



**HAL**  
open science

# A Resource Perspective on E-Waste: A Global Problem with Local Solutions?

David Kreps, Per Fors

► **To cite this version:**

David Kreps, Per Fors. A Resource Perspective on E-Waste: A Global Problem with Local Solutions?. Leon Strous; Roger Johnson; David Alan Grier; Doron Swade. Unimagined Futures – ICT Opportunities and Challenges :, AICT-555, Springer International Publishing, pp.129-141, 2020, IFIP Advances in Information and Communication Technology, 978-3-030-64245-7. 10.1007/978-3-030-64246-4\_11 . hal-03194548

**HAL Id: hal-03194548**

**<https://inria.hal.science/hal-03194548v1>**

Submitted on 9 Apr 2021

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Distributed under a Creative Commons Attribution 4.0 International License

# A resource perspective on E-waste: A global problem with local solutions?

David Kreps<sup>1</sup>[0000-0002-5776-2888] and Per Fors<sup>2</sup>[0000-0001-6673-7935]

<sup>1</sup> University of Salford, Maxwell Building, 43 The Crescent, Salford M5 4WT, UK

<sup>2</sup> Uppsala University, Ångströmlaboratoriet, Lägerhyddsvägen 1, 751 21 Uppsala, Sweden  
D.G.Kreps@salford.ac.uk, Per.Fors@angstrom.uu.se

**Abstract.** ICT is, at least to some extent, material, and different phases of the ICT lifecycle present us with different challenges related to the physical properties of ICT. E-waste is a term used to describe discarded electronic and electrical equipment that is neither reused or repaired, nor refurbished. While it is clear that e-waste is currently mainly a big social and environmental problem, we also see opportunities in re-introducing materials from existing e-waste into the ICT supply chain. Although e-waste is a pressing problem, it can also be seen as, and become a resource. The shift in perspective required is towards a life-cycle perspective on all materials in the production, marketing, and end-of-life processes of ICT artefacts. A combination of Design for Repairability and End-of-life Design can contribute to a set of electronics design guidelines that would meet circular economy principles.

**Keywords:** E-Waste, Green IT, design for repairability, end-of-life design

## 1 Introduction

Because of the abstract nature of ICT, many have long assumed that the negative social and environmental side effects of ICT are non-existent, or at least negligible given the immense potential of ICT to create wealth and prosperity and even to promote sustainability [41, 16]. However, in recent decades it has become increasingly apparent that ICT is, at least to some extent, material, and that different phases of the ICT life-cycle present us with different challenges related to the physical properties of ICT. ICT products – such as mobile phones, servers, desktops and laptops – are produced by an increasing number of different materials that need to be extracted from the earth in one way or another, usually with severe environmental, health and safety issues. Components used in ICT products also need to be produced, and these components need to be assembled into the final product. In this phase, we are also presented with different problems related to social and environmental factors. It is in the use phase of ICT products where the social, economic and potentially also environmental benefits are reaped. However, we are also becoming increasingly aware of the energy consumption of these products. Although these products are becoming more energy-efficient by the day, the

quantity of ICT products is rapidly increasing, and the total amount of electricity needed for them to function also increases.

While all phases of the ICT lifecycle are intimately connected, this chapter will focus on the disposal phase, or the end-of-life (EoL) of ICT products, often termed electronic waste or e-waste. E-waste is a term used to describe discarded electronic and electrical equipment that is neither reused or repaired, nor refurbished [30]. According to the Solving The e-waste Problem initiative, e-waste should be defined as “all types of electrical and electronic equipment (EEE) and its parts that have been discarded by the owner as waste without the intention of re-use” (StEP). While we acknowledge the fact that e-waste is not entirely made up of ICT products, we mainly focus on ICT related e-waste in this chapter. Both since the majority of the products referred to as e-waste are ICT products and also since this book has a focus on ICT.

There are many reasons materials used in ICT products are not properly recycled. The main reasons include the complex material composition of ICT products, that make them virtually impossible to fully recycle, at least without the use of extremely high-tech facilities. Such facilities can recycle between 70 and 90 percent of the materials in e-waste, but they only exist in few locations around the world (Sweden, Japan, Canada, Germany and Belgium). A second reason is the lack of incentive for ICT companies to design products for longevity, repairability, upgradeability, disassembly and recycling – rather than for cost-efficiency, performance, aesthetics and a relatively short useful life. A third reason is the lack of proper systems for recovery and recycling of e-waste in many places, and a lack of incentive for consumers of electronic goods to actually use these existing systems and hand back worn-out electronics. There are also other reasons that we have failed to create a circular system for ICT products with the accumulation of e-waste as a result, including the use of virgin materials over recycled materials, short-term profits of exporting waste over long-term profits of keeping them in the cycle, and the overconsumption of new electronic products in the developed world.

