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E-Waste Management: Global Trade Scenario in E-Waste

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ABSTRACT: F or more than a decade the problem of electronic waste ('e-waste') has been framed in terms of exports from wealthy countries – particularly the USA, Canada and those in Europe – reaching poor countries to be processed in conditions hazardous to workers and the environment. Reports by the Basel Action Network (BAN 2002), Toxics Link India (2003) and Greenpeace International (2005) sounded early alarms about e-waste being processed under such conditions in now infamous sites in Asia and Africa. The bulk of reports, news media and peer-reviewed literature on e-waste has largely left this basic premise unquestioned. Yet, emerging evidence suggests we need to think differently about the past, present and likely future patterns of international trade and traffic of e-waste. Evidence from a variety of sources collected using a diversity of methods suggests a new – though still minority – position: the bulk of e-waste imports are not waste but are instead working or repairable equipment; domestic sources rather than only foreign dumping contribute significant volumes of electronic discards in 'developing' countries; and trade from rich 'developed' nations to poor 'developing' nations represents a modest portion of e-waste flows relative to flows within these regions.

KEYWORDS-e-waste, global, trade, toxics, electronic, dumping

I.INTRODUCTION

Last year saw a three per cent contraction, equalling roughly $1 trillion, compared to the record high of $32 trillion in 2022.Despite this decline, the services sector showed resilience with a $500 billion (eight per cent) increase from the previous year, while trade in goods experienced a $1.3 trillion, or five per cent, decline compared to 2022.The fourth quarter of 2023 marked a departure from previous ones, with both merchandise and services trade stabilising. Developing countries, especially those in Africa, East Asia and South Asia, saw a return to growth.

Regional dynamics

While major economies generally saw a decline last year in merchandise trade – or the import and export of goods – there were exceptions, said UNCTAD.Russia "exhibited notable volatility in trade statistics", and towards the end of 2023, trade in goods grew in China (up five per cent in terms of imports) and India (five per cent growth in exports) although it declined for Russia and the European Union.During 2023, trade performance declined in the developing world by approximately four per cent and by around six per cent in developed economies.South-South trade, or trade between developing economies, saw a steeper decline of around seven per cent.However, these trends reversed in the last quarter of 2023, with developing countries and South-South trade resuming growth while trade in developed countries remained stable.Geopolitical tensions continued to impact bilateral trade, as shown by Russia reducing its trade dependence on the European Union while increasing its reliance on China. Trade interdependence between China and the United States decreased further in 2023.Regionally, trade between African economies bucked the global trend by increasing six per cent last year, whereas intraregional trade in East Asia and Latin America lagged behind the global average.

E-waste mountain growing five times faster than recycling rate

The amount of electronic waste – or e-waste – that we produce is at least 62 million tonnes, and it's rising five times faster than the amount being recycled.That's the worrying finding of the UN Global E-waste Monitor report, published The report looked into the sheer volume of old phones, batteries and other tech that's thrown away and found that all this e-waste would fill over one and a half million 40-tonne trucks – that's about enough to form a bumper-to-bumper line of lorries around the Equator.

Only 25 per cent of e-waste is recycled

Data crunched by the UN agencies behind the report – ITU and UNITAR – also found that only around 25 per cent of e-waste in 2022 was officially recorded to have been recycled.This means $62 billion worth of recoverable natural resources are unaccounted for, increasing pollution risks to communities worldwide. Worldwide, e-waste is rising by

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2.6 million tonnes annually, meaning that we're on track to reach 82 million tonnes by 2030. E-waste – any discarded product with a plug or battery – is a health and environmental hazard, containing toxic additives or hazardous substances such as mercury, which can damage the human brain and nervous system. 7,000 avoidable deaths in Europe due to COVID-19 pandemic: WHOThere were nearly 7,000 excess deaths from tuberculosis (TB) in the UN World Health Organization's (WHO) European region during the three years of the COVID-19 pandemic, new data published Based on pre-2020 estimates, the deaths would not have occurred if TB diagnosis and treatment efforts had not been disrupted, WHO said.The revelation comes via the latest TB surveillance and monitoring report from WHO/Europe and the European Centre for Disease Prevention and Control (ECDC), released annually in anticipation of World TB Day, which takes place on 24 March."Our latest report reveals a heartbreaking, entirely preventable situation; people affected by TB were not protected during the pandemic and 7,000 needlessly lost their lives because of disruptions to TB services," said Dr. Hans Kluge, WHO Regional Director for Europe."The report also reveals another evolving, preventable tragedy: the prevalence of drug-resistant TB continues to rise," he said. "We urge national authorities to strengthen TB testing programmes, diagnose promptly and apply the latest WHO guidelines."According to ECDC Director Dr Andrea Ammon, "we still have a long road ahead of us for meeting the TB elimination targets" in the aftermath of COVID-19. "Timely strengthening of prevention, testing and treatment are key elements in fighting TB, and any delays are translated into further suffering and death. Countries must act now," she said.

II.DISCUSSION

- E-waste is the fastest growing solid waste stream in the world (1).
- In 2019, an estimated 53.6 million tonnes of e-waste were produced globally, but only 17.4% was documented as formally collected and recycled (2).
- Lead is one of the common substances released into the environment if e-waste is recycled, stored or dumped using inferior activities, such as open burning (3).
- E-waste recycling activities may have several adverse impacts on human health. Children and pregnant women are particularly vulnerable.
- ILO and WHO estimate that millions of women and child labourers working in the informal recycling sector around the world may be at risk of e-waste exposure

Every year millions of electrical and electronic devices are discarded as products break or become obsolete and are thrown away. These discarded devices are considered e-waste and can become a threat to the environment and to human health if they are not treated, disposed of, and recycled appropriately. Common items in e-waste streams include computers, mobile phones, and large household appliances, as well as medical equipment. Every year, millions of tonnes of e-waste are recycled using environmentally unsound techniques and are likely stored in homes and warehouses, dumped, exported or recycled under inferior conditions. When e-waste is treated using inferior activities, it can release as many as 1000 different chemical substances into the environment, including harmful neurotoxicants such as lead (3). Pregnant women and children are particularly vulnerable due to their unique pathways of exposure and their developmental status. The International Labour Organization (ILO) estimates that 16.5 million children were working in the industrial sector in 2020, of which waste processing is a subsector (4).

Electronic waste (e-waste) is the fastest growing solid waste stream in the world, increasing 3 times faster than the world's population (1). Less than a quarter of e-waste produced globally in 2019 was known to be formally recycled; however, e-waste streams contain valuable and finite resources that can be reused if they are recycled appropriately. E-waste has therefore become an important income stream for individuals and even communities. However, people living in low- and middle-income (LMICs), particularly children, face the most significant risks from e-waste due to lack of appropriate regulations, recycling infrastructure and training. Despite international regulations targeting the control of the transport of e-waste from one country to another, the transboundary movement of e-waste to LMICs continues, frequently illegally. E-waste is considered hazardous waste as it contains toxic materials or can produce toxic chemicals when treated inappropriately. Many of these toxic materials are known or suspected to cause harm to human health, and several are included in the 10 chemicals of public health concern, including dioxins, lead and mercury. Inferior recycling of e-waste is a threat to public health and safety.

Exposure to e-waste

Electrical and electronic items contain many different toxic substances. While users are unlikely to have contact with any of these substances when the items are in use, when they become waste, these toxicants can be released into the

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environment if the devices are managed using environmentally unsound practices and activities. Several unsound practices have been observed at e-waste sites including:

- scavenging
- dumping on land or in water bodies
- landfilling along with regular waste
- opening burning or heating
- acid baths or acid leaching
- stripping and shredding plastic coatings
- manual disassembly of equipment.

These activities are considered hazardous to the environment and human health as they release toxic pollutants, contaminating the air, soil, dust, and water at recycling sites and in neighbouring communities. Burning or heating is considered one of the most hazardous activities due to the toxic fumes created. Once in the environment, toxic pollutants from e-waste or produced through unsound recycling activities can travel significant distances from the point of pollution, exposing people in faraway areas to health-damaging substances.

Children are the most vulnerable

A range of adverse health outcomes linked to e-waste recycling activities have been posed.

Children and pregnant women are especially vulnerable to the effects of hazardous pollutants from informal e-waste recycling activities. Children are often involved in waste picking and scavenging, burning discarded e-waste and the manual dismantlement of items into component parts. In some countries, children may serve as a source of cheap labour and their small hands give them an advantage in taking apart the smallest items. These activities directly expose children to injury and high levels of hazardous chemicals. Working as a waste picker is hazardous labour and is considered one of the worst forms of child labour by the ILO. In 2020, the ILO estimated that as many as 16.5 million children globally were working in the industrial sector, of which waste processing is a subsector (4). It is unknown how many child labourers participate in informal e-waste recycling.

E-waste exposure may be linked to the following health effects during pregnancy and in infants and children:

- adverse neonatal outcomes, including increased rates of stillbirth and premature birth;
- neurodevelopment, learning and behaviour outcomes, especially associated with lead released through informal e-waste recycling activities; and
- reduced lung and respiratory function and increased asthma incidence, which may be linked to high levels of contaminated air pollution that characterize many e-waste recycling sites.

