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RESEARCH ARTICLE

Zero E-waste: Regulatory impediments and blockchain imperatives

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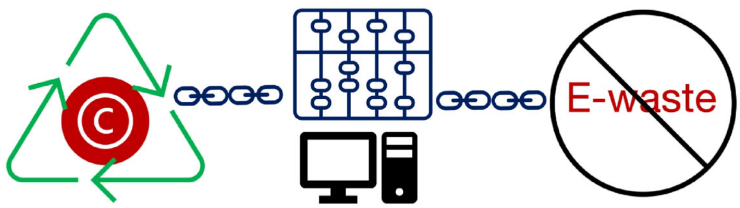
HIGHLIGHTS

- Copyrights on electronic products are impediments in promoting circular economy.
- Manufacturers antagonize refurbishment and remanufacturing to maximize profit.
- International harmonization of copyright laws will aid repair and remanufacture.
- Blockchain – digital immutable ledgers – can promote trust among stakeholders.

GRAPHIC ABSTRACT



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ABSTRACT

The concept of zero waste is an ideal situation that will require different solutions for different categories of waste. Electronic waste (E-waste), the fastest growing category of solid hazardous waste presents various unique challenges. Electronic product repair, reuse and remanufacture (*3re*) are crucial for effective source reduction of E-waste and the integration of the electronics industry into a circular or zero-waste economy framework. Increasingly, *3re* implementation is restricted by regulatory difficulties, particularly the invocation of copyright laws. Here, we use the examples of electronic printer cartridges and restored compact discs (CDs) to identify the challenges and to explore solutions for managing the risks associated with E-waste through circular economy and the opportunities presented by innovative Blockchain solutions. A set of international consensuses on judicial definitions, such as *3re*, refurbish fake/counterfeit product and copyright exhaustion, are proposed to accelerate source reduction in E-waste management toward the goal of zero waste.

1 Introduction

For more than two decades, electronic waste (E-waste) has been the fastest growing category of hazardous urban waste generated and transported worldwide accompanied by toxicity risks to human health and environmental quality (Ogunseitan et al., 2009). Less than 20% of more than 53 million metric tons of E-waste generated globally in 2019 was collected and recycled through formal processes, and there are major gaps between production and recycling in various geographical regions (Fig. 1), acknowledging the considerable engagement of informal collection and recycling processes that occur in many countries with economies in transition.

More E-waste is generated in the Asia region than in any other, although on a per-capita basis, the Americas

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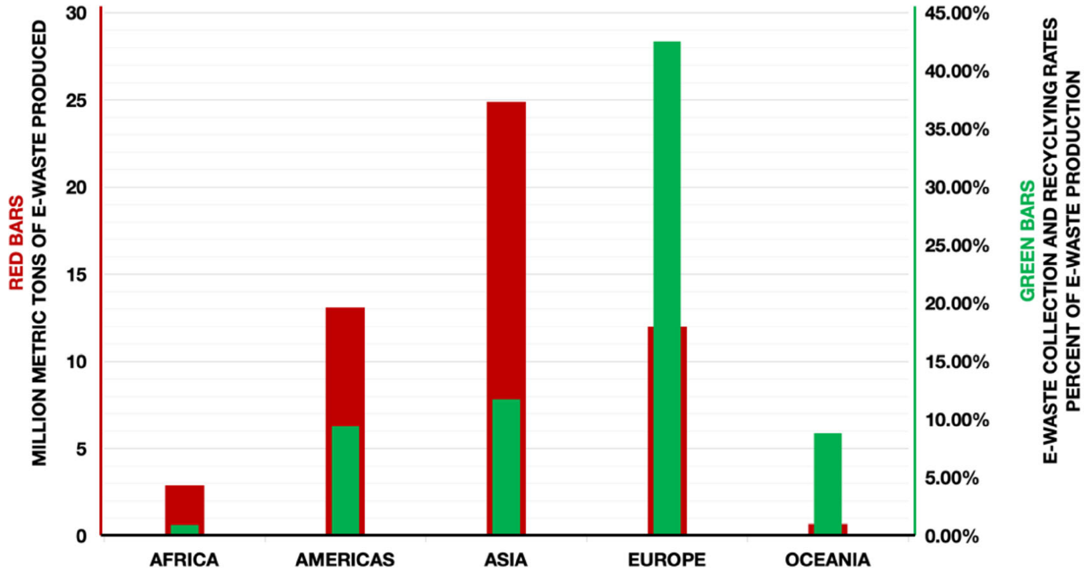