However, while it is clear that e-waste is currently mainly a big social and environmental problem, we also see opportunities in re-introducing materials from existing e-waste into the ICT supply chain. There are indications that the linear production system (i.e. take-make-waste) is not only inferior from a sustainability-perspective, but also that many elements (such as copper and gold) are getting increasingly profitable to recycle rather than to extract from virgin ore [25]. Considering the three pillars of sustainability (social, environmental, economic), we argue that with e-waste recycling we have a rare case of “win-win-win” synergies, as solving the e-waste problem will lead to economic, social and environmental benefits.

This chapter will discuss e-waste from a social, environmental and economic standpoint on both the local and global level. The principal areas of concern for this chapter are e-waste, sustainable development and resource use and reuse and these concepts will be briefly touched upon in the next section of the chapter.

## 2 Background

Sustainable development is a term that was coined in the late 1980s and got its famous definition in the renowned “Brundtland report” *Our Common Future* [8]. Here, it was concluded that sustainable development should be seen as human development that meets the needs of the present without compromising the ability of future generations to meet their own needs [8]. Since then, sustainable development has become a buzzword with many different interpretations. What unites these interpretations is the fact that sustainable development is an assemblage of complex and interrelated social, environmental and economic aspects that need to be taken into consideration simultaneously. Despite the focus on different sustainability-related goals, in more recent decades, not least the Millennium Development Goals (MDGs) and the Sustainable Development Goals (SDGs), sustainable development should not be seen as an end-goal or something that “can be achieved”, but rather as a process of continuous improvements.

It is clear that the e-waste problem presents numerous sustainability-related challenges, as it affects the environment and human societies at both local and global levels. Turning to the SDGs, it is clear that the e-waste problem needs to be solved in order to reach some of them, most notably Goal 3, to “Ensure healthy lives and promote well-being for all at all ages”, Goal 8, to “Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all”, Goal 9, to “Build resilient infrastructure, promote sustainable industrialization and foster innovation,” Goal 11, to “Make cities and human settlements inclusive safe resilient and sustainable”, and Goal 12, to “Ensure sustainable consumption and production patterns”. For a closer scrutinization of how the e-waste problem relates to the targets within each SDG, please see the UN Environmental Management Group (EMG) report “United Nations System-wide Response to Tackling E-waste” [51].

## 3 Resource Use

As Meadows et. al. [38] famously announced in their 1970s report to the Club of Rome, there are Limits to Growth. Economist Hermann Daly pointed out in 1973, moreover, “in a finite world continual growth is impossible. Given finite stomachs, finite lifetimes, and the kind of man who does not live by bread alone, growth becomes undesirable long before it becomes impossible” [12, p.5]. These warnings, however, went largely unheeded. Instead, faith in technology as “an omnipotent deus ex machina who (sic) will get us out of any growth-induced problems” [ibid. p.5] continues to guide economists, technologists and politicians to this day. Daly’s ultimate and fundamental point nonetheless remains key: “nature really does impose ‘an inescapable general scarcity,’ and it is a serious delusion to believe otherwise” [ibid. p.8]. Dutch atmospheric chemist Paul Crutzen, by the turn of the millennium, had concluded that a new stage in Earth’s history had begun: the Anthropocene [10]. Defined as a new geological era, the Anthropocene is characterised by the extent of man-made changes – not least to the weather system – our activities have effected upon the planet we share. The Great Acceleration [48] of these changes since 1945, moreover, means that the modern period

“deserves to be marked off as different from what came before it in environmental history” [37, p.208]. The crucial point here is that although the Anthropocene is here to stay, the acceleration must stop, if humans are to be able to continue living on this planet in anything like the manner we have been used to over the last 10,000 years – i.e. in settled, civilised conditions supported by the planet’s ecosystems.

Key to an understanding of these changes – and how to remedy them – remains economics. The production cycle of our economic growth model – how we make, use, and then discard things – is extremely inefficient, leading to massive and unsustainable resource depletion, and enormous amounts of polluting waste. As John Bellamy Foster [17] and others have outlined, our systems of production and trade are so divorced from the needs of the natural world - and so efficient at its use - that they are “killing the planet” [17, p. 8]. The core premise of this thinking is that we cannot continue to use natural resources in such flagrant and wasteful a manner as we have become used to, without devastating consequences. According to the Global Footprint Network, “Humans use as much ecological resources as if we lived on 1.75 Earths” [19]. According to 2011 figures, the average American uses seven “global hectares”, compared to a global average of 2.7, so if we all lived like US citizens we would need four Earths, not one [36]. New economic thinking, including ideas like the steady-state economy [13], and the more recent ‘doughnut’ economics of Kate Raworth [42, 43], are complementing the ambitions of supra-national bodies such as the UN and the EU to move toward a “circular economy” [7, 40] fundamentally changing the habits of industrial capitalism.

As is becoming increasingly clear, moreover, “digital’s (growing) contribution to the ecological catastrophe unfolding in the 21st century” [29] cannot go unchallenged. The production cycle of digital devices is immensely wasteful. To take just one example, over a billion iPhones have been made since 2007 using some 40 million tons of gold ore. How little of this is recycled is quite shocking, considering that gold was made trillions of years ago in the heart of exploding stars, later to coalesce into the rocks and dust from which planets such as ours were formed around our own, relatively young Sun.