Children and pregnant women are at higher risk than adults to contaminants released through informal e-waste recycling activities due to their unique vulnerabilities. Children have different exposures to e-waste recycling activities. E-waste recycling activities release toxic chemicals that can cross the placenta and may contaminate breastmilk, for example mercury. Additionally, children are highly sensitive to many of the pollutants released through e-waste recycling due to their rapidly developing bodies, including their respiratory, immune and central nervous systems. E-waste contains multiple known and suspected neurotoxicants, including lead and mercury, that may disrupt the development of the central nervous system during pregnancy, infancy, childhood and adolescence. Some harmful toxicants from e-waste may also impact the structural development and function of the lungs. Changes to children's developing systems from e-waste may cause irreparable harm and affect them for the rest of their lives.

Prevention and management

National and international actions are essential to protect communities from dangerous e-waste recycling activities. Actions that can be taken include:

- adopting and enforcing high-level international agreements;
- developing and implementing national e-waste management legislation that protects public health;
- incorporating health protection measures into national legislation;
- monitoring e-waste sites and surrounding communities;
- implementing and monitoring interventions that improve informal e-waste recycling activities, protect public health and ensure vital sources of community revenue;
- educating health workers across all levels on e-waste-related child health issues;
- eliminating child labour.

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International agreements
The Basel Convention controls the transboundary movement of hazardous wastes and their disposal. It is a comprehensive environmental agreement that aims to tackle issues surrounding hazardous wastes, including e-waste and its management. In 2019, the Ban Amendment to the Basel Convention entered into force. It prohibits the movement of hazardous wastes, including e-waste, from countries of the Organisation for Economic Co-operation and Development (OECD), the European Commission countries and Liechtenstein to other states that are party to the Convention. The Basel Convention runs programmes and workshops to develop and deliver guidance on environmentally sound management of e-waste. It also provides states with guidelines to distinguish between waste and non-waste and the transboundary movement of e-waste. Additionally, regional conventions also exist, such as the Bamako Convention and the Waigani Convention. Both these regional conventions have arisen in response to the Basel Convention and aim to further restrict the movement of hazardous wastes, including e-waste, in African and South Pacific countries, respectively.

WHO response
WHO's Initiative on E-waste and Child Health is contributing to a number of international e-waste programmes and pilot projects in countries in Latin America and Africa. These pilot projects are developing frameworks to protect children's health from e-waste exposures that can be adapted and replicated in other countries and settings. The Initiative aims to:

- increase access to evidence, knowledge and awareness of the health impacts of e-waste
- improve health sector capacity to manage and prevent risks
- facilitate monitoring of exposure to e-waste and interventions that protect public health.

In 2021, WHO released its first global report on e-waste and child health, which called for greater effective and binding action to protect children from the growing threat. WHO has developed training tools for the health sector, such as the recently updated training package for health care providers, including a specific training module on lead and on e-waste and child health. Additionally, WHO contributes to multi-agency capacity training tools including a MOOC and a joint course with PAHO.

III.RESULTS

The global trade in electronic waste destined for recycling, disposal or reuse (E-waste) poses a significant risk to human health and the natural environment from improper recycling and disposal. However, in part due to the lack of regulatory attention, few empirical studies of this issue exist. In this paper, we fill this knowledge gap by applying a conservation criminology framework to E-waste. Specifically, we draw on criminology and criminal justice, natural-resources management, and risk and decision sciences to describe the nature of the trade, relevant stakeholders, and current interventions. Our initial step is to develop a more holistic picture of E-waste and identify knowledge gaps for future research, working toward building theoretical explanations necessary for effective policy development.

Electronic waste (or e-waste) describes discarded electrical or electronic devices. It is also commonly known as waste electrical and electronic equipment (WEEE) or end-of-life (EOL) electronics.[1] Used electronics which are destined for refurbishment, reuse, resale, salvage recycling through material recovery, or disposal are also considered e-waste. Informal processing of e-waste in developing countries can lead to adverse human health effects and environmental pollution. The growing consumption of electronic goods due to the Digital Revolution and innovations in science and technology, such as bitcoin, has led to a global e-waste problem and hazard. The rapid exponential increase of e-waste is due to frequent new model releases and unnecessary purchases of electrical and electronic equipment (EEE), short innovation cycles and low recycling rates, and a drop in the average life span of computers.[2]
Electronic scrap components, such as CPUs, contain potentially harmful materials such as lead, cadmium, beryllium, or brominated flame retardants. Recycling and disposal of e-waste may involve significant risk to the health of workers and their communities.[3]

E-waste or electronic waste is created when an electronic product is discarded after the end of its useful life. The rapid expansion of technology and the consumption driven society results in the creation of a very large amount of e-waste.
In the US, the United States Environmental Protection Agency (EPA) classifies e-waste into ten categories:

1. Large household appliances, including cooling and freezing appliances
2. Small household appliances
3. IT equipment, including monitors
4. Consumer electronics, including televisions

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5. Lamps and luminaires
6. Toys
7. Tools
8. Medical devices
9. Monitoring and control instruments
10. Automatic dispensers

These include used electronics which are destined for reuse, resale, salvage, recycling, or disposal as well as re-usables (working and repairable electronics) and secondary raw materials (copper, steel, plastic, or similar). The term "waste" is reserved for residue or material which is dumped by the buyer rather than recycled, including residue from reuse and recycling operations, because loads of surplus electronics are frequently commingled (good, recyclable, and non-recyclable). Several public policy advocates apply the term "e-waste" and "e-scrap" broadly to apply to all surplus electronics. Cathode ray tubes (CRTs) are considered one of the hardest types to recycle.[4][5]

Using a different set of categories, the Partnership on Measuring ICT for Development defines e-waste in six categories:

1. Temperature exchange equipment (such as air conditioners, freezers)
2. Screens, monitors (TVs, laptops)
3. Lamps (LED lamps, for example)
4. Large equipment (washing machines, electric stoves)
5. Small equipment (microwaves, electric shavers)
6. Small IT and telecommunication equipment (such as mobile phones, printers)

Products in each category vary in longevity profile, impact, and collection methods, among other differences.[6] Around 70% of toxic waste in landfills is electronic waste.[7]

CRTs have a relatively high concentration of lead and phosphors (not to be confused with phosphorus), both of which are necessary for the display. The United States Environmental Protection Agency (EPA) includes discarded CRT monitors in its category of "hazardous household waste"[8] but considers CRTs that have been set aside for testing to be commodities if they are not discarded, speculatively accumulated, or left unprotected from weather and other damage. These CRT devices are often confused between the DLP Rear Projection TV, both of which have a different recycling process due to the materials of which they are composed.

The EU and its member states operate a system via the European Waste Catalogue (EWC) – a European Council Directive, which is interpreted into "member state law". In the UK, this is in the form of the List of Wastes Directive. However, the list (and EWC) gives a broad definition (EWC Code 16 02 13*) of what is hazardous electronic waste, requiring "waste operators" to employ the Hazardous Waste Regulations (Annex 1A, Annex 1B) for refined definition. Constituent materials in the waste also require assessment via the combination of Annex II and Annex III, again allowing operators to further determine whether waste is hazardous.[9]

Debate continues over the distinction between "commodity" and "waste" electronics definitions. Some exporters are accused of deliberately leaving difficult-to-recycle, obsolete, or non-repairable equipment mixed in loads of working equipment (though this may also come through ignorance, or to avoid more costly treatment processes). Protectionists may broaden the definition of "waste" electronics in order to protect domestic markets from working secondary equipment.

The high value of the computer recycling subset of electronic waste (working and reusable laptops, desktops, and components like RAM) can help pay the cost of transportation for a larger number of worthless pieces than what can be achieved with display devices, which have less (or negative) scrap value. A 2011 report, "Ghana E-waste Country Assessment",[10] found that of 215,000 tons of electronics imported to Ghana, 30% was brand new and 70% was used. Of the used product, the study concluded that 15% was not reused and was scrapped or discarded. This contrasts with published but uncredited claims that 80% of the imports into Ghana were being burned in primitive conditions.

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Quantity

A fragment of a discarded circuit board from a television remote

E-waste is considered the "fastest-growing waste stream in the world"[11] with 44.7 million tonnes generated in 2016- equivalent to 4500 Eiffel towers.[6] In 2018, an estimated 50 million tonnes of e-waste was reported, thus the name 'tsunami of e-waste' given by the UN.[11] Its value is at least $62.5 billion annually.[11]

Rapid changes in technology, changes in media (tapes, software, MP3), falling prices, and planned obsolescence have resulted in a fast-growing surplus of electronic waste around the globe. Technical solutions are available, but in most cases, a legal framework, a collection, logistics, and other services need to be implemented before a technical solution can be applied.