Fig. 1 A total of 53.6 million metric tons (mmt) of E-waste was generated globally in 2019 (red bars), representing 7.3 kg per person. E-waste production increased by 9.2 mmt since 2014. E-waste collection and recycling rate is highest in Europe at 42.5% and as low as 0.9% in Africa (green bars), leaving wide gap between production and resource recovery and the attendant adverse impacts on human health and the environment (Forti et al., 2020).

generate more than others. From the perspective of sustainability and circular economy (Awasthi et al., 2019), the percentage of E-waste collected and recycled is more informative. The Europe region exhibits the highest percentage of E-waste collection and recycling rates, although still below half of E-waste generated in that region. In the Americas, particularly in the United States where many global corporations responsible for the innovative drivers of the electronic manufacturing industry, and where per-capita generation of E-waste is highest, just a little over one-tenth of E-waste generated is collected and recycled. There are many impediments to E-waste collection and recycling both structural and procedural, although only some of these have been documented in the literature, and few are cross-national in scope (Saphores et al., 2006; 2007; 2009; Nixon et al., 2009; Saphores et al., 2012; Li et al., 2015). Here, we focus on copyright laws as an impediment, and we propose the deployment of emerging Blockchain architecture to overcome structural and economic barriers against distributive strategies for E-waste management that minimize toxic exposures and their adverse consequences for human health and environmental quality.

2 Toxicity of E-waste and resource conservation warrants innovative management strategies

Electronic product manufacturing imposes adverse occupational and environmental health impacts on societies sometimes distant from the locations where experts conceptualize, design, and generate specifications for the final product. Even more concerning are the adverse impacts imposed to population health and environmental quality by electronic products discarded at the end of their useful life. The risks associated with E-waste has been demonstrated worldwide, wherever people use mobile phones, computers, and digital as opposed to analog household appliances (Ogunseitan et al., 2009; Li et al., 2015; Awasthi et al., 2019). The risks to population health have a dimension of socioeconomic disparity because the labor for rudimentary E-waste processing typically attracts only the poor, and conditions under which they work are largely unregulated (Ogunseitan, 2013). The profile of disease and disability due to population exposures to toxic chemicals and materials used as constituents of electronic products or in processing their manufacture is extensive, ranging from cognitive impairment due to lead poisoning from tin-lead solders used in printed circuit boards to cancers from nickel, and reproductive and developmental health problems associated with organic chemicals such as halogenated flame retardants (Ogunseitan, 2013). Manual laborers involved in E-waste resource recovery and recycling in many countries with economies in transition are attracted to the occupation because older electronic products contained precious metals such as gold and other valuable metals such as copper (Hibbert and Ogunseitan, 2014). The process of mining E-waste for such resources exposes workers and the environment to toxicants embedded in components including batteries, screens, plastic casing, printed circuit boards, and wires (Fig. 2). The liberated toxicants such as cadmium, halogenated flame retardants, mercury, flame retardants, and dioxins, are notoriously linked to several diseases (Hibbert and Ogunseitan, 2014; Guo et al., 2020).

As a consequence of epidemiological studies that have linked toxic components of E-waste to adverse health impacts, there have been numerous attempts to develop and implement policies that aim to restrict the concentrations of toxic chemicals in electronic products, and to make manufacturers responsible for E-waste collection and management. Perhaps the best known of such regional regulations is the European Union's RoHS: restriction of the use of certain hazardous substances in electrical and electronic equipment (RoHS-1; Directive 2002/95/EC) (European Commission, 2020). The RoHS Directive bans sales of electronic products in the European Union if the concentration of cadmium, chromium-6, lead (Pb), mercury, polybrominated biphenyl, and polybrominated diphenyl ether exceed specified amounts (European Commission – The ROHS Directive,2020). An updated version (RoHS 2, Directive 2011/65/EU) effective in 2017 addressed prevention strategies for E-waste hierarchy's highest priority. The update promotes reduction of toxic substances content in electronic materials and products to benefit safety considerations in E-waste management through reuse of products and the recycling of used materials, in support of circular economy (European Commission, 2020). The European Union's Waste Electrical and Electronic Equipment preceded RoHS to impose the post-consumer responsibility on manufacturers in