Perhaps the most extraordinary tale, however, concerning the resources used by our everyday technological devices, is that of Rare Earth Elements, or RREs. These are precious resources found in only a very few places on Earth, each fraught with problems. China, which has the greatest sources of these precious materials, has either restricted or blocked their export on a number of occasions. It is perhaps as much - or more - to do with these resources than the relatively cheaper labour that is behind the decisions of Apple and other smartphone manufacturers to base their manufacturing operations in China, rather than elsewhere [15, 26, 31, 57]. In the US, deposits of these materials are to be found, but only with relative difficulty, and thus expense. A Congressional Research Service Report on Rare Earth Minerals [24] pointed out that in 2011 96.9% of all Rare Earth Mineral production took place in China, where some 50% of global reserves are to be found, compared to only some 13% in the US, with the rest spread across the world, notably in Russia.

Resource depletion is a growing problem for many industries. As the global population rises, and the economic model of GDP growth encourages constant innovation, the

use of resources is increasing rapidly. This rapaciousness includes the depletion of metals, such as gold and aluminium as well as RREs, [15, 26, 31, 57], which are central to the production of ICTs. The recycling of e-waste, for the recovery of these minerals (urban mining), is thus a central concern for the electronics industry.

#### 4 The “e-waste problem”

Having briefly touched upon some of the problems with e-waste, this section of the chapter will focus upon different sustainability-related (social, economic and environmental) problems, both on a local and a global scale.

E-waste, often referred to as the fastest growing waste stream globally, is a global problem with both local and global consequences. According to the Global E-Waste Monitor “the world generated 44.7 million metric tonnes (Mt) of e-waste and only 20% was recycled through appropriate channels” in 2016 [4]. The majority of the other 80% remains with the user [56], is thrown in residual waste (4%), is exported as second-hand goods or illegally exported as e-waste to be informally recycled under inferior circumstances. The Global E-Waste Monitor records that the United States produced 6.3 Mt of e-waste in 2016, of which only 1.4 Mt was collected (22%). Norway produces the most e-waste (28.5 kg per inhabitant), but it has one of the highest collection rates (49.2%). While the West has traditionally been the largest producers of e-waste, it is estimated that by 2030, China will be the biggest producers of e-waste, with over 28 million tons produced each year. This makes China a bigger producer than all countries in the EU combined [58].

A crucial aspect that has contributed to the e-waste problem is the fact that electronic goods have not and are not designed with longevity and recycling – but instead with attributes such as cost-efficiency, performance and aesthetics – in mind. Planned obsolescence also remains a key problem in the ICT industry [55, 3]. For example, many current smartphones are glued, rather than screwed together, making battery replacement difficult and expensive. Diminished battery capacity is one of the primary drivers for replacement of the whole device [45]. In pursuit of cost-efficiency and performance, the material composition of electronic goods is also becoming increasingly complex. According to [35], a microprocessor used in desktops in the 1980s consisted of 12 different chemical elements. Today, a microprocessor is usually made up of as many as 60, or more than half of all the elements in the periodic table. While high-technological facilities for recycling of e-waste do exist, as previously mentioned, they are few and can currently not keep up with the rapid technological developments within the ICT industry.

While approximately 70 to 90 percent by weight of each electronic product can be recycled today, very few of these many different elements are actually recycled. For example, most, if not all, of the Rare Earth Elements (REEs) will end up in landfills because of the small amount used in each product [45]. REEs, such as iridium, palladium and gallium, are elements used to give electronic products certain unique properties. The name is used collectively for Group 3 elements of the periodic table, and they are chemically similar and are often found together in the Earth’s crust [28]. While

these are used in very small amounts, the use of them gives rise to local environmental and social problems as well as global environmental problems. Many of these precious resources are found in only a very few places on Earth, each fraught with problems[47] have looked into REE extraction in China and conclude that refining REEs is a very energy-intensive process which often causes emissions into water and air due to heavy use of chemical materials being used in the process. In one of the largest REE mines (Bayan Obo in China), a large number of environmental and health issues have been identified due to the huge amount of gas, liquid and solid waste generated by the mining operation. Even in the few REE mines that do not contain radioactive elements (e.g. thorium), many environmental and health issues were identified. Many illegal mines also exist in China, where environmental, health and safety issues are more or less ignored. China has also either restricted or blocked their export on a number of occasions.

Many actors along the value chain of ICT products, moreover, have traditionally tried to avoid the responsibility of the e-waste problem. According to [50], only around 20 percent of all End-of-Life (EoL) electronic devices are properly recycled, while the remaining 80 percent is shipped as second-hand goods to developing parts of the world. According to the Basel Convention, while the exportation of second-hand goods is legal, exporting e-waste is illegal. However, only about two-thirds of the second-hand equipment is still functioning and sold in local second-hand markets. The rest is repaired and sold or ends up at local scrap yards. According to Basel Action Network (BAN), the biggest importers of e-waste are China, Pakistan and India, while the biggest exporters are the US, the EU and Australia. From the US, according to [33], between 50 and 80 percent of all e-waste is exported rather than being recycled nationally. The lack of sustainable e-waste management results in wide-scale environmental impacts as well as health impacts to the people and communities working in or living near these sites [1, 2, 20, 31].