Display units (CRT, LCD, LED monitors), processors (CPU, GPU, or APU chips), memory (DRAM or SRAM), and audio components have different useful lives. Processors are most frequently out-dated (by software no longer being optimized) and are more likely to become "e-waste" while display units are most often replaced while working without repair attempts, due to changes in wealthy nation appetites for new display technology. This problem could potentially be solved with modular smartphones (such as the Phonebloks concept). These types of phones are more durable and have the technology to change certain parts of the phone making them more environmentally friendly. Being able to simply replace the part of the phone that is broken will reduce e-waste.[12] An estimated 50 million tons of e-waste are produced each year.[13] The USA discards 30 million computers each year and 100 million phones are disposed of in Europe each year. The Environmental Protection Agency estimates that only 15–20% of e-waste is recycled, the rest of these electronics go directly into landfills and incinerators.[14][15]

Electronic waste at Agbogbloshie, Ghana

In 2006, the United Nations estimated the amount of worldwide electronic waste discarded each year to be 50 million metric tons.[16] According to a report by UNEP titled, "Recycling – from e-waste to Resources," the amount of e-waste being produced – including mobile phones and computers – could rise by as much as 500 percent over the next decade in some countries, such as India.[17] The United States is the world leader in producing electronic waste, tossing away about 3 million tons each year.[18] China already produces about 10.1 million tons (2020 estimate) domestically, second only to the United States. And, despite having banned e-waste imports, China remains a major e-waste dumping ground for developed countries.[18]

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An iPhone with a damaged screen

Society today revolves around technology and by the constant need for the newest and most high-tech products we are contributing to a mass amount of e-waste.[19] Since the invention of the iPhone, cell phones have become the top source of e-waste products .[citation needed] Electrical waste contains hazardous but also valuable and scarce materials. Up to 60 elements can be found in complex electronics.[20] Concentration of metals within the electronic waste is generally higher than a typical ore, such as copper, aluminium, iron, gold, silver, and palladium.[21] As of 2013, Apple has sold over 796 million iDevices (iPod, iPhone, iPad). Cell phone companies make cell phones that are not made to last so that the consumer will purchase new phones. Companies give these products such short lifespans because they know that the consumer will want a new product and will buy it if they make it.[22][better source needed] In the United States, an estimated 70% of heavy metals in landfills comes from discarded electronics.[23][24]

While there is agreement that the number of discarded electronic devices is increasing, there is considerable disagreement about the relative risk (compared to automobile scrap, for example), and strong disagreement whether curtailing trade in used electronics will improve conditions, or make them worse. According to an article in Motherboard, attempts to restrict the trade have driven reputable companies out of the supply chain, with unintended consequences.[25]

E-waste legislative frameworks

The European Union (EU) has addressed the issue of electronic Waste by introducing two pieces of legislation. The first, the Waste Electrical and Electronic Equipment Directive (WEEE Directive) came into force in 2003. [1] The main aim of this directive was to regulate and motivate electronic waste recycling and re-use in member states at that moment. It was revised in 2008, coming into force in 2014.[2] Furthermore, the EU has also implemented the Directive on the restriction of the use of certain hazardous substances in electrical and electronic equipment from 2003.[3] This documents was additionally revised in 2012.[4] When it comes to Western Balkan countries, North Macedonia has adopted a Law on Batteries and Accumulators in 2010, followed by the Law on Management of electrical and electronic equipment in 2012. Serbia has regulated management of special waste stream, including electronic waste, by National waste management strategy (2010–2019).[5] Montenegro has adopted Concessionary Act concerning electronic waste with ambition to collect 4 kg of this waste annually per person until 2020.[6] Albanian legal framework is based on the draft act on waste from electrical and electronic equipment from 2011 which focuses on the design of electrical and electronic equipment. Contrary to this, Bosnia and Herzegovina is still missing a law regulating electronic waste.

As of October 2019, 78 countries globally have established either a policy, legislation or specific regulation to govern e-waste.[32] However, there is no clear indication that countries are following the regulations. Regions such as Asia and Africa are having policies that are not legally binding and rather only programmatic ones.[33] Hence, this poses as a challenge that e-waste management policies are yet not fully developed by globally by countries.

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Solving the e-waste Problem (StEP) initiative

Solving the E-waste Problem is a membership organization that is part of United Nations University and was created to develop solutions to address issues associated with electronic waste. Some of the most eminent players in the fields of Production, Reuse and Recycling of Electrical and Electronic Equipment (EEE), government agencies and NGOs as well as UN Organisations count themselves among its members. StEP encourages the collaboration of all stakeholders connected with e-waste, emphasizing a holistic, scientific yet applicable approach to the problem.:[34]

Waste electrical and electronic equipment

The European Commission (EC) of the EU has classified waste electrical and electronic equipment (WEEE) as the waste generated from electrical devices and household appliances like refrigerators, televisions, and mobile phones and other devices. In 2005 the EU reported total waste of 9 million tonnes and in 2020 estimates waste of 12 million tonnes. This electronic waste with hazardous materials if not managed properly, may end up badly affecting our environment and causing fatal health issues. Disposing of these materials requires a lot of manpower and properly managed facilities. Not only the disposal, manufacturing of these types of materials require huge facilities and natural resources (aluminum, gold, copper and silicon, etc.), ending up damaging our environment and pollution. Considering the impact of WEEE materials make on our environment, EU legislation has made two legislations: 1. WEEE Directive; 2. RoHS Directive: Directive on usage and restrictions of hazardous materials in producing these Electrical and Electronic Equipment.

WEEE Directive: This Directive was implemented in February 2003, focusing on recycling electronic waste. This Directive offered many electronic waste collection schemes free of charge to the consumers (Directive 2002/96/EC [7]). The EC revised this Directive in December 2008, since this has become the fastest growing waste stream. In August 2012, the WEEE Directive was rolled out to handle the situation of controlling electronic waste and this was implemented on 14 February 2014 (Directive 2012/19/EU [8]). On 18 April 2017, the EC adopted a common principle of carrying out research and implementing a new regulation to monitor the amount of WEEE. It requires each member state to monitor and report their national market data. - Annex III to the WEEE Directive (Directive 2012/19/EU): Re-examination of the timelines for waste collection and setting up individual targets (Report [9]).

WEEE Legislation: - On 4 July 2012, the EC passed legislation on WEEE (Directive 2012/19/EU [10]). To know more about the progress in adopting the Directive 2012/19/EU (Progress [11]). - On 15 February 2014, the EC revised the Directive. To know more about the old Directive 2002/96/EC, see (Report [12]).

RoHS Directive: In 2003, the EC not only implemented legislation on waste collection but also on the alternative use of hazardous materials (Cadmium, mercury, flammable materials, polybrominated biphenyls, lead and polybrominated diphenyl ethers) used in the production of electronic and electric equipment (RoHS Directive 2002/95/EC [13]). This Directive was again revised in December 2008 and later again in January 2013 (RoHS recast Directive 2011/65/EU [14]). In 2017, the EC has made adjustment to the existing Directive considering the impact assessment [15] and adopted to a new legislative proposal [16] (RoHS 2 scope review [17]). On 21 November 2017, the European Parliament and Council has published this legislation amending the RoHS 2 Directive in their official journal [18].

European Commission legislation on batteries and accumulators (Batteries Directive)

Each year, the EU reports nearly 800 000 tons of batteries from automotive industry, industrial batteries of around 190 000 tons and consumer batteries around 160 000 tons entering the Europe region. These batteries are one of the most commonly used products in household appliances and other battery powered products in our day-to-day life. The important issue to look into is how this battery waste is collected and recycled properly, which has the consequences of resulting in hazardous materials release into the environment and water resources. Generally, many parts of these batteries and accumulators / capacitors can be recycled without releasing these hazardous materials release into our environment and contaminating our natural resources. The EC has rolled out a new Directive to control the waste from the batteries and accumulators known as 'Batteries Directive'[19] aiming to improve the collecting and recycling process of the battery waste and control the impact of battery waste on our environment. This Directive also supervises and administers the internal market by implementing required measures. This Directive restricts the production and marketing of batteries and accumulators which contains hazardous materials and are harmful to the environment, difficult to collect and recycle them. Batteries Directive [20] targets on the collection, recycling and other recycling activities of batteries and accumulators, also approving labels to the batteries which are environment neutral. On 10 December 2020, The EC has proposed a new regulation (Batteries Regulation [21]) on the batteries waste which aims to make sure that batteries entering the European market are recyclable, sustainable and non-hazardous (Press release [22]).

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Legislation: In 2006, the EC has adopted the Batteries Directive and revised it in 2013. - On 6 September 2006, the European Parliament and European Council have launched Directives in waste from Batteries and accumulators (Directive 2006/66/EC [23]). - Overview of Batteries and accumulators Legislation [24]
Evaluation of Directive 2006/66/EC (Batteries Directive): Revising Directives could be based on the Evaluation [25] process, considering the fact of the increase in the usage of batteries with an increase in the multiple communication technologies, household appliances and other small battery-powered products. The increase in the demand of renewable energies and recycling of the products has also led to an initiative 'European Batteries Alliance (EBA)' which aims to supervise the complete value chain of production of more improved batteries and accumulators within Europe under this new policy act. Though the adoption of the Evaluation [26] process has been broadly accepted, few concerns rose particularly managing and monitoring the use of hazardous materials in the production of batteries, collection of the battery waste, recycling of the battery waste within the Directives. The evaluation process has definitely gave good results in the areas like controlling the environmental damage, increasing the awareness of recycling, reusable batteries and also improving the efficiency of the internal markets.

