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Using Artificial Intelligence in Order to Improve Circularity in the Consumer Electronics Sector

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Introduction

Consumer electronic devices have become integral to our everyday lives, influencing our work, leisure activities, and interpersonal communications. However, we often discard these devices after a brief period of use. In 2019, a record 53.6 million metric tonnes (Mt) of e-waste—products with a battery or plug, such as computers and smartphones—were reported as generated globally, marking a 21 percent increase over five years. The report forecasts that global e-waste will reach 74 Mt by 2030, nearly double the figure from 2014, driven by rising consumption of electric and electronic equipment (EEE), shorter product lifespans, and limited repair options. In 2019, Asia produced the highest amount of e-waste at 24.9 Mt, followed by the Americas with 13.1 Mt and Europe with 12 Mt, while Africa and Oceania contributed 2.9 Mt and 0.7 Mt, respectively. Only 17.4 percent of e-waste was officially recorded as collected and recycled in 2019. This indicates that valuable materials such as iron, copper, and gold, estimated to be worth around US $57 billion—more than the GDP of many countries—were largely discarded or incinerated instead of being properly processed for reuse. By recycling and reusing valuable materials found in e-waste, we can foster a circular economy through the use of secondary materials (The Global E-Waste Monitor 2020 Quantities Flows and the Circular Economy Potential, 2020).

The predominant portion of electronic waste is typically disposed of rather than salvaged or subjected to recycling processes, resulting in the forfeiture of intrinsic energy, materials, and economic worth, in addition to significant adverse environmental and societal repercussions, particularly within the realm of informal recycling activities (The Human and Environmental Effects of E-Waste, n.d.).

The traditional linear economy operates on the "buy, use, and dispose" model, which follows a straightforward path from extracting raw materials to product usage and ultimately ending up in a landfill or incineration. However, there is an increasing need to adopt the circular economy approach, which emphasizes the repeated use of materials and closing resource loops. Implementing circular economy strategies is essential for promoting global sustainability. The circular economy focuses on minimizing waste generated during production and distribution, while also reinforcing the connection between circular economy and waste management, thereby effectively aiding in waste reduction. In a future characterized by a circular economy, the concept of electronic waste would become obsolete. Electronic devices would be utilized for extended periods, either by a single user or multiple users. Instead of being discarded, these devices will be reused, repaired, refurbished, remanufactured, and shared among users with varying needs, including those in market segments that require lower performance. This extension of usage is facilitated by thoughtful design, software upgradability, and innovative business models. Devices would be constructed for easy repair by knowledgeable technicians or users, or they may be remanufactured before being passed on to the next owner. Some devices would be offered through access models instead of traditional ownership, allowing users to utilize them as long as they meet their needs, after which they can be returned to the producer or given to another user. Markets for second-hand products would support the exchange and trade of devices among users. Ultimately, all consumer electronics that are no longer in use would be collected and recycled into raw materials that could be reintegrated into the production of new devices.

In summary, a circular economic future for consumer electronics envisions a system where products are designed, manufactured, utilized, and disposed of in a manner that reduces waste and enhances resource efficiency. This approach seeks to tackle the environmental and economic issues associated with the current linear production and consumption model, which generates significant electronic waste and depletes resources. By embracing circular economy principles, the consumer electronics sector can lessen its environmental impact, preserve valuable materials, and develop sustainable business practices.

Methodology

For consumer electronic products, AI could play a crucial role to accelerate the circular economy. The electronics sector continues to be a rapidly evolving part of the economy. Unfortunately, this ongoing advancement, while offering numerous advantages, comes with risks associated with environmental impact (Clarke et al., 2019)

. In particular, the limited operational lifespan and insufficient recycling rates of electronic devices inexorably result in an increasing volume of waste. Consequently, electronic waste is regarded as a rapidly proliferating environmental issue, particularly in developed nations (Abalansa et al., 2021).

AI has the opportunity to influence the consumer electronics sector in the following ways:

1. Lifetime extension: Using circularity principles while designing the products can aim to increase the use period by identifying causes of failure and improving those aspects of the design. AI can also enable targeted marketed, dynamic pricing, predictive maintenance, and other measures that will enable the products to be used for a longer period of time. (Baragde & Jadhav, 2020)
2. Reducing waste at end-of-life: An infrastructure powered using AI solutions could enable the recovery of valuable materials from reused, repaired, remanufactured or recycled devices, components and materials. (Althaf et al., 2019)
3. Material utilization efficiency: AI can help with optimization of manufacturing processes which would in turn improve material use efficiency and reduce waste in production. (Recovering Critical Raw Materials from WEEE Using Artificial Intelligence, 2022)
4. Optimizing R&D: AI can enhance and accelerate innovation processes, resulting in a more efficient use of resources through rapid testing. (Ghoreishi & Happonen, 2020)

AI assisted design of consumer electronics

A key factor in driving change is the design of products and materials. Consumer electronics and their components should be created in a more standardized and modular fashion to facilitate disassembly for refurbishment, remanufacturing, and material recovery. Additionally, it is crucial for personal data to be easily transferable to encourage device reuse and models like phone-as-a-service. Manufacturers must also ensure that products remain software-compatible to enable upgrades and prevent the disposal of fully functional devices. AI technology can accelerate and enhance the design and product development process for consumer electronics. Algorithms can quickly generate numerous design options, optimizing for various circular economy variables and other design aspects. Moreover, insights from currently used products can be analyzed to incorporate best practices into new designs. (Náñez Alonso et al., 2021)