According to the WEEE handbook, e-waste generally contains many different toxic substances, such as mercury, lead, chromium and cadmium, but also various other chemicals including ozone-depleting substances and flame retardants. The amount of toxic substances in e-waste vary, but generally speaking older equipment contains more toxic substances, but also more valuable materials, making these devices more attractive to informal recyclers. Many CRT (Cathode Ray Tube) monitors, for example, contain valuable materials such as cadmium, which should only be managed by professionals. If humans or animals are exposed to cadmium, bones and kidneys can be affected. This substance is now banned by the European Restriction on Hazardous Substance Directive. While CRT monitors have been more or less phased out, flat-screen monitors can also be dangerous to handle, as they may contain mercury which is highly toxic and can cause damage to different vital organs in humans and animals. Also, this toxic substance can be passed on to children when breast-fed by someone who has been exposed to the substance. Cables and wiring are often informally recycled in order to extract the copper. Cables are often coated in plastics (incl. PVC plastics), and the fastest/easiest way to access the copper is to burn the plastic coating away. However, PVC release dioxins when burned, and these dioxins can affect the immune and reproductive systems of humans and animals. Other standard procedures include heating and manual

removal of components from printed circuit boards (PBCs), and acid digestion of components, both of these with potential negative effects on the health of the workers. Needless to say, these workers are not trained to properly manage e-waste, but many (including children) are forced to engage in these activities to survive.

This highlights another problem related to e-waste, namely that the whole problem is highly unequal from a global world-system perspective. Lennerfors et. al. [32] review the ICT lifecycle from a sustainability perspective, and present a critique toward research, policy and practical initiatives that present ICT as a solution to different sustainability-related problems. They see that while ICT in the use phase can be used for sustainability purposes (dematerialization, optimization, etc.) locally in the developed world, this also results in environmental degradation and social problems in developing countries where much of the extraction, production, manufacturing and disposal takes place. They argue that using ICT to achieve different sustainability-related problems usually resembles a “zero-sum game”, where developing countries suffer local environmental and social problems in order to “keep the [developed] core green and clean” [23]. Thus, there is certainly an important aspect of global inequalities related to the e-waste problem that needs to be taken into consideration.

## 5 Initiatives to solve the problem

There are several global initiatives that aim to regulate and create incentives for increased circularity within the ICT industry. As of 2018, two-thirds of countries are covered by a national e-waste management policy. [4]. Almost all national and international policies include a take-back system, often based on an Extended Producer Responsibility (EPR) clause, in which the producer or distributor is obliged to collect used electronic and electrical products for reuse and recycling. Even though “policymakers, producers and recyclers in various countries have created specialized ‘take-back and treatment’ systems to collect e-waste from final owners and process it in professional treatment facilities (...) the collection and state-of-the-art treatment of e-waste is limited, and most nations are still without such e-waste management systems” [5]. In Sweden, where recycling is the norm [21], a sophisticated take-back system is implemented (Ei-kretsen), and where one of the few high-technological recycling facilities is located, only a very small amount of small electronic devices such as mobile phones are actually recycled.

Perhaps the most well-known global initiative is the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal, which came into place in 1992 and restricts the movement of hazardous waste from high-income to low-income countries [6]. Of the high-income countries, only the USA has not ratified the Convention. In 1995, the Basel Ban Amendment was proposed, which would ban all shipment of e-waste from OECD countries to low-income countries, including export for recycling, but this Amendment remains unratified, because not enough countries support it. The European Union countries and Norway and Switzerland have fully implemented the Amendment in their national legislation [46]. After the Basel Convention, the Partnership for Action on Computing Equipment (PACE)



was initiated. PACE is described as a "multi-stakeholder public-private partnership" where many different actors are represented, including producers, recyclers, researchers, environmental groups, and so on. The final guidance documents that were adopted by the parties in 2017 deals with environmentally sound management of end-of-life computing equipment.

In the EU, a Waste Electrical and Electronics Equipment (WEEE) Directive in 2012 promoted the "re-use, recycling and other forms of recovery of waste electrical and electronic equipment (WEEE) in order to reduce the quantity of such waste to be disposed and to improve the environmental performance of the economic operators involved in the treatment of WEEE" [14]. Another organization that focuses on e-waste is The International Environmental Technology Centre (IETC). Their focus is to promote environmentally sustainable technological solutions focusing on holistic waste management. To realize this vision, IETC provides support to governments that want to enhance their use of more sustainable practices, strategies and technologies. They focus on innovative waste prevention methods and technologies and aim to improve human well-being and reduce the impact of e-waste on climate change. IETC is a part of the United Nations Environment Programme (UNEP) and is located in Osaka, Japan. Another UN initiative is the Environmental Management Group, which was established in 2001. In 2016, they started focusing also on e-waste more specifically, by attempting to strengthen collaboration between different policy initiatives within the UN, and to support already existing initiatives and projects related to design and life cycle approaches for sustainability.

