dispersion and deposition. Sci Total Environ 2009b;407:1105–13.
53. Mauerer O. New reactive, halogen-free flame retardant system for epoxy resins. Polym Degrad Stab 2005;88:70–3. Mester A, Fraunholcz N, van Schaik A, Reuter MA. Characterization of the hazardous components in end-of-life notebook display. Light Met 2005;2005:1213–6.
54. Micklethwait J. Small but disruptive. The Economist; 2009a. Micklethwait J. Unlocking the cloud. The Economist; 2009b. Mielke HW, Reagan PL. Soil is an important pathway of human lead exposure. Environ Health Perspect 1998;106:217–29.
55. Morf LS, Tremp J, Gloor R, Schuppisser F, Stengele M, Taverna R. Metals, non-metals and PCB in electrical and electronic waste — actual levels in Switzerland. Waste Manag 2007;27:1306–16.
56. Nationmaster. Media Statistics. www.nationmaster.com accessed June 2009., 2009. Niu XJ, Li YD. Treatment of waste printed wire boards in electronic waste for safe disposal. J Hazard Mater 2007;145:410–6.
57. OECD. OECD Environmental Outlook to 2030. 2009. Organisation for Economic Cooperation and Development http://213.253.134.43/oecd/pdfs/browseit/9708011E. PDF, 2008.
58. Puckett J, Westervelt S, Gutierrez R, Takamiya Y. The digital dump. Exporting re-use and abuse to Africa. Report from the Basel Action Network, Seattle, 2005.
59. Puttlitz KJ, Galyon GT. Impact of the ROHS Directive on high-performance electronic systems — Part II: key reliability issues preventing the implementation of lead-free solders. J Mater Sci: Mater Electron 2007;18:347–65.
60. Qu WY, Bi XH, Sheng GY, Lu SY, Fu H, Yuan J, et al. Exposure to polybrominated diphenyl ethers among workers at an electronic waste dismantling region in Guangdong, China. Environ Int 2007;33:1029–34.
61. Scheutz C, Mosbaek H, Kjeldsen P. Attenuation of methane and volatile organic compounds in landfill soil covers. J Environ Qual 2004;33:61–71. Schmidt CW. Unfair trade — E-waste in Africa. Environ Health Perspect 2006;114: A232–5.
62. Shen C, Chen Y, Huang S, Wang Z, Yu C, Qiao M, et al. Dioxin-like compounds in agricultural soils near e-waste recycling sites from Taizhou area, China: Chemical and bioanalytical characterization. Environ Int 2009a;35:50–5.
63. Shen CF, Chen YX, Huang SB, Wang ZJ, Yu CN, Qiao M, et al. Dioxin-like compounds in agricultural soils near e-waste recycling sites from Taizhou area, China: chemical and bioanalytical characterization. Environ Int 2009b;35:50–5.
64. B.H. Robinson / Science of the Total Environment 408 (2009) 183–191 Shi T, Chen SJ, Luo XJ, Zhang XL, Tang CM, Luo Y, et al. Occurrence of brominated flame retardants other than polybrominated diphenyl ethers in environmental and biota samples from southern China. Chemosphere 2009;74:910–6.
65. Sinha-Khetriwal D, Kraeuchi P, Schwaninger M. A comparison of electronic waste recycling in Switzerland and in India. Environ Impact Assess Rev 2005;25:492–504.
66. Spalvins E, Dubey B, Townsend T. Impact of electronic waste disposal on lead concentrations in landfill leachate. Environ Sci Technol 2008;42:7452–8.
67. Tschan M, Robinson BH, Schulin R. Antimony in the soil-plant system — a review. Environ Chem 2009;6:106–15.
68. Tseng LH, Li MH, Tsai SS, Lee CW, Pan MH, Yao WJ, et al. Developmental exposure to decabromodiphenyl ether (PBDE 209): Effects on thyroid hormone and hepatic enzyme activity in male mouse offspring. Chemosphere 2008;70:640–7.
69. Wang JP, Guo XK. Impact of electronic wastes recycling on environmental quality. Biomed Environ Sci 2006;19:137–42. Weidenhamer JD, Clement ML. Leaded electronic waste is a possible source material for lead-contaminated jewelry. Chemosphere 2007a;69:1111–5.
70. Weidenhamer JD, Clement ML. Widespread lead contamination of imported low-cost jewelry in the US. Chemosphere 2007b:67. Widmer R, Oswald-Krapf H, Sinha-Khetriwal D, Schnellmann M, Boni H. Global perspectives on e-waste. Environ Impact Assess Rev 2005;25:436–58.
71. Wilmoth RC, Hubbard SJ, Bruckle JO, Martin JF. Production and processing of metals: their disposal and future risks. In: Merian E, editor. Metals and their compounds in the environment. Occurrence, analysis and biological relevance. VCH: Weinheim; 1991. p. 19–65.
72. Wong CSC, Duzgoren-Aydin NS, Aydin A, Wong MH. Evidence of excessive releases of metals from primitive e-waste processing in Guiyu, China. Environ Pollut 2007;148:62–72.
73. Wu JP, Luo XJ, Zhang Y, Luo Y, Chen SJ, Mai BX, et al. Bioaccumulation of polybrominated diphenyl ethers (PBDEs) and polychlorinated biphenyls (PCBs) in wild aquatic species from an electronic waste (e-waste) recycling site in South China. Environ Int 2008;34:1109–13.
74. Xing GH, Chan JKY, Leung AOW, Wu SC, Wong MH. Environmental impact and human exposure to PCBs in Guiyu, an electronic waste recycling site in China. Environ Int 2009;35:76–82.
75. Yang ZZ, Zhao XR, Zhao Q, Qin ZF, Qin XF, Xu XB, et al. Polybrominated diphenyl ethers in leaves and soil from typical electronic waste polluted area in South China. Bull Environ Contam Toxicol 2008;80:340–4.
76. Zhang J, Min H. Eco-toxicity and metal contamination of paddy soil in an e-wastes recycling area. J Hazard Mater 2009;165:744–50.
77. Zhao G, Zhou H, Wang D, Zha J, Xu Y, Rao K, et al. PBBs, PBDEs, and PCBs in foods collected from e-waste disassembly sites and daily intake by local residents. Sci Total Environ 2009;407:2565–75.
78. Zhao GF, Wang ZJ, Dong MH, Rao KF, Luo JP, Wang DH, et al. PBBs, PBDEs, and PCBs levels in hair of residents around e-waste disassembly sites in Zhejiang Province, China, and their potential sources. Sci Total Environ 2008;397:46–57.
79. Zhao GF, Xu Y, Han GG, Ling B. Biotransfer of persistent organic pollutants from a large site in China used for the disassembly of electronic and electrical waste. Environ Geochem Health 2006;28:341–51.
80. Zheng LK, Wu KS, Li Y, Qi ZL, Han D, Zhang B, et al. Blood lead and cadmium levels and relevant factors among children from an e-waste recycling town in China. Environ Res 2008;108:15–20.