An example of a company using AI in the design of electronics is Motivo, whose services provide insights about the optimization of the design of integrated circuits, using big data from multiple sources and machine learning algorithms. Thanks to its technology, design processes that previously took as long as a year have been reduced to approximately four weeks, resulting in significant savings in both time and costs associated with iterative testing. Additionally, AI is being utilized to innovate material designs for electronics. For instance, numerous initiatives are underway to discover safer substitutes for the flammable liquid electrolytes commonly used in lithium-ion rechargeable batteries found in devices like laptops, mobile phones, and other rechargeable consumer electronics. (Chawla et al., 2019)

Another aspect of the circular economy that could benefit from AI is operation of a circular business model. Products designed for a circular economy, like consumer electronics, necessitate specific business models that incorporate features aimed at ensuring a dependable return flow of products and components, along with efficient reverse logistics for collection and transportation. (Nußholz, 2018)

Circular business models, such as product-as-a-service, and supporting elements like robust secondary markets, face various challenges that must be addressed to effectively compete with traditional linear models. (Vermunt et al., 2019)

For instance, the adoption of secondary markets for consumer electronics may be hindered by worries about personal data remaining on devices and doubts regarding the condition and fair pricing of second-hand products. (Veghes et al., 2009)

AI assisted circular business models

In order to enhance the competitive edge of circular business models, the integration of AI-enabled tools is paramount. The implementation of dynamic pricing mechanisms for pre-owned and leased products, dictated by AI-derived insights into consumer behavior, can facilitate the establishment of markets for these items and invigorate trade and reutilization by leveraging cost efficiencies over the acquisition of new linear products. (Shakya et al., 2010)

Furthermore, AI technologies can be combined with the utilization of intelligent assets equipped with diagnostic software and a network of sensors. This combination would possess the potential to significantly enhance the evaluation of a product's condition, thereby enabling predictive maintenance and allowing for a more precise determination of the secondary value of a previously utilized device. (Lee et al., 2019)

The concept of AI-driven predictive maintenance, which is presently extensively utilized in the context of industrial machinery and installations, may be modified and implemented within the realm of consumer electronics to assist in evaluating the condition of devices and to notify consumers and/or manufacturers when a device necessitates an upgrade or replacement. When comprehensive information regarding the condition of used devices is accessible, AI can also contribute to the creation of transparency regarding options for subsequent utilization cycles. By combining data from diverse sources, including product reuse marketplaces, spare parts databases, and recycled material pricing, algorithms can furnish consumers or providers with a comprehensive overview of options for resale, repair, refurbishment, remanufacturing, or recycling. (Shah et al., 2010)

This encourages demand for new components as replacement parts, along with enhancing the supply of used devices and components, both of which are essential for the optimization of secondary markets. The incorporation of information about pricing for each alternative will further catalyze the evolution of these secondary markets and could yield increased efficiencies, such as a reduction in the costs associated with electronics collection. Finally, targeted marketing initiatives grounded in AI-enabled consumer preference analysis have the potential to elevate consumer awareness regarding access-over-ownership and other circular business models. (Olan et al., 2021).

AI for remanufacturing and refurshibment

Additional uses of AI in the fields of remanufacturing and refurbishment include matching spare parts and detecting faults. For instance, Humai has created a tool named xRec that utilizes AI and computer vision to automatically recognize components or parts needed for machine maintenance, thereby streamlining labor-intensive tasks like reordering spare parts and retrieving documentation. Furthermore, AI can be programmed to optimize and fine-tune existing recycling equipment and systems to manage specific material flows efficiently. (Gibson, 2020)

E-waste varies greatly in size, shape, and condition, which often necessitates customized settings and processes that require manual adjustments to recycling machinery, leading to downtime. (Renteria & Alvarez, 2012)

AI has the potential to alleviate some of this burden in current recycling, refurbishment, and remanufacturing facilities by assessing the condition of end-of-life consumer electronics and automating the necessary adjustments to processing equipment.

Conclusions

AI has the potential to facilitate and speed up the shift towards a circular economy. This document proposes that AI technologies can be utilized in three main areas of a circular economy: designing circular products, components, and materials; implementing circular business models; and enhancing infrastructure to maintain circular flows of products and materials.

Enhancing awareness and comprehension of how AI can aid a circular economy is crucial for promoting its use in design, business models, and infrastructure. By examining the potential applications presented in this paper, stakeholders can identify relevant opportunities for implementing AI in the circular economy, grounded in a clear understanding of AI's capabilities and limitations, as well as an appreciation of how circular economy principles can be integrated into their specific interests or industries.

To enhance data accessibility and sharing, innovative strategies and active cooperation among stakeholders will be essential. Access to pertinent, high-quality data is crucial for both training algorithms and providing input data, which will play a key role in developing AI applications aimed at promoting a circular economy. The effective implementation and scaling of AI to redesign various facets of our economy will rely on the collaborative efforts of key participants, supported by new cross-sector mechanisms and convening organizations. Such collaboration among stakeholders—including businesses, governments, and NGOs—will be particularly vital for the generation, collection, and sharing of data. In certain instances, especially when relevant data is gathered by different players within the supply chain or across various sectors, a central facilitation entity may be necessary to aid these initiatives.

Future Work

This paper presents several compelling examples of the opportunities and advantages that emerge at the intersection of two significant megatrends: AI and the circular economy. However, there remains considerable work to be done in order to achieve the goal of utilizing AI to assist in the intricate process of redesigning entire economic systems. It is evident that new types of collaborative efforts across value chains, supported by a shared vision and guiding principles, could leverage the capabilities of AI to transform the economy into one that is regenerative, resilient, and sustainable for the long term.

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