There are other initiatives aiming to solve problems related to e-waste, or to design, use, and dispose of electronic equipment in ways that promote circularity and sustainability. Examples include The UN agency International Telecommunication Union (ITU), The International Solid Waste Association, responsible for the well-known report the Global E-Waste Monitor, first released in 2014, Solving the E-Waste Problem (StEP), and more. Another central initiative that works for sustainability in the ICT industry more broadly, but also specifically targets the e-waste problem is the Karlskrona Manifesto for Sustainable Design. According to the manifesto, not only producers of hardware are responsible for sustainable design of technology. Rather, software practitioners who design software systems that "run our world" also have a big impact on the sustainability of ICT and other technological devices. Finally, the International Federation for Information Processing (IFIP) has recently taken a stance in the e-waste discussion with the IFIP Position Paper on e-waste. The work on this paper began in IFIP's Technical Committee 9 in the Autumn of 2017, led by David Kreps, with the goal of setting out some of the details of the problem, as it currently stands, and what role IFIP affirms it can play in trying to redress it. Here, just like in the Karlskrona Manifesto, IFIP establishes which actor (e.g. users, designers and producers of ICT products) has the responsibility for what aspect of the e-waste problem, and how each actor can take their responsibility [30].

## 6 E-waste as a resource

While the magnitude of the e-waste problem is growing, much current research is showing that there are many benefits in recycling e-waste, and the recovery of precious materials such as plastic, iron, platinum, copper, aluminium, gold, silver and palladium. While finding a solution to the e-waste problem is likely to be costly initially, there are thus important synergies that need to be taken into consideration. Since virgin materials have traditionally been both cheaper and of better quality than recycled materials, initiatives for ICT companies to adopt more circular business models have been driven either by good will/CSR or by regulations. According to [58] Zeng et al. (2019), much research has focused on how to recover different types of materials from e-waste. However, few studies have focused on the economic feasibility of recovering such materials from e-waste rather than from virgin – mined - materials. Recently, however, it has been suggested that many precious metals (such as gold and copper) are becoming cheaper to extract from e-waste than from virgin ore. The biggest potential for recycled materials compared with virgin materials is according to [22] that the content of precious metals in e-waste is usually much higher than in virgin ores. This means that while ore usually exists in larger quantities in each specific location compared with e-waste, it can be very profitable to extract metals from e-waste instead, given that it is possible to gather large enough quantities [11]. According to Cucchiella et al. CRT monitors, smart phones, LCD TVs, cellphones and LCD notebooks are probably the products with most potential to be profitable when recycled, due to the high amount of precious materials in them [11]. The Global E-waste Monitor [5] concludes that the total value of all raw materials present in e-waste is estimated at approximately €55 billion in 2016. However, Cucchiella et al. [11] estimate that the potential profit from recycling materials in e-waste is €2.15 billion. This much lower figure is affected by a number of factors such as transportation, collection rates, etc. However, given the increased interest in circular business models, and increased regulatory pressure, it would be surprising if not more ICT companies started to see the potential of e-waste as a resource in the near future. After all, the ICT industry is heavily dependent on metals such as copper and gold and utilizes about 30 and 12 percent of the total consumption respectively [58].

According to the WEEE handbook (p. 5), “from a resource perspective, e-waste is an urban mine providing tremendous resources for manufacturing and refurbishing”. Zeng et al. [58] argue that as virgin-mined materials are getting more expensive, and e-waste more easily accessible, recycled materials will soon be more profitable than virgin-mined materials. They show that in China, a country with large quantities of e-waste available for recycling, pure gold and copper recovered from e-waste is now cheaper compared with virgin mining of ores. More specifically,

*the cost of urban mined gold from [e-waste] has been far lower than the world commodity price each year, and is falling as per the learning curve associated with the processes of demanufacturing involved. By 2015 the estimated cost of urban mined gold had fallen to US \$1,591 per kg in 2015, compared with the world commodity price of just under US\$4,000 in the same year [58].*

As China will soon be the biggest importer and producer of e-waste, the economic benefit of recycling will most likely increase in the future, given the investment in proper recycling facilities. Zeng et al. [58] argue that this could also be the case for other materials and in other geographical contexts. However, at the moment many OECD countries lack the required infrastructure and collection systems, making alternatives to formal recycling more attractive, as they provide a smaller but immediate short-term benefit [25].