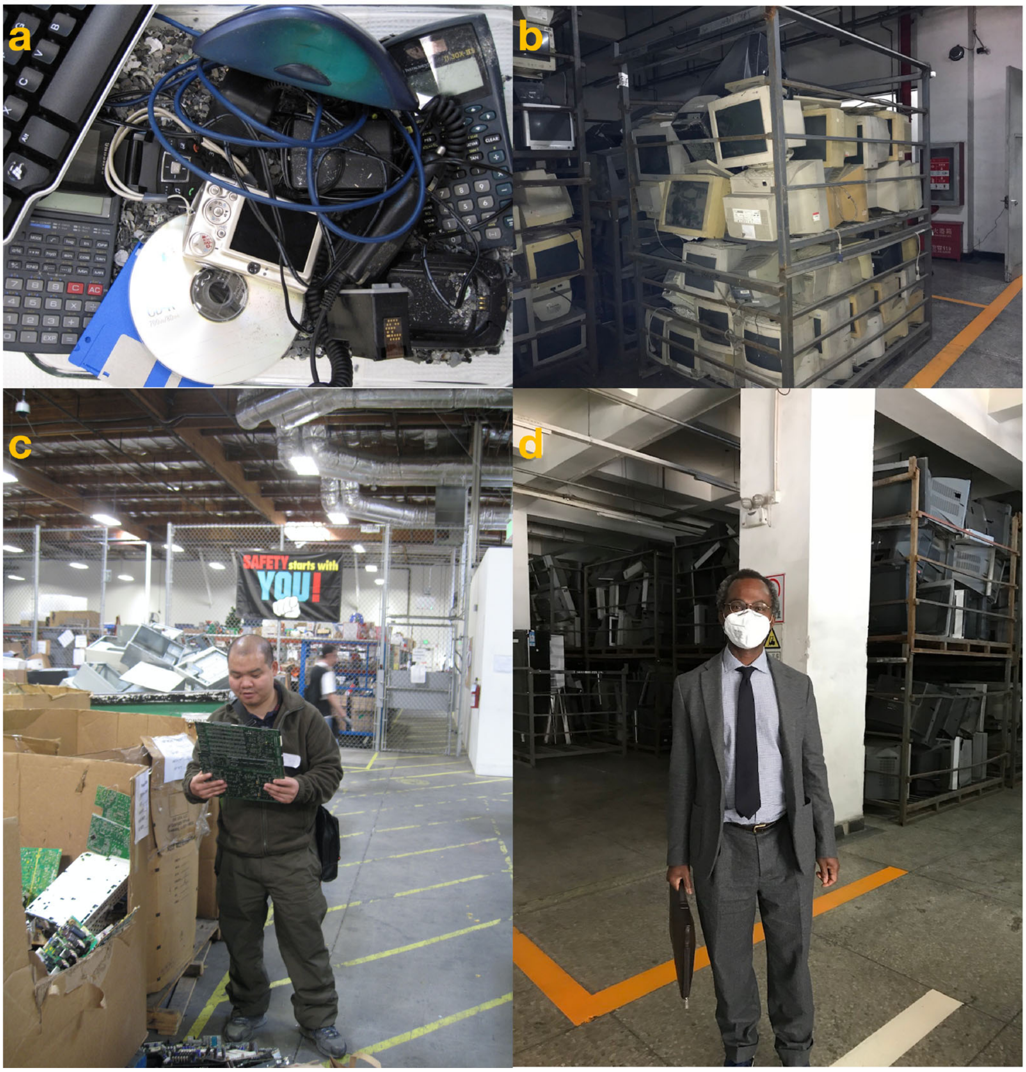

Fig. 2 E-waste consists of small (panel a) and large (panel b) electronic products of various model years, and large E-waste collection and recycling facilities visited by authors in Santa Ana, California (Chen) and Beijing, China (Ogunseitan) require moderation of copyright laws to fully implement the opportunities for refurbishment and re-sale. Portraits are of the two authors of this article, and grant publishing permit. All photo credits to Oladele A. Ogunseitan.