However, there are few limitations in the implementations of the Batteries Directive in the process of collecting batteries waste and recovering the usable materials from them. The evaluation process throws some light on the gap in this process of implementation and collaborate technical aspects in the process and new ways to use makes it more difficult to implement and this Directive maintains the balance with technological advancements. The EC's regulations and guidelines has made the evaluation process more impactful in a positive way. The participation of number of stakeholders in the evaluation process who are invited and asked to provide their views and ideas to improve the process of evaluation and information gathering. On 14 March 2018, stakeholders and members of the association participated to provide information about their findings, support and increase the process of Evaluation Roadmap [27].

Global trade issues

Electronic waste is often exported to developing
One theory is that increased regulation of electronic wastes and concern over the environmental harm in nature economies creates an economic disincentive to remove residues prior to export. Critics of trade in used electronics maintain that it is still too easy for brokers calling themselves recyclers to export unscreened electronic waste to developing countries, such as China,[47] India and parts of Africa, thus avoiding the expense of removing items like bad cathode ray tubes (the processing of which is expensive and difficult). The developing countries have become toxic dump yards of e-waste. Developing countries receiving foreign e-waste often go further to repair and recycle forsaken equipment.[48] Yet still 90% of e-waste ended up in landfills in developing countries in 2003.[48] Proponents of international trade point to the success of fair trade programs in other industries, where cooperation has led to creation of sustainable jobs and can bring affordable technology in countries where repair and reuse rates are higher.

Defenders of the trade[who?] in used electronics say that extraction of metals from virgin mining has been shifted to developing countries. Recycling of copper, silver, gold, and other materials from discarded electronic devices is considered better for the environment than mining. They also state that repair and reuse of computers and televisions has become a "lost art" in wealthier nations and that refurbishing has traditionally been a path to development.

South Korea, Taiwan, and southern China all excelled in finding "retained value" in used goods, and in some cases have set up billion-dollar industries in refurbishing used ink cartridges, single-use cameras, and working CRTs. Refurbishing has traditionally been a threat to established manufacturing, and simple protectionism explains some criticism of the trade. Works like "The Waste Makers" by Vance Packard explain some of the criticism of exports of working product, for example, the ban on import of tested working Pentium 4 laptops to China, or the bans on export of used surplus working electronics by Japan.

Opponents of surplus electronics exports argue that lower environmental and labor standards, cheap labor, and the relatively high value of recovered raw materials lead to a transfer of pollution-generating activities, such as smelting of copper wire. Electronic waste is often sent to various African and Asian countries such as China, Malaysia, India, and Kenya for processing, sometimes illegally. Many surplus laptops are routed to developing nations as "dumping grounds for e-waste".[49]

Because the United States has not ratified the Basel Convention or its Ban Amendment, and has few domestic federal laws forbidding the export of toxic waste, the Basel Action Network estimates that about 80% of the electronic waste directed to recycling in the U.S. does not get recycled there at all, but is put on container ships and sent to countries

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such as China.[50][51][52][53] This figure is disputed as an exaggeration by the EPA, the Institute of Scrap Recycling Industries, and the World Reuse, Repair and Recycling Association.

Independent research by Arizona State University showed that 87–88% of imported used computers were priced above the constituent materials they contained, and that "the official trade in end-of-life computers is thus driven by reuse as opposed to recycling".[54]

Trade

Sacks of mobile phones in Agbogbloshie, Ghana

Proponents of the trade say growth of internet access is a stronger correlation to trade than poverty. Haiti is poor and closer to the port of New York than southeast Asia, but far more electronic waste is exported from New York to Asia than to Haiti. Thousands of men, women, and children are employed in reuse, refurbishing, repair, and re-manufacturing, unsustainable industries in decline in developed countries. Denying developing nations access to used electronics may deny them sustainable employment, affordable products, and internet access, or force them to deal with even less scrupulous suppliers. In a series of seven articles for The Atlantic, Shanghai-based reporter Adam Minter describes many of these computer repair and scrap separation activities as objectively sustainable.[55]

Opponents of the trade argue that developing countries utilize methods that are more harmful and more wasteful. An expedient and prevalent method is simply to toss equipment onto an open fire, in order to melt plastics and to burn away non-valuable metals. This releases carcinogens and neurotoxins into the air, contributing to an acrid, lingering smog. These noxious fumes include dioxins and furans. Bonfire refuse can be disposed of quickly into drainage ditches or waterways feeding the ocean or local water supplies.[53]

In June 2008, a container of electronic waste, destined from the Port of Oakland in the U.S. to Sanshui District in mainland China, was intercepted in Hong Kong by Greenpeace.[56] Concern over exports of electronic waste were raised in press reports in India,[57][58] Ghana,[59][60][61] Côte d'Ivoire,[62] and Nigeria.[63]

The research that was undertaken by the Countering WEEE Illegal Trade (CWIT) project, funded by the European Commission, found that in Europe only 35% (3.3 million tons) of all the e-waste discarded in 2012 ended up in the officially reported amounts of collection and recycling systems. The other 65% (6.15 million tons) was either:

- Exported (1.5 million tons),
- Recycled under non-compliant conditions in Europe (3.15 million tons),
- Scavenged for valuable parts (750,000 tons), or
- Simply thrown in waste bins (750,000 tons).[64]

Guiyu

Guiyu in the Guangdong region of China is a massive electronic waste processing community.[50][65] It is often referred to as the "e-waste capital of the world." Traditionally, Guiyu was an agricultural community; however, in the mid-1990s it transformed into an e-waste recycling center involving over 75% of the local households and an additional 100,000 migrant workers.[66] Thousands of individual workshops employ laborers to snip cables, pry chips from circuit boards, grind plastic computer cases into particles, and dip circuit boards in acid baths to dissolve the precious metals. Others work to strip insulation from all wiring in an attempt to salvage tiny amounts of copper wire.[67] Uncontrolled burning, disassembly, and disposal has led to a number of environmental problems such as groundwater contamination, atmospheric pollution, and water pollution either by immediate discharge or from surface runoff (especially near

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coastal areas), as well as health problems including occupational safety and health effects among those directly and indirectly involved, due to the methods of processing the waste.

Six of the many villages in Guiyu specialize in circuit-board disassembly, seven in plastics and metals reprocessing, and two in wire and cable disassembly. Greenpeace, an environmental group, sampled dust, soil, river sediment, and groundwater in Guiyu. They found very high levels of toxic heavy metals and organic contaminants in both places.[68] Lai Yun, a campaigner for the group found "over 10 poisonous metals, such as lead, mercury, and cadmium." Guiyu is only one example of digital dumps but similar places can be found across the world in Nigeria, Ghana, and India.[69]

Other informal e-waste recycling sites

A pile of discarded TVs and computer monitors

Guiyu is likely one of the oldest and largest informal e-waste recycling sites in the world; however, there are many sites worldwide, including India, Ghana (Agbogbloshie), Nigeria, and the Philippines. There are a handful of studies that describe exposure levels in e-waste workers, the community, and the environment. For example, locals and migrant workers in Delhi, a northern union territory of India, scavenge discarded computer equipment and extract base metals using toxic, unsafe methods.[70] Bangalore, located in southern India, is often referred as the "Silicon Valley of India" and has a growing informal e-waste recycling sector.[71][72] A study found that e-waste workers in the slum community had higher levels of V, Cr, Mn, Mo, Sn, Tl, and Pb than workers at an e-waste recycling facility.[71]

Cryptocurrency e-waste

Bitcoin mining has also contributed to higher amounts in electronic waste. Bitcoin and other cryptocurrencies can be used for payment or speculation. Per de Vries & Stoll in the journal Resources, Conservation and Recycling the average bitcoin transaction yields 272 grams of electronic waste and generated approximately 112.5 million grams of waste in 2020 alone.[73] Other estimates indicate that the bitcoin network discards as much "small IT and telecommunication equipment waste produced by a country like the Netherlands," totalling to 30.7 metric kilotons every year.[73] Furthermore, the rate at which Bitcoin disposes of its waste exceeds that of major financial organizations such as VISA, which produces 40 grams of waste for every 100,000 transactions.[74]

A major point of concern is the rapid turnover of technology in the bitcoin industry which results in such high levels of e-waste. This can be attributed to the proof-of-work principle bitcoin employs where miners receive currency as a reward for being the first to decode the hashes that encode its blockchain.[75] As such, miners are encouraged to compete with one another to decode the hash first.[75] However, computing these hashes requires massive computing power which, in effect, drives miners to obtain rigs with the highest processing power possible. In an attempt to achieve this, miners increase the processing power in their rigs by purchasing more advanced computer chips.[75]

According to Koomey's Law, efficiency in computer chips doubles every 1.5 years,[76] meaning that miners are incentivized to purchase new chips to keep up with competing miners even though the older chips are still functional. In some cases, miners even discard their chips earlier than this timeframe for the sake of profitability.[73] However, this leads to a significant build up in waste, as outdated application-specific integrated circuits (ASIC computer chips) cannot be reused or repurposed.[75] Most computer chips used to mine bitcoin are ASIC chips, whose sole function is to mine bitcoin, rendering them useless for other cryptocurrencies or operation in any other piece of technology.[75] Therefore, outdated ASIC chips can only be disposed of since they are unable to be repurposed.