There are obviously many other benefits to recycling materials found in e-waste. For example, metals can be extracted from e-waste with far less environmental impact than by extracting the same amount of metals from ore, given that the waste is formally recycled. The approximate content of different metals in e-waste is often known beforehand, making the refining process more efficient. Furthermore, much less solid waste material is generated from extracting metals from e-waste compared to from virgin ore [25]. There are also obvious social benefits from formal recycling, such as the cleaning up of “e-waste villages”, and replacement of harmful informal recycling practices with formal recycling. Two problems that arise with increased formal recycling is that initial costs are high before proper regulations, take-back systems and recycling facilities are in place; that many people today make a living out of informal recycling practices; and that take-back systems and regulations need to be more impactful than they are today. As emphasized by [25], increased recycling rates and improved processing of end-of-life products are necessary in order to achieve sustainability in metal life cycles.

## 7 Conclusions

In conclusion, it is clear that although e-waste is a pressing problem, it can also be seen as, and become a resource. The shift in perspective required is towards a life-cycle perspective on all materials in the production, marketing, and end-of-life processes of ICT artefacts.

Such a perspective includes attention to:

- Sustainable (social + environmental + economic) extraction of materials (both virgin materials but more importantly from existing (e-)waste).
- Sustainable production of hardware and software (for repair, longevity, dismantling, upgradeability, etc.)
- Reparation and refurbishing of discarded products
- Effective take-back systems
- Effective dismantling and separation of precious materials (e.g. iron, platinum, copper, aluminium, plastic, gold, silver, palladium and more).
- Re-use of precious materials

Any attempt to address the issue of electronic waste and sustainability needs first, therefore, to consider the interdependence of the different aspects of the issue as discussed in this chapter: design, resource depletion, environmental degradation, and human health impacts are all interwoven. For example:

- Design for repairability can extend the lifespan of ICTs through plug-and-play upgrades and improvements, both hardware and software [27], as well as a modular design that encourages repair [9].
- End-of-life design results in a less complex disassembly process and less scrap [53].

The combination of Design for repairability and End-of-life design can contribute to a set of electronics design guidelines that meet circular economy principles [7]. In addition, a Best of 2 Worlds (Bo2W) approach, in which informal disassembly of electronics is combined with formal high tech recycling, may diminish health and environmental impacts [54].

These changes are challenging, but not insurmountable. They will need to be supported by supra- and national policy and regulations, encouraged by taxation and other levers of behaviour change; and CSR. They will increasingly be driven by virgin resource scarcity.

The responsibility for rising to these challenges lies, therefore, with the ICT industry, first and foremost, but also with policymakers and governments, ICT professionals working in the industry, and ultimately the users/consumers of ICT products, who can help to drive change through consumer choice. Lastly, waste handling companies must be engaged more by the industry, to ensure their own requirements are built-in to the design of artefacts, streamlining the life cycle from design to disassembly.

## References

1. Asamoah, A, Essumang, D, Muff, J, Kucheryavskiy, S, Søgaaard, E.: Assessment of PCBs and Exposure Risk to Infants in Breast Milk of Primiparae and Multiparae Mothers in an Electronic Waste Hot Spot and Non-Hot Spot Areas in Ghana. *Science of the Total Environment* 612, 1473-1479 (2018)
2. Awasthi, A, Zeng, Z, Li, J.: Environmental Pollution of Electronic Waste Recycling in India: A Critical Review. *Environmental Pollution* 211, 259–70. <https://doi.org/10.1016/j.envpol.2015.11.027>. (2016)
3. Bakker, C, Wang, F, Huisman, J, Hollander, M.: Products That Go Round: Exploring Product Life Extension through Design. *Journal of Cleaner Production* 69: 10–16. <https://doi.org/10.1016/j.jclepro.2014.01.028>. (2014)
4. Balde, C.P., Wang, F., Kuehr, R., Huisman, J.: The global e-waste monitor – 2014. United Nations University, IAS-SCUCLE, Bonn, Germany. Available from <https://i.unu.edu/media/unu.edu/news/52624/UNU-1stGlobal-E-Waste-Monitor-2014-small.pdf> (2015).
5. Baldé, C. P., Forti, V., Gray, V., Kuehr, R., Stegmann, P.: The global e-waste monitor – 2017. United Nations University, IAS-SCUCLE, Bonn, Germany. Available from <https://www.itu.int/en/ITU-D/Climate-Change/Documents/GEM%202017/Global-E-waste%20Monitor%202017%20.pdf> (2017)
6. Basel Convention Text, <http://www.basel.int/TheConvention/Overview/TextoftheConvention/tabid/1275/Default.aspx> (1992)
7. Bovea, M. D., Pérez-Belis, V.: Identifying design guidelines to meet the circular economy principles: A case study on electric and electronic equipment. *Journal of Environmental Management*, 228, 483–494. <https://doi.org/10.1016/j.jenvman> (2018)
8. Brundtland Commission.: Our Common Future: Report of the World Commission on Environment and Development <http://www.un-documents.net/our-common-future.pdf> (1987)