terms of collection and processing of end-of-useful life of their products. These regional policies and regulations have engendered innovative research and development on safer or "greener, less toxic" alternative materials (Ogunseitan, 2013; Li et al., 2015; Awasthi et al., 2019). However, they have also revealed policy differences across jurisdictional boundaries, which calls for global regulations and policies under the United Nations' authority. In addition gaps in research to improve understanding of resource recovery and recycling has become important in the context of proprietary product design strategies and protection of intellectual property rights, while also ensuring that electronic products contain sufficient innovative features to attract new and existing customers to purchase new models that are released periodically (Chen et al., 2018; Singh et al., 2019).

As a major consumer of electronic products and producer of E-waste, the United States has unfortunately not yet enacted national-level policies to guide the adoption of alternatives to toxic components of electronics. Moreover, international regulatory policies such as the United Nation's Basel Convention on the Control of Transboundary Movement of Hazardous Wastes and their Disposal have not dealt effectively with preventive measures, and concerns about protecting international trade and commerce has limited the effectiveness of the Conventions role in promoting innovation and protection of intellectual property rights (United Nations Environment Program, 2020). Researchers working to assess the health and environmental impacts of E-waste face uncertainties in quantifying variability of exposures and multivariate sources of target chemicals because many toxic chemicals in electronics are also be found in other consumer products, for examples, flame retardants are also used in furniture, lead is found in paint and automobile batteries, and mercury is present in household fluorescent light products. Therefore, it is difficult to track exposures due to electronics manufacturing and E-waste management throughout the product lifecycle. This difficulty has complicated the progress in innovation that might otherwise be attributed to regional and international policy enactments.

3 Electronic product life cycle information should inform guide E-waste management and regulatory approaches

Traditionally, researchers have developed Life Cycle Assessment (LCA) methodology as a useful tool for identifying opportunities to reduce environmental impacts and to promote innovation through changing product design, improving recycling, or reducing energy and resource use. LCA methods to quantitatively evaluate environmental impacts across product life cycle stages have become commonplace, but rarely do these methods account for chemical toxicity (Hibbert and Ogunseitan, 2014; Chen et al., 2018; Singh et al., 2019). Moreover, these methods cannot be easily used early in the design process due to severe limitations in databases and methodological sophistication. Thus, the application of LCA to green design and risk characterization shows considerable promise for tracking innovation from mining operations and manufacturing to consumer use, disposal, and E-waste management. To support initiatives, the United Nations Environment Program (UNEP collaborated with the Society for Environmental Toxicology and Chemistry (SETAC) to launch the Life Cycle Initiative as a strategy to reduce this knowledge gap. For example, we have used the resulting USETox LCA model to characterize the human health and environmental impacts of artisanal mining of discarded mobile phones, which resulted in identifying specific chemical components of these electronic products that should be considered for safer alternatives including beryllium, nickel, and dioxin-generating materials (Hibbert and Ogunseitan, 2014). However, the supply chains of mining, design, manufacturing, and assembly of finished products is extensive and complicated, and tracking and testing can be dauting without application of digital ledger systems (Awasthi et al., 2019).

Regulatory policies for e-waste are as diverse as states, regions, countries and international regimes. It is important to understand the context in which laborers and artisanal miners of e-waste work within these regimes. There is still some uncertainty about the coverage of e-waste under the Basel convention, and in the United States, not all states regulate e-waste disposal and treatment, and there is no federal mandate. The US EPA discourages international shipment of hazardous waste, and there are some incentives at the national level for manufacturers to reduce the toxic components of their products. However, regrettable substitutions plagued previous regulations. Under California's Safer Consumer Products Law, manufacturers must compare data on human health, environmental, technical and economic impacts across the lifecycle of the regulated product with the same information about potential alternatives (Saphores et al., 2006; Saphores et al., 2007; Ogunseitan, 2013). Development and evaluation of innovation in the context of alternative materials analysis methods raise substantial questions in the regulatory context, including how to contend with significant data gaps, and how to structure choices among alternatives. Alternative Analysis requires balancing numerous, incommensurable decision criteria and evaluating the trade-offs among those criteria presented by multiple alternatives. Although formal decision analysis methods suitable for such situations are well developed, they are rarely applied in practice (Malloy et al., 2017).