The bitcoin e-waste problem is further exacerbated by the fact that many countries and corporations lack recycling programs for ASIC chips.[73] Developing a recycling infrastructure for bitcoin mining may prove to be beneficial, though, as the aluminum heat sinks and metal casings in ASIC chips can be recycled into new technology.[73] Much of this responsibility falls onto Bitmain, the leading manufacturer of bitcoin, which currently

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lacks the infrastructure to recycle waste from bitcoin mining.[73] Without such programs, much of bitcoin waste ends up in landfill along with 83.6% of the global total of e-waste.[73]

Many argue for relinquishing the proof-of-work model altogether in favour of the proof-of-stake one. This model selects one miner to validate the transactions in the blockchain, rather than have all miners competing for it.[77] With no competition, the processing speed of miners' rigs would not matter.[73] Any device could be used for validating the blockchain, so there would be no incentive to use single-use ASIC chips or continually purchase new and dispose of old ones.[73][77]

Environmental impact

Old keyboards and a mouse

The processes of dismantling and disposing of electronic waste in developing countries led to a number of environmental impacts as illustrated in the graphic. Liquid and atmospheric releases end up in bodies of water, groundwater, soil, and air and therefore in land and sea animals – both domesticated and wild, in crops eaten by both animals and humans, and in drinking water.[78]

One study of environmental effects in Guiyu, China found the following:[13]

- Airborne dioxins – one type found at 100 times levels previously measured
- Levels of carcinogens in duck ponds and rice paddies exceeded international standards for agricultural areas and cadmium, copper, nickel, and lead levels in rice paddies were above international standards
- Heavy metals found in road dust – lead over 300 times that of a control village's road dust and copper over 100 times

The Agbogbloshie area of Ghana, where about 40,000 people live, provides an example of how e-waste contamination can pervade the daily lives of nearly all residents. Into this area—one of the largest informal e-waste dumping and processing sites in Africa—about 215,000 tons of secondhand consumer electronics, primarily from Western Europe, are imported annually. Because this region has considerable overlap among industrial, commercial, and residential zones, Pure Earth (formerly Blacksmith Institute) has ranked Agbogbloshie as one of the world's 10 worst toxic threats (Blacksmith Institute 2013).[79]

A separate study at the Agbogbloshie e-waste dump, Ghana found a presence of lead levels as high as 18,125 ppm in the soil.[80] US EPA standard for lead in soil in play areas is 400 ppm and 1200 ppm for non-play areas.[81] Scrap workers at the Agbogbloshie e-waste dump regularly burn electronic components and auto harness wires for copper recovery,[82] releasing toxic chemicals like lead, dioxins and furans[83] into the environment.

Researchers such as Brett Robinson, a professor of soil and physical sciences at Lincoln University in New Zealand, warn that wind patterns in Southeast China disperse toxic particles released by open-air burning across the Pearl River Delta Region, home to 45 million people. In this way, toxic chemicals from e-waste enter the "soil-crop-food pathway," one of the most significant routes for heavy metals' exposure to humans. These chemicals are not biodegradable— they persist in the environment for long periods of time, increasing exposure risk.[84]

In the agricultural district of Chachoengsao, in the east of Bangkok, local villagers had lost their main water source as a result of e-waste dumping. The cassava fields were transformed in late 2017, when a nearby Chinese-run factory started bringing in foreign e-waste items such as crushed computers, circuit boards and cables for recycling to mine the electronics for valuable metal components like copper, silver and gold. But the items also contain lead, cadmium and mercury, which are highly toxic if mishandled during processing. Apart from feeling faint from noxious fumes emitted during processing, a local claimed the factory has also contaminated her water. "When it was raining, the water went

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through the pile of waste and passed our house and went into the soil and water system. Water tests conducted in the province by environmental group Earth and the local government both found toxic levels of iron, manganese, lead, nickel and in some cases arsenic and cadmium. The communities observed when they used water from the shallow well, there was some development of skin disease or there are foul smells", founder of Earth, Penchom Saetang, said: "This is proof, that it is true, as the communities suspected, there are problems happening to their water sources."[85]

Research

In May 2020, a scientific study was conducted in China that investigated the occurrence and distribution of traditional and novel classes of contaminants, including chlorinated, brominated, and mixed halogenated dibenzo-p-dioxins/dibenzofurans (PCDD/Fs, PBDD/Fs, PXDD/Fs), polybrominated diphenyl ethers (PBDEs), polychlorinated biphenyls (PCBs) and polyhalogenated carbazoles (PHCZs) in soil from an e-waste disposal site in Hangzhou (which has been in operation since 2009 and has a treatment capacity of 19.6 Wt/a). While the study area has only one formal emission source, the broader industrial zone has a number of metal recovery and reprocessing plants as well as heavy traffic on adjacent motorways where normal and heavy-duty devices are used. The maximum concentrations of the target halogenated organic compounds HOCs were 0.1–1.5 km away from the main source and overall detected levels of HOCs were generally lower than those reported globally. The study proved what researchers have warned, i. e. on highways with heavy traffic, especially those serving diesel powered vehicles, exhaust emissions are larger sources of dioxins than stationary sources. When assessing the environmental and health impacts of chemical compounds, especially PBDD/Fs and PXDD/Fs, the compositional complexity of soil and long period weather conditions like rain and downwind have to be taken into account. Further investigations are necessary to build up a common understanding and methods for assessing e-waste impacts.[88]

Information security

Discarded data processing equipment may still contain readable data that may be considered sensitive to the previous users of the device. A recycling plan for such equipment can support information security by ensuring proper steps are followed to erase the sensitive information. This may include such steps as re-formatting of storage media and overwriting with random data to make data unrecoverable, or even physical destruction of media by shredding and incineration to ensure all data is obliterated. For example, on many operating systems deleting a file may still leave the physical data file intact on the media, allowing data retrieval by routine methods.

Recycling

Computer monitors are typically packed into low stacks on wooden pallets for recycling and then shrink-wrapped.

Recycling is an essential element of e-waste management. Properly carried out, it should greatly reduce the leakage of toxic materials into the environment and militate against the exhaustion of natural resources. However, it does need to be encouraged by local authorities and through community education. Less than 20% of e-waste is formally recycled, with 80% either ending up in landfill or being informally recycled – much of it by hand in developing countries, exposing workers to hazardous and carcinogenic substances such as mercury, lead and cadmium.[89]

There are generally three methods of extracting precious metals from electronic waste, namely hydrometallurgical, pyrometallurgical, and hydro-pyrometallurgical methods. Each of these methods has its own advantages and disadvantages together with the production of toxic waste.[21]

One of the major challenges is recycling the printed circuit boards from electronic waste. The circuit boards contain such precious metals as gold, silver, platinum, etc. and such base metals as copper, iron, aluminum, etc. One way e-waste is processed is by melting circuit boards, burning cable sheathing to recover copper wire and open- pit acid

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leaching for separating metals of value.[13] Conventional method employed is mechanical shredding and separation but the recycling efficiency is low. Alternative methods such as cryogenic decomposition have been studied for printed circuit board recycling,[90] and some other methods are still under investigation. Properly disposing of or reusing electronics can help prevent health problems, reduce greenhouse-gas emissions, and create jobs.[91]

Consumer awareness efforts

A campaign to promote E-waste recycling in Ghana

The U.S. Environmental Protection Agency encourages electronic recyclers to become certified by demonstrating to an accredited, independent third party auditor that they meet specific standards to safely recycle and manage electronics. This should work so as to ensure the highest environmental standards are being maintained. Two certifications for electronic recyclers currently exist and are endorsed by the EPA. Customers are encouraged to choose certified electronics recyclers. Responsible electronics recycling reduces environmental and human health impacts, increases the use of reusable and refurbished equipment and reduces energy use while conserving limited resources. The two EPA-endorsed certification programs are Responsible Recyclers Practices (R2) and E-Stewards. Certified companies ensure they are meeting strict environmental standards which maximize reuse and recycling, minimize exposure to human health or the environment, ensure safe management of materials and require destruction of all data used on electronics.[92] Certified electronics recyclers have demonstrated through audits and other means that they continually meet specific high environmental standards and safely manage used electronics. Once certified, the recycler is held to the particular standard by continual oversight by the independent accredited certifying body. A certification board accredits and oversees certifying bodies to ensure that they meet specific responsibilities and are competent to audit and provide certification.[93]