9. Cordella, M., Sanfeliu, J., & Alfieri, F.: Development of an Approach for Assessing the Reparability and Upgradability of Energy-related Products. *Procedia CIRP*, 69, 888–892. <https://doi.org/10.1016/j.procir.2017.11.080> (2018)
10. Crutzen, P.J.: The Anthropocene.: In Ehlers, P, Krafft D, (eds) *Earth System Science in the Anthropocene*. Springer Berlin Heidelberg, pp. 13–18 (2006)
11. Cucchiella, F, D’Adamo, I, Ko, S, Rosa, P.: Recycling of WEEEs: An economic assessment of present and future e-waste streams. *Renewable and Sustainable Energy Reviews* 51. [10.1016/j.rser.2015.06.010](https://doi.org/10.1016/j.rser.2015.06.010) (2015)
12. Daly, H.E. (ed): *Economics, Ecology and Ethics: Essays Toward a Steady-State Economy*. San Francisco: Freeman & Co (1973)
13. Daly, H.E.: *Beyond Growth*. Boston: Beacon Press (1996)
14. EU Directive 2012/19/EU of the European Parliament and of the Council of 4 July 2012 on waste electrical and electronic equipment (WEEE) <https://eur-lex.europa.eu/eli/dir/2012/19/oj>
15. Ferris, <https://www.eenews.net/stories/1060011478> (2015)
16. Fors, P.: *Problematizing Sustainable ICT*. Doctoral Thesis. Uppsala University. <https://www.diva-portal.org/smash/record.jsf?pid=diva2%3A1282900&dswid=-6325> (2019)
17. Foster, J.B, Clark, B., York, R.: *The Ecological Rift*. New York: Monthly Review Press. (2010)
18. Geeraerts, K, Illes, A., Schweizer, J.: e-waste from the EU: A case study on illegal e-waste export from the EU to China. A study compiled as part of the EFFACE project. London: IEEP. (2015)
19. GFN; <https://www.footprintnetwork.org/> (2020)
20. Grant, C, Goldizen, F, Sly, P, Brune, M, Neira, M, Berg, M, Norman, R.: Health Consequences of Exposure to E-Waste: A Systematic Review. *The Lancet Global Health* 1(6), 350–61. [https://doi.org/10.1016/S2214-109X\(13\)70101](https://doi.org/10.1016/S2214-109X(13)70101) (2013)
21. Hage, O., Söderholm, P., Berglund, C.: Norms and economic motivation in household recycling: Empirical evidence from Sweden. *Resources, Conservation and Recycling* 53, no. 3 (2009): 155-165.
22. Hagelüken, C., Corti, C.: Recycling of gold from electronics: Cost-effective use through ‘Design for Recycling’. *Gold bulletin*, 43(3), 209-220. (2010).
23. Hornborg, A.: *The power of the machine: Global inequalities of economy, technology, and environment*. AltaMira Press. (2001)
24. Humphries, [www.crs.gov](http://www.crs.gov) 2013
25. Izatt, R, Izatt, S, Bruening, R, Izatt, N, Moyer, B.: Challenges to achievement of metal sustainability in our high-tech society. *Chemical Society Reviews*, 8. (2014)
26. Jolly, [https://www.nytimes.com/2014/03/27/business/international/china-export-quotas-on-rare-earths-violate-law-wto-panel-says.html?\\_r=0](https://www.nytimes.com/2014/03/27/business/international/china-export-quotas-on-rare-earths-violate-law-wto-panel-says.html?_r=0) (2014)
27. Karlskrona, <http://sustainabilitydesign.org/karlskrona-manifesto/> (2015)
28. Kassem, M., Cardona, E., Bertoli, L., Yu, Y., Sandikcilar, Y., Natarajan, S, Carrasco-Gallego, R.: Metals in Our IT Equipment: Social and Economic Impacts, Geopolitical Conflicts. *Other Social Impacts of ICT Manufacturing*. *International Journal of Engineering Innovation & Research*, 4(6), 2277–5668. (2015).
29. Kreps, D.: *Against Nature: The Metaphysics of Information Systems* London: Routledge (2018)
30. Kreps, D., Van Der Velden, Fors, P., M., Patrignani, N., Davison, R., Lennerfors, T., Zielinski, C, Kasper, G.M., Schultze, U.: *IFIP Position Paper on E-Waste*. Vienna: IFIP (2019)
31. Krugman, P. <https://www.nytimes.com/2010/10/18/opinion/18krugman.html> (2010)