E-waste is typically managed through four processes: 1) remanufacture, repair, and reuse (*3re*); 2) waste-to-new materials; 3) waste-to-new products; and 4) waste-to-energy. From the perspective of a life cycle impact assessment, it is clear that *3re* extends the life span of products, especially for information and communication technology (ICT) products such as mobile phones, thus reducing environmental pollution and saving material resources and energy (Ogunseitan et al., 2009; Awasthi et al., 2019). The principles and protocols of *3re* can be effective in promoting circular economy and the achievement of significant reduction of urban solid waste generation, and is complementary to other initiatives to reduce the toxic potential of materials used to manufacture electronic products (Schoenung et al., 2004). The protocol of *3re* seems to be more effectively applied to large size products such as automobiles than to small items such as consumer electronics, which have become notorious sources of hazardous waste that have challenges international regulations designed for restricting transboundary shipments (Williams, 2011; Matthew, 2019).

We assert that an important unaddressed limitation in the application of *3re* to E-waste are patents and copyright policies, and that a promising solution is emerging in the use of digital ledgers popularly known as Blockchain. We propose that Blockchain architecture which has the advantage of a digital ledger that can store large amounts of information for every transaction including, manufacturers' specifications, materials composition, and applicable laws and policies such as copyright and disposal practices. Every transfer of a product before and after the supply chain can be accompanied with transparent vital information. Blockchain solution can expand the range of E-waste management activities while protecting the economic value that manufacturers seek to protect, even when they do not have the capacity to recover and properly manage E-waste worldwide where electronic products are marketed and used. In the following sections, we examine the role of copyright laws as impediments for distributed E-waste management, and we explore potential solutions including the application of Blockchain across the life cycle of electronic products to support improved integration of this sector into the circular economy.

4 Copyright laws as impediments for E-waste management

Evidence for the role of patent and copyright laws in retarding circular economy is mounting, and we begin with the 2006 case of *Canon, Inc.* v. *Recycle Assist* litigation regarding printer ink cartridges (Scott, 2007). Recycle Assist Company (RAC) imported used printer cartridges of Canon from Macao, which were not designed for refill. RAC cleaned the residual ink, refilled with new ink and then sold these cartridges on the market. Canon then sued RAC on the grounds of copyright violation. This case set the precedent that any company that intends to collect nonfunctional or non-used ICTs from the owners and then repair and resell them will face the threat of litigation. Another example pertains to the E-waste recycler Eric Lundgren who made and sold 28,000 copies of Microsoft digital disks that may be used by consumers to restore the factory settings on their personal computers (Los Angeles Times, 2018; Roberts, 2018a; 2018b). Microsoft testified in court that Lundgren infringed its copyright privilege. The outcome led to Lundgren's incarceration for one year.

Copyright violation has never been identified as a problem in the management of used automobiles, and we argue that there is no credible reason to treat electronic ICT products differently. For example, once a buyer purchases a new mobile phone, the hardware and software become the property of the consumer, and the copyright no longer resides with the primary manufacturer. After being used or defunct, the owner has the right to sell the mobile phone to a third party that collects E-waste for recycling, at which point the copyright is now transferred to the recycler. The recycler may repair, remanufacture, and reuse the recycled devices and then sell them in the open market. Therefore, the question is whether a recycler, such as *Recycle Assist*, can sell such a mobile phone without violating the copyright held by the primary manufacturer. It is not permissible for a recycler to sell a *3re* mobile phone as a repaired refurbished product without the authorization of the primary manufacturer because it is considered "fake product" (The Supreme People's Procuratorate of China, 2001; Grinvald and Tur-Sinai, 2019). However, if a recycler sells the mobile phone and advertises it as a *3re* product, it is acceptable. Otherwise, this implies that the primary manufacturer still has the copyright to the *3re* devices and could ask for financial compensation from recyclers. If this is practice holds, then electronic product manufacturers such as Apple, Canon, Dell, and IBM, will be entitled to some money each time the device is recycled — even if recycling alters product function and performance.