Some U.S. retailers offer opportunities for consumer recycling of discarded electronic devices.[94][95] In the US, the Consumer Electronics Association (CEA) urges consumers to dispose properly of end-of-life electronics through its recycling locator. This list only includes manufacturer and retailer programs that use the strictest standards and third-party certified recycling locations, to provide consumers assurance that their products will be recycled safely and responsibly. CEA research has found that 58 percent of consumers know where to take their end-of-life electronics, and the electronics industry would very much like to see that level of awareness increase. Consumer electronics manufacturers and retailers sponsor or operate more than 5,000 recycling locations nationwide and have vowed to recycle one billion pounds annually by 2016,[96] a sharp increase from 300 million pounds industry recycled in 2010.
The Sustainable Materials Management (SMM) Electronic Challenge was created by the United States Environmental Protection Agency (EPA) in 2012.[97] Participants of the Challenge are manufacturers of electronics and electronic retailers. These companies collect end-of-life (EOL) electronics at various locations and send them to a certified, third-party recycler. Program participants are then able publicly promote and report 100% responsible recycling for their companies.[98] The Electronics TakeBack Coalition (ETBC)[99] is a campaign aimed at protecting human health and limiting environmental effects where electronics are being produced, used, and discarded. The ETBC aims to place responsibility for disposal of technology products on electronic manufacturers and brand owners, primarily through community promotions and legal enforcement initiatives. It provides recommendations for consumer recycling and a list of recyclers judged environmentally responsible.[100] While there have been major benefits from the rise in recycling and waste collection created by producers and consumers, such as valuable materials being recovered and kept away from landfill and incineration, there are still many problems present with the EPR system including "how to ensure proper enforcement of recycling standards, what to do about waste with positive net value, and the role of competition," (Kunz et al.). Many stakeholders agreed there needs to be a higher standard of accountability and efficiency to improve the systems of recycling everywhere, as well as the growing amount of waste being an opportunity more so than

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downfall since it gives us more chances to create an efficient system. To make recycling competition more cost-effective, the producers agreed that there needs to be a higher drive for competition because it allows them to have a wider range of producer responsibility organizations to choose from for e-waste recycling.[101]

The Certified Electronics Recycler program[102] for electronic recyclers is a comprehensive, integrated management system standard that incorporates key operational and continual improvement elements for quality, environmental and health and safety performance. The grassroots Silicon Valley Toxics Coalition promotes human health and addresses environmental justice problems resulting from toxins in technologies. The World Reuse, Repair, and Recycling Association (wr3a.org) is an organization dedicated to improving the quality of exported electronics, encouraging better recycling standards in importing countries, and improving practices through "Fair Trade" principles. Take Back My TV[103] is a project of The Electronics TakeBack Coalition and grades television manufacturers to find out which are responsible, in the coalition's view, and which are not.

There have also been efforts to raise awareness of the potentially hazardous conditions of the dismantling of e-waste in American prisons. The Silicon Valley Toxics Coalition, prisoner-rights activists, and environmental groups released a Toxic Sweatshops report that details how prison labor is being used to handle e-waste, resulting in health consequences among the workers.[104] These groups allege that, since prisons do not have adequate safety standards, inmates are dismantling the products under unhealthy and unsafe conditions.[105]

Processing techniques

Recycling the lead from batteries

In many developed countries, electronic waste processing usually first involves dismantling the equipment into various parts (metal frames, power supplies, circuit boards, plastics), often by hand, but increasingly by automated shredding equipment. A typical example is the NADIN electronic waste processing plant in Novi Iskar, Bulgaria—the largest facility of its kind in Eastern Europe.[106][107] The advantages of this process are the human worker's ability to recognize and save working and repairable parts, including chips, transistors, RAM, etc. The disadvantage is that the labor is cheapest in countries with the lowest health and safety standards.

In an alternative bulk system,[108] a hopper conveys material for shredding into an unsophisticated mechanical separator, with screening and granulating machines to separate constituent metal and plastic fractions, which are sold to smelters or plastics recyclers. Such recycling machinery is enclosed and employs a dust collection system. Some of the emissions are caught by scrubbers and screens. Magnets, eddy currents, and Trommel screens are employed to separate glass, plastic, and ferrous and nonferrous metals, which can then be further separated at a smelter.

Copper, gold, palladium, silver and tin are valuable metals sold to smelters for recycling. Hazardous smoke and gases are captured, contained and treated to mitigate environmental threat. These methods allow for safe reclamation of all valuable computer construction materials. Hewlett-Packard product recycling solutions manager Renee St. Denis describes its process as: "We move them through giant shredders about 30 feet tall and it shreds everything into pieces about the size of a quarter. Once your disk drive is shredded into pieces about this big, it's hard to get the data off".[109] An ideal electronic waste recycling plant combines dismantling for component recovery with increased cost-effective processing of bulk electronic waste. Reuse is an alternative option to recycling because it extends the lifespan of a device. Devices still need eventual recycling, but by allowing others to purchase used electronics, recycling can be postponed and value gained from device use.

In early November 2021, the U.S. state of Georgia announced a joint effort with Igneo Technologies to build an $85 million large electronics recycling plant in the Port of Savannah. The project will focus on lower-value, plastics-heavy devices in the waste stream using multiple shredders and furnaces using pyrolysis technology.[110]

Benefits of recycling

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Recycling raw materials from end-of-life electronics is the most effective solution to the growing e-waste problem.[111] Most electronic devices contain a variety of materials, including metals that can be recovered for future uses. By dismantling and providing reuse possibilities, intact natural resources are conserved and air and water pollution caused by hazardous disposal is avoided. Additionally, recycling reduces the amount of greenhouse gas emissions caused by the manufacturing of new products.[112] Another benefit of recycling e-waste is that many of the materials can be recycled and re-used again. Materials that can be recycled include "ferrous (iron-based) and non-ferrous metals, glass, and various types of plastic." "Non-ferrous metals, mainly aluminum and copper can all be re-smelted and re-manufactured. Ferrous metals such as steel and iron also can be re-used."[113] Due to the recent surge in popularity in 3D printing, certain 3D printers have been designed (FDM variety) to produce waste that can be easily recycled which decreases the amount of harmful pollutants in the atmosphere.[114] The excess plastic from these printers that comes out as a byproduct can also be reused to create new 3D printed creations.[115]

Benefits of recycling are extended when responsible recycling methods are used. In the U.S., responsible recycling aims to minimize the dangers to human health and the environment that disposed and dismantled electronics can create. Responsible recycling ensures best management practices of the electronics being recycled, worker health and safety, and consideration for the environment locally and abroad.[116] In Europe, metals that are recycled are returned to companies of origin at a reduced cost.[117] Through a committed recycling system, manufacturers in Japan have been pushed to make their products more sustainable. Since many companies were responsible for the recycling of their own products, this imposed responsibility on manufacturers requiring many to redesign their infrastructure. As a result, manufacturers in Japan have the added option to sell the recycled metals.[118]

Improper management of e-waste is resulting in a significant loss of scarce and valuable raw materials, such as gold, platinum, cobalt and rare earth elements. As much as 7% of the world's gold may currently be contained in e-waste, with 100 times more gold in a tonne of e-waste than in a tonne of gold ore.[89]

Repair as waste reduction method

There are several ways to curb the environmental hazards arising from the recycling of electronic waste. One of the factors which exacerbate the e-waste problem is the diminishing lifetime of many electrical and electronic goods. There are two drivers (in particular) for this trend. On the one hand, consumer demand for low cost products militates against product quality and results in short product lifetimes.[119] On the other, manufacturers in some sectors encourage a regular upgrade cycle, and may even enforce it though restricted availability of spare parts, service manuals and software updates, or through planned obsolescence.

Consumer dissatisfaction with this state of affairs has led to a growing repair movement. Often, this is at a community level such as through repair cafês or the "restart parties" promoted by the Restart Project.[120]

The Right to Repair is spearheaded in the US by farmers dissatisfied with non-availability of service information, specialised tools and spare parts for their high-tech farm machinery. But the movement extends far beyond farm machinery with, for example, the restricted repair options offered by Apple coming in for criticism. Manufacturers often counter with safety concerns resulting from unauthorised repairs and modifications.[121]

An easy method of reducing electronic waste footprint is to sell or donate electronic gadgets, rather than dispose of them. Improperly disposed e-waste is becoming more and more hazardous, especially as the sheer volume of e-waste increases. For this reason, large brands like Apple, Samsung, and others have started giving options to customers to recycle old electronics. Recycling allows the expensive electronic parts inside to be reused. This may save significant energy and reduce the need for mining of additional raw resources, or manufacture of new components. Electronic recycling programs may be found locally in many areas with a simple online search; for example, by searching "recycle electronics" along with the city or area name.