32. Lennerfors, T. T., Fors, P., & van Rooijen, J.: ICT and environmental sustainability in a changing society. *Information Technology & People*, 28(4), 758-774. (2015)
33. Lepawsky, J, Araujo, E, Davis, J, Kahhat, R.: Best of Two Worlds? Towards Ethical Electronics Repair, Reuse, Repurposing and Recycling. *Geoforum* 81, 87–99. <https://doi.org/10.1016/j.geoforum.2017.02.007>. (2017)
34. Li, H, La Guardia, M, Liu, H, Hale, R, Mainor, T, Harvey, E, Sheng, G, Fu, J, Peng, P.: Brominated and Organophosphate Flame Retardants along a Sediment Transect Encompassing the Guiyu, China e-Waste Recycling Zone. *Science of The Total Environment* 646, 58–67. <https://doi.org/10.1016/j.scitotenv.2018.07.276> (2019)
35. Löser, F.: Strategic information systems management for environmental sustainability: enhancing firm competitiveness with Green IS (Vol. 6). *Universitätsverlag der TU Berlin*. (2015)
36. MacDonald, C., <https://www.bbc.co.uk/news/magazine-33133712> (2015)
37. McNeill, J.R., Engelke, P.: *The Great Acceleration: An Environmental History of the Anthropocene since 1945* Harvard: Belknap (2014)
38. Meadows, D.H., Meadows D.L., Randers, J. Behrens, W.: *The Limits to Growth*. New York: Signet (1972)
39. Moore, Gordon E.: Cramming more components onto integrated circuits. *Electronics Magazine*. p. 4. (1965).
40. PACE The Platform for Accelerating the Circular Economy: A New Circular Vision for Electronics: Time for a Global Reboot. E-Waste Coalition <https://www.itu.int/en/ITU-D/Climate-Change/Documents/2019/A-New-Circular-Vision-for-Electronics.pdf> (2019)
41. Rattle, R.: *Computing Our Way to Paradise?: The Role of Internet and Communication Technologies in Sustainable Consumption and Globalization*. Rowman & Littlefield. (2010).
42. Raworth, K.: *A safe and just space for humanity: can we live within the doughnut*. Oxfam (2012)
43. Raworth, K.: *Doughnut Economics*. Milton Keynes: Penguin Random House. (2017)
44. Richter, F.: Battery Life Is A Key Feature For Mobile Devices. <https://www.statista.com/chart/563/improvements-wanted-by-mobile-device-users/> (2012)
45. Reck, B. K., & Graedel, T. E.L: Challenges in metal recycling. *Science*, 337(6095), 690-695. (2012)
46. Rucevska I., Nellemann C., Isarin N., Yang W., Liu N., Yu K., Sandnæs S., Olley K., McCann H., Devia L., Bisschop L., Soesilo D., Schoolmeester T., Henriksen, R., Nilsen, R.: *Waste Crime – Waste Risks: Gaps in Meeting the Global Waste Challenge*. A UNEP Rapid Response Assessment. United Nations Environment Programme and GRID-Arendal, Nairobi and Arendal, [www.grida.no](http://www.grida.no) 2015.
47. Schüler, D., Buchert, M., Liu, R., Dittrich, S., & Merz, C.: Study on rare earths and their recycling. *Öko-Institut eV Darmstadt*. (2011)
48. Steffen, W., Broadgate, W., Deutsch, L., Gaffney, O. and Ludwig, C.: The trajectory of the Anthropocene: The Great Acceleration. *The Anthropocene Review*. 1–18, published online 16/1/15. (2015)
49. StEP White Paper.: *One Global Definition of E-waste*. Accessed from <http://www.step-initiative.org/e-waste-challenge.html> (2014)
50. Umair, S., Anderberg, S., Potting J.: Ewaste Imports and Informal Recycling in Pakistan. *Journal of Solid Waste Technology and Management* 42(3):222-235 (2016)
51. United Nations Environment Management Group: *United Nations System-wide Response to Tackling E-waste*. <https://www.unenvironment.org/news-and-stories/story/end-electronic-waste-united-nations-organisations-highlight-their-commitment> (2017)
52. U.N. <https://www.un.org/sustainabledevelopment/infrastructure-industrialization/> 2020

53. Xing, K., Abhary, K., Luong, L.: IREDA: An Integrated Methodology for Product Recyclability and End-of-life Design. *The Journal of Sustainable Product Design*, 3(3), 149–171. <https://doi.org/10.1007/s10970-005-3925-9> (2003)
54. Wang, F., Huisman, J., Meskers, C. E. M., Schluerp, M., Stevels, A., Hagelüken, C.: The Best-of-2-Worlds philosophy: Developing local dismantling and global infrastructure network for sustainable e-waste treatment in emerging economies. *Waste Management*, 32(11), 2134–2146. <https://doi.org/10.1016/j.wasman.2012.03.029> (2012)
55. Wieser, H.: Beyond Planned Obsolescence: Product Lifespans and the Challenges to a Circular Economy. *GAIA - Ecological Perspectives for Science and Society* 25, no. 3, 156–60. <https://doi.org/10.14512/gaia.25.3.5>. (2016)
56. Wilson, G. T., Smalley, G, Suckling, J, Lilley, D, Lee, J, Mawle, R.: The Hibernating Mobile Phone: Dead Storage as a Barrier to Efficient Electronic Waste Recovery. *Waste Management*, Special Thematic Issue: Urban Mining and Circular Economy, 60, 521–33. <https://doi.org/10.1016/j.wasman.2016.12.023>. (2017)
57. WSJ, <https://www.wsj.com/articles/chinas-rare-earths-bust-1468860856> (2016)
58. Zeng, X., & Li, J.: Measuring the recyclability of e-waste: an innovative method and its implications. *Journal of Cleaner Production*, 131, 156-162. (2016)