In 2013, the World Intellectual Property Organization (WIPO) released a report on "Patent Landscape Report on E-waste Recycling Technologies" (Thomson-Reuters, 2013), which concluded that the global innovation in E-waste is increasing sharply, dominating in Asian (especially China and Japan), followed by Europe. The patent activity on E-waste is limited in the United States. Current interpretation of patent and copyright laws regarding E-waste strongly favor waste-to-new materials management strategies, but the technology is not yet mature for recovery of reusable rare earth metals such as lanthanum, neodymium and praseodymium, which are increasingly subject to international trade conflicts (Hearty, 2019).

The subjective interpretation of patent and copyright laws is not helped by the wide variation in international regulations to support the proper management of E-waste for the purpose of reducing risks to the environment and human health, and the elimination of transboundary movement of hazardous waste. The European Union's original 2006 directive on Waste Electrical and Electronic Equipment (updated to Version 2.0 in 2014), strives for 70%– 80% recycling rate (European Union, 2012). In the US, the National Computer Recycling Act and the Resource Conservation and Recovery Act are the primary policy instruments for E-waste management, but they are largely silent on the application of patent and copyright laws (Schoenung et al., 2004). Twenty-five US states have enacted independent policies on E-waste management, including, for example, California, which adopted Senate Bill 20 (Electronic Waste Recycling Act of 2003) (Saphores et al., 2006), and Senate Bill 50 (Emergency Amendment to SB 20) (Nixon et al., 2009). China and Japan, large generators of E-waste, have also implemented various regulations on E-waste. Most of the regulations adopt the extended responsibility approach whereby manufacturers are incentivized to reduce the use of toxic constituents in their products, and to voluntarily invest in E-waste recycling to promote circular economy (Awasthi et al., 2019).

5 Emerging solutions for E-waste management

It is important for the sake of removing cogs in the wheel of a much-needed circular economy for electronics manufacturers to cooperate in deriving a common understanding and application of patent and copyright laws to post-consumer products. A set of international regulations, including repair, reuse, remanufacture, refurbish, fake/counterfeit product and copyright exhaustion beyond the first point of sale of a new product can also identify the point in a product's life cycle when copyright enforcement should end. The printer cartridges infringed the copyright of Cannon because the Intellectual Property High Court of Japan rejected repair as opposed to reproduction because of lack of clear definition of copyright exhaustion (Intellectual Property High Court, 2006). Existing juridical interpretation of repair and remanufacture in the US does not necessarily apply in other countries (USLEGAL, 2006;2020). So far, no nation currently has a set of clear definition of repair, reuse, remanufacture, refurbish, fake/counterfeit product and copyright exhaustion. International advocates of a circular economy are left to wrestle with judicial interpretations that are difficult to extrapolate to current and future scenarios. It is important to develop policies that do not infringe on the rights of consumers nor hinder creativity.

We propose that new thinking on the use of distributed digital ledgers, popularly known as Blockchain technology, can address the distrust of second-hand dealers who are prepared to support the reduction of E-waste through *3re* (Fig. 3). A Blockchain can perhaps be thought of as consensus of shared, synchronized, and replicated digital data spread across several geographic locations, countries, or institutions without a central administrator (United Kingdom Government Office for Science, 2020). Blockchain technology was invented in 2008 as part of the creation of Bitcoin peer-to-peer digital cash (Bitcoin, 2020). All participants within a specific Blockchain network have identical copies of the transactions ledger, which instantly and simultaneously reflect any changes to assets in the ledger. The security and accuracy of ledger