Cloud services have proven to be useful in storing data, which is then accessible from anywhere in the world without the need to carry storage devices. Cloud storage also allows for large storage, at low cost. This offers convenience, while reducing the need for manufacture of new storage devices, thus curbing the amount of e-waste generated.[122]

Electronic waste classification

The market has a lot of different types of electrical products. To categorize these products, it is necessary to group them into sensible and practical categories. Classification of the products may even help to determine the process to be used for disposal of the product. Making the classifications, in general, is helping to describe e-waste. Classifications has not defined special details, for example when they do not pose a threat to the environment. On the other hand, classifications should not be too aggregated because of countries differences in interpretation.[123] The UNU-KEYs

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system closely follows the harmonized statistical (HS) coding. It is an international nomenclature which is an integrated system to allow classify common basis for customs purposes.[123]

Electronic waste substances

Several sizes of button and coin cell with 2 9v batteries as a size comparison. They are all recycled in many countries since they often contain lead, mercury and cadmium.
Some computer components can be reused in assembling new computer products, while others are reduced to metals that can be reused in applications as varied as construction, flatware, and jewellery. Substances found in large quantities include epoxy resins, fiberglass, PCBs, PVC (polyvinyl chlorides), thermosetting plastics, lead, tin, copper, silicon, beryllium, carbon, iron, and aluminum. Elements found in small amounts include cadmium, mercury, and thallium.[124] Elements found in trace amounts include americium, antimony, arsenic, barium, bismuth, boron, cobalt, europium, gallium, germanium, gold, indium, lithium, manganese, nickel, niobium, palladium, platinum, rhodium, ruthenium, selenium,[125] silver, tantalum, terbium, thorium, titanium, vanadium, and yttrium. Almost all electronics contain lead and tin (as solder) and copper (as wire and printed circuit board tracks), though the use of lead-free solder is now spreading rapidly. The following are ordinary applications:
Hazardous

Recyclers in the street in São Paulo, Brazil, with old computers

Hazardous waste material from e-waste

E-waste Component	Electric Appliances in which they are found	Adverse Health Effects
Americium	The radioactive source in smoke alarms.	It is known to be carcinogenic.[126]
Lead	Solder, CRT monitor glass, lead–acid batteries, some formulations of PVC. A typical 15-inch cathode ray tube may contain 1.5 pounds of lead,[8] but other CRTs have been estimated as having up to 8 pounds of lead.	Adverse effects of lead exposure include impaired cognitive function, behavioral disturbances, attention deficits, hyperactivity, conduct problems, and lower IQ.[127] These effects are most damaging to children whose developing nervous systems are very susceptible to damage caused by lead, cadmium, and mercury.[128]
Mercury	Found in fluorescent tubes (numerous applications), tilt switches (mechanical doorbells, thermostats),[129] and ccfl backlights in flat screen monitors.	Health effects include sensory impairment, dermatitis, memory loss, and muscle weakness. Exposure in-utero causes fetal deficits in motor function, attention, and verbal domains.[127] Environmental effects in animals include death, reduced fertility, and slower growth and development.
Cadmium	Found in light-sensitive resistors, corrosion-resistant alloys	The inhalation of cadmium can

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	for marine and aviation environments, and nickel–cadmium batteries. The most common form of cadmium is found in nickel–cadmium rechargeable batteries. These batteries tend to contain between 6 and 18% cadmium. The sale of nickel–cadmium batteries has been banned in the EU except for medical use. When not properly recycled it can leach into the soil, harming microorganisms and disrupting the soil ecosystem. Exposure is caused by proximity to hazardous waste sites and factories and workers in the metal refining industry.	cause severe damage to the lungs and is also known to cause kidney damage.[130] Cadmium is also associated with deficits in cognition, learning, behavior, and neuromotor skills in children.[127]
Hexavalent chromium	Used in metal coatings to protect from corrosion.	A known carcinogen after occupational inhalation exposure.[127] There is also evidence of cytotoxic and genotoxic effects of some chemicals, which have been shown to inhibit cell proliferation, cause cell membrane lesion, cause DNA single-strand breaks, and elevate Reactive Oxygen Species (ROS) levels.[131]
Sulfur	Found in lead–acid batteries.	Health effects include liver damage, kidney damage, heart damage, eye and throat irritation. When released into the environment, it can create sulfuric acid through sulfur dioxide.
Brominated Flame Retardants (BFRs)	Used as flame retardants in plastics in most electronics. Includes PBBs, PBDE, DecaBDE, OctaBDE, PentaBDE.	Health effects include impaired development of the nervous system, thyroid problems, liver problems.[132] Environmental effects: similar effects as in animals as humans. PBBs were banned from 1973 to 1977 on. PCBs were banned during the 1980s.
Perfluorooctanoic acid (PFOA)	Used as an antistatic additive in industrial applications and found in electronics, also found in non-stick cookware (PTFE). PFOAs are formed synthetically through environmental degradation.	Studies in mice have found the following health effects: Hepatotoxicity, developmental toxicity, immunotoxicity, hormonal effects and carcinogenic effects. Studies have found increased maternal PFOA levels to be associated with an increased risk of spontaneous abortion (miscarriage) and stillbirth. Increased maternal levels of PFOA are also associated with decreases in mean gestational age (preterm birth), mean birth weight (low birth weight), mean birth length (small for gestational age), and mean APGAR score.[133]
Beryllium oxide	Filler in some thermal interface materials such as thermal	Occupational exposures

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	grease used on heatsinks for CPUs and power transistors,[134] magnetrons, X-ray-transparent ceramic windows, heat transfer fins in vacuum tubes, and gas lasers.	associated with lung cancer, other common adverse health effects are beryllium sensitization, chronic beryllium disease, and acute beryllium disease.[135]
Polyvinyl chloride (PVC)	Commonly found in electronics and is typically used as insulation for electrical cables.[136]	In the manufacturing phase, toxic and hazardous raw material, including dioxins are released. PVC such as chlorine tend to bioaccumulate.[137] Over time, the compounds that contain chlorine can become pollutants in the air, water, and soil. This poses a problem as human and animals can ingest them. Additionally, exposure to toxins can result in reproductive and developmental health effects.[138]

Generally non-hazardous

An iMac G4 that has been repurposed into a lamp (photographed next to a Mac Classic and a Motorola MicroTAC)

Human health and safety

Residents living near recycling sites

Residents living around the e-waste recycling sites, even if they do not involve in e-waste recycling activities, can also face the environmental exposure due to the food, water, and environmental contamination caused by e-waste, because they can easily contact to e-waste contaminated air, water, soil, dust, and food sources. In general, there are three main exposure pathways: inhalation, ingestion, and dermal contact.[140]

Studies show that people living around e-waste recycling sites have a higher daily intake of heavy metals and a more serious body burden. Potential health risks include mental health, impaired cognitive function, and general physical health damage[141] (see also Electronic waste#Hazardous). DNA damage was also found more prevalent in all the e-waste exposed populations (i.e. adults, children, and neonates) than the populations in the control area.[141] DNA breaks can increase the likelihood of wrong replication and thus mutation, as well as lead to cancer if the damage is to a tumor suppressor gene.[131]

Prenatal exposure and neonates' health

Prenatal exposure to e-waste has found to have adverse effects on human body burden of pollutants of the neonates. In Guiyu, one of the most famous e-waste recycling sites in China, it was found that increased cord blood lead concentration of neonates was associated with parents' participation in e-waste recycling processes, as well as how long the mothers spent living in Guiyu and in e-waste recycling factories or workshops during pregnancy.[140] Besides, a higher placental metallothionein (a small protein marking the exposure of toxic metals) was found among neonates from Guiyu as a result of Cd exposure, while the higher Cd level in Guiyu's neonates was related to the involvement in e-waste recycling of their parents.[142] High PFOA exposure of mothers in Guiyu is related to adverse effect on growth of their new-born and the prepotency in this area.[143]

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Prenatal exposure to informal e-waste recycling can also lead to several adverse birth outcomes (still birth, low birth weight, low Apgar scores, etc.) and longterm effects such as behavioral and learning problems of the neonates in their future life.[144]

Children

Children are especially sensitive to e-waste exposure because of several reasons, such as their smaller size, higher metabolism rate, larger surface area in relation to their weight, and multiple exposure pathways (for example, dermal, hand-to-mouth, and take-home exposure).[145][141] They were measured to have an 8-time potential health risk compared to the adult e-waste recycling workers.[141] Studies have found significant higher blood lead levels (BLL) and blood cadmium levels (BCL) of children living in e-waste recycling area compared to those living in control area.[146][147] For example, one study found that the average BLL in Guiyu was nearly 1.5 times compared to that in the control site (15.3 ug/dL compared to 9.9 ug/dL),[146] while the CDC of the United States has set a reference level for blood lead at 5 ug/dL.[148] The highest concentrations of lead were found in the children of parents whose workshop dealt with circuit boards and the lowest was among those who recycled plastic.[146]

Exposure to e-waste can cause serious health problems to children. Children's exposure to developmental neurotoxins containing in e-waste such as lead, mercury, cadmium, chromium, arsenic, nickel [149] and PBDEs can lead to a higher risk of lower IQ, impaired cognitive function, exposure to known human carcinogens[149] and other adverse effects.[150] In certain age groups, a decreased lung function of children in e-waste recycling sites has been found.[140] Some studies also found associations between children's e-waste exposure and impaired coagulation,[151] hearing loss,[152] and decreased vaccine antibody tilters[153] in e-waste recycling area. For instance, nickel exposure in boys aged 8–9 years at an e-waste site leads to lower forced vital capacity, decrease in catalase activities and significant increase in superoxide dismutase activities and malondialdehyde levels.[149]

E-waste recycling workers

Agbogbloshie e-waste workers completing a burn for copper recovery, 2010

The complex composition and improper handling of e-waste adversely affect human health. A growing body of epidemiological and clinical evidence has led to increased concern about the potential threat of e-waste to human health, especially in developing countries such as India and China. For instance, in terms of health hazards, open burning of printed wiring boards increases the concentration of dioxins in the surrounding areas. These toxins cause an increased risk of cancer if inhaled by workers and local residents. Toxic metals and poison can also enter the bloodstream during the manual extraction and collection of tiny quantities of precious metals, and workers are continuously exposed to poisonous chemicals and fumes of highly concentrated acids. Recovering resalable copper by burning insulated wires causes neurological disorders, and acute exposure to cadmium, found in semiconductors and chip resistors, can damage the kidneys and liver and cause bone loss. Long-term exposure to lead on printed circuit boards and computer and television screens can damage the central and peripheral nervous system and kidneys, and children are more susceptible to these harmful effects.[154]

The Occupational Safety & Health Administration (OSHA) has summarized several potential safety hazards of recycling workers in general, such as crushing hazards, hazardous energy released, and toxic metals.[155]

OSHA has also specified some chemical components of electronics that can potentially do harm to e-recycling workers' health, such as lead, mercury, PCBs, asbestos, refractory ceramic fibers (RCFs), and radioactive substances.[155] Besides, in the United States, most of these chemical hazards have specific Occupational exposure limits (OELs) set by OSHA, National Institute for Occupational Safety and Health (NIOSH), and American Conference of Governmental Industrial Hygienists (ACGIH).