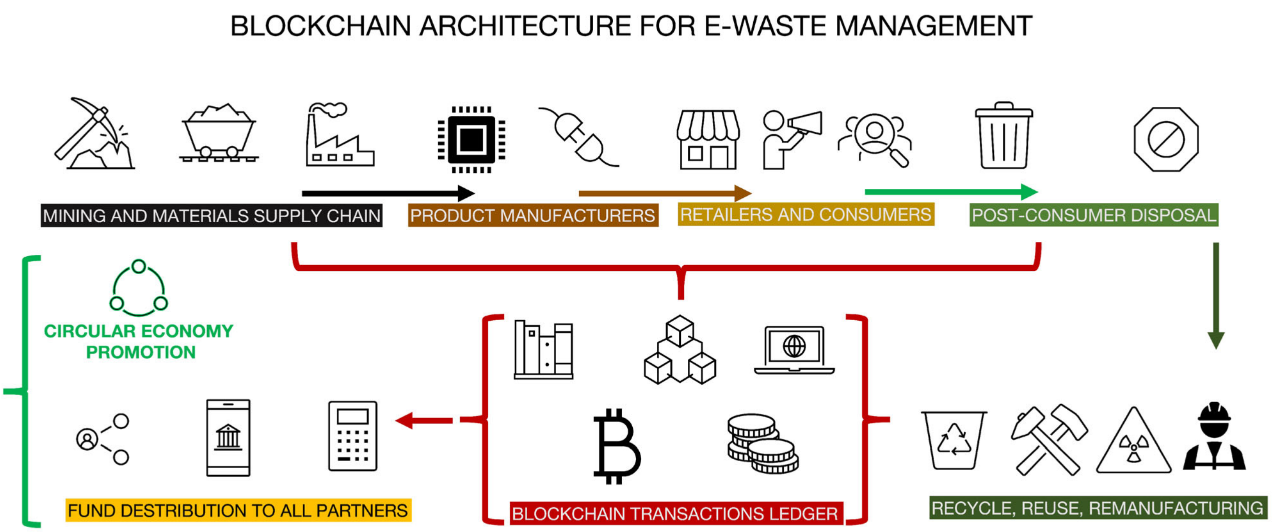

Fig. 3 Schematic diagram of the application of Blockchain to the Life Cycle of Electronic Products including E-waste Management. Blockchain architecture is well established for tracking minerals at source (black text box) to the manufacturer's supply chain (brown text box), which is typically shielded from retailers and consumers (beige text box), except in cases where manufacturers advertise "green" production or sustainable practices. Blockchain architecture needs to be extended to manage post-consumer disposal of E-waste (light green text box) and recycle, reuse, and remanufacturing processes (dark green text box) to overcome impediments associated with copyright infringements, and to promote integration of E-waste into a circular economy.

contents are maintained through cryptographical keys to control access. Blockchain rules agreed upon determine whether updates can be entered by one, some or all of the participants. The process must be profitable for all parties to be sustainable, yet potential buyers must be assured that the cost differential between a new product and a refurbished product keeps the incentive intact. It is likely that this process already exists in the transaction of high-end costly electronic products for which buyers and sellers negotiate on individual products. However, for relatively lower cost items such mobile phones, bulk transactions are necessary, and the similarity to the transactions regarding raw minerals.

In 2019, IBM launched a Blockchain initiative for tracking controversial minerals such as cobalt that are essential for electronics manufacturing (Garrett, 2020; Teicher 2020). The IBM proposal focused on tracking conflict and/or contested minerals used in the manufacture of electronic products, particularly cobalt, which is a major constituent of rechargeable batteries (Kang et al., 2013). The impetus for implementing Blockchain strategies at the first node of the lifecycle of electronic products and E-waste is driven by the Dodd-Frank Wall Street Reform and Consumer Protection Act enacted on 21 July 2010 (United States Commodity Futures Trading Commission, 2020). Section 1502 of the Dodd-Frank Act dealt with “conflict minerals,” defined as columbite-tantalite (coltan), cassiterite, gold, wolframite, or their derivatives; and any other mineral or its derivatives determined by the US Secretary of State to be financing conflict in the Democratic Republic of the Congo or an adjoining country (United States Commodity Futures Trading Commission, 2020). Coltan falls in the “itemized” category of conflict minerals, whereas Cobalt is in the category of minerals that are suspected to finance conflict, and its mining is associated with illicit child labor in the Democratic Republic of Congo, which supplies about 10% of the world demand for cobalt, most of which is consumed by the electronics industry. Section 1502 of the Dodd-Frank Act aims to break the link between conflict and minerals in the Central Africa region through the development of a strategy and map for monitoring and stopping commercial mining activities that contribute to the activities of armed groups and human rights violations in the Democratic Republic of the Congo. The IBM Blockchain architecture specifically addresses a plan to guide commercial entities such as electronics designers and manufacturers seeking to “exercise due diligence on and formalize the origin and chain of custody of conflict minerals used in their products and on their suppliers to ensure that conflict minerals used in the products of such suppliers do not directly or indirectly finance armed conflict or result in labor or human rights violations” (One Hundred Eleventh Congress of the United States, 2020).