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Informal and formal industries
Hazard controls
For occupational health and safety of e-waste recycling workers, both employers and workers should take actions. Suggestions for the e-waste facility employers and workers given by California Department of Public Health are illustrated in the graphic.

Safety suggestion for e-waste recycling facilities employers and workers[156]

Hazards	What must employers do	What should workers do
General	Actions include: Determine the hazards in the workplace and take actions to control them; Check and make correction to the workplace condition regularly; Supply safe tools and PPE to workers; Provide workers with training about hazards and safe work practice; A written document about injury and illness prevention.	Suggestions include: Wear PPE when working; Talk with employers about ways to improve working conditions; Report anything unsafe in the workplace to employers; Share experience of how to work safely with new workers.
Dust	Actions include: Offer a clean eating area, cleaning area and supplies, uniforms and shoes, and lockers for clean clothes to the workers; Provide tools to dismantle the e-waste. If the dust contains lead or cadmium: Measure the dust, lead and cadmium level in the air; Provide cleaning facilities such as wet mops and vacuums; Provide exhaust ventilation. If it is still not sufficient to reduce the dust, provide workers with respirators; Provide workers with blood lead testing when lead level is not less than 30 mg/m3.	Protective measures include: Clean the workplace regularly, and do not eat or smoke when dealing with e-waste; Do not use brooms to clean the workplace since brooms can raise dust; Before going home, shower, change into clean clothes, and separate the dirty work clothes and clean clothes; Test the blood lead, even if the employers do not provide it; Use respirator, check for leaks every time before use, always keep it on your face in the respirator use area, and clean it properly after use.
Cuts and lacerations	Protective equipment such as gloves, masks and eye protection equipments should be provided to workers	When dealing with glass or shredding materials, protect the hands and arms using special gloves and oversleeves.
Noise	Actions include: Measure the noise in the workplace, and use engineering controls when levels exceed the exposure limit; Reduce the vibration of the working desk by rubber matting; Provide workers with earmuffs when necessary.	Wear the hearing protection all the time when working. Ask for the employer about the noise monitoring results. Test the hearing ability.
Lifting injuries	Provide facilities to lift or move the e-waste and adjustable work tables.	When handling e-waste, try to decrease the load per time. Try to get help from other workers when lifting heavy or big things.

IV.CONCLUSION

Informal e-recycling industry refers to small e-waste recycling workshops with few (if any) automatic procedures and personal protective equipment (PPE). On the other hand, formal e-recycling industry refers to regular e-recycling facilities sorting materials from e-waste with automatic machinery and manual labor, where pollution control and PPE

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are common.[140][162] Sometimes formal e-recycling facilities dismantle the e-waste to sort materials, then distribute it to other downstream recycling department to further recover materials such as plastic and metals.[162]

The health impact of e-waste recycling workers working in informal industry and formal industry are expect to be different in the extent.[162] Studies in three recycling sites in China suggest that the health risks of workers from formal e-recycling facilities in Jiangsu and Shanghai were lower compared to those worked in informal e-recycling sites in Guiyu.[141] The primitive methods used by unregulated backyard operators (e.g., the informal sector) to reclaim, reprocess, and recycle e-waste materials expose the workers to a number of toxic substances. Processes such as dismantling components, wet chemical processing, and incineration are used and result in direct exposure and inhalation of harmful chemicals. Safety equipment such as gloves, face masks, and ventilation fans are virtually unknown, and workers often have little idea of what they are handling.[163] In another study of e-waste recycling in India, hair samples were collected from workers at an e-waste recycling facility and an e-waste recycling slum community (informal industry) in Bangalore.[164] Levels of V, Cr, Mn, Mo, Sn, Tl, and Pb were significantly higher in the workers at the e-waste recycling facility compared to the e-waste workers in the slum community. However, Co, Ag, Cd, and Hg levels were significantly higher in the slum community workers compared to the facility workers.

Even in formal e-recycling industry, workers can be exposed to excessive pollutants. Studies in the formal e-recycling facilities in France and Sweden found workers' overexposure (compared to recommended occupational guidelines) to lead, cadmium, mercury and some other metals, as well as BFRs, PCBs, dioxin and furans. Workers in formal industry are also exposed to more brominated flame-retardants than reference groups.[162]

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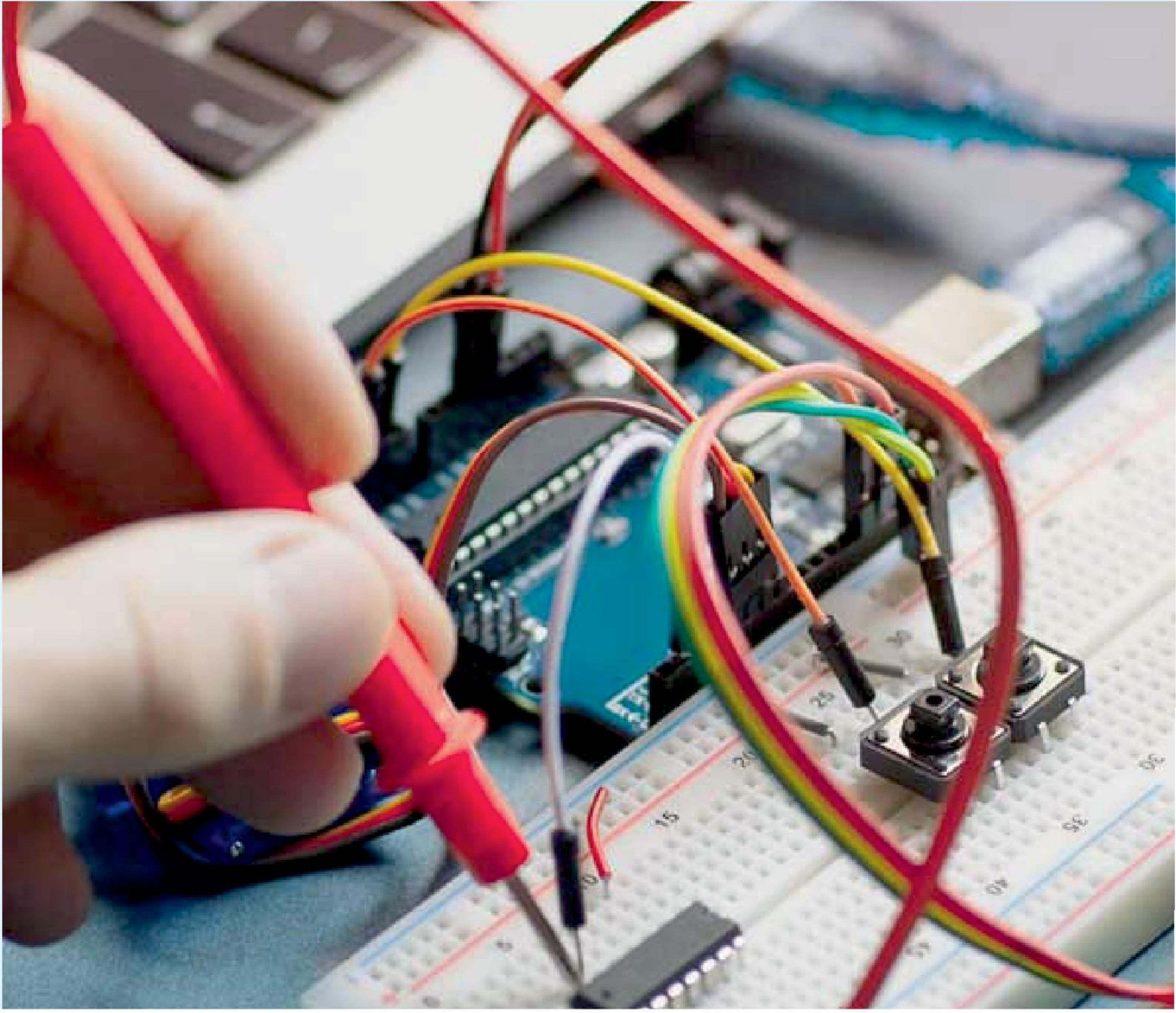

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