Joining IBM as early adopters of the Blockchain for conflict mineral initiative are electronics manufacturer LG Chem, automobile manufacturers including Ford Motor Company, natural resources service providers including RCS Global Group, and mining corporations including Huayou Cobalt. The Blockchain architecture for responsible sources of minerals used in electronic products extends beyond cobalt, and includes tin, tantalum and tungsten (3Ts). A second Blockchain consortium involves a partnership of IBM and MineHub Technologies which is establishing a web-based platform for streamlining procedures from mines to metal processing and applications factories to promote transparency, save operating costs, and quickly secure transactions. Other emerging Blockchain platforms relevant to E-waste management is “Cobalt Blockchain” (COBC), a Canada-based operation that was the first such company established specifically to comply with the guidelines established by the Organization for Economic Co-operation and Development (OECD) on ethical procurement of cobalt (Organization for Economic Cooperation and Development, 2020). The OECD’s guidelines, formally known as “Due Diligence Guidance” provides recommendations to assist any company seeking to acquire minerals or metals from conflict-affected and high-risk areas to “respect human rights and avoid contributing to conflict through their mineral purchasing decisions and practices.” The Due Diligence Guidance applies to all mineral supply chains, and it is global in scope, having been adopted by all 37 member countries of OECD and non-member countries Argentina, Brazil, Costa Rica, Morocco, Peru and Romania (Cobalt Blockchain, 2020). COBC has guaranteed production of at least 40,000 t of cobalt concentrate per annum from DRC mines processed through Blockchain traceability from mines to end-users. The tightening of cobalt supplies has engendered new interest in recovery of cobalt from end-of-life electronic products such as rechargeable batteries. This provides incentives for E-waste collection and recycling through the adoption of beneficial management practices (Quintero-Almanza et al., 2019; Maroufi et al., 2020; Takahashi et al., 2020). It is increasing important to integrate raw materials acquisition through virgin mining operations with post-consumer resource recovery strategies. Blockchain strategies are positioned to play a major facilitating role in the integration. Mining and beneficiation companies such as Umicore that also process E-waste on a large scale are positioned to develop Blockchain strategies throughout the Lifecyle of electronic products (Bertuol et al., 2016; Huang et al., 2019; Umicore, 2020; Zhang et al., 2020).

McGrenary (2019) proposed Blockchain solution for E-waste through a process whereby satellite recycling consoles are installed in locations where people can exchange their end-of-life electronic products for digital tokens. The data on each product inputted into the consoles becomes part of a permanent record in the Blockchain ledger, and so is the value of the digital token, which is associated with estimated cost of repair or refurbishment, and all parties including the original manufacturer have access to the financial and physical fate of the products, and the unchangeability of the record will assure honest transactions in profit sharing, thereby limiting the invocation of legal instruments for dispute resolution.

6 Conclusions

In Fig. 3, we present the schematic representation of a new vision where Blockchain application to mining operations as developed by the IBM project is integrated into a lifecycle perspective, including manufacturing, retailing, consumers, product end-of-life fate of products, and E-waste management including recycling, reuse, and refurbishment. Benefits of the proposed Blockchain architecture, in addition to assuring trust in profit distribution and protection of intellectual property is the linkage to appropriate procedures for E-waste management that reduces adverse impacts on human health and environmental quality. We also acknowledge potential adverse impacts of the Blockchain architecture through the generation of addition E-waste because of the rapid turnover of hardware necessary for secure virtual transactions (de Vries, 2019). We propose further research to ensure that such solutions can be implemented worldwide particularly in places where rudimentary E-waste managements exacts unsustainable tolls on human health and environmental quality.

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