Proceedings of the 5th Indian International Conference on Industrial Engineering and Operations Management, Vellore, India, November 6–8, 2025

Proceedings of the International Conference on Industrial Engineering and Operations Management

Publisher: IEOM Society International, USA DOI: 10.46254/IN05.20250389
Published: November 6, 2025

Circular Economy Approach for Efficient Management of Mobile Phone E-Waste: Component Extraction, Environmental Impacts and Economic Considerations

Sangeeth Kirushika C
School of Mechanical Engineering
Vellore Institute of Technology, Vellore, India
sangeeth.kirushika@vitstudent.ac.in

Rajyalakshmi G
School of Mechanical Engineering
Vellore Institute of Technology, Vellore, India
rajyalakshmimed@gmail.com

Abstract

With the rise of electronic devices, particularly mobile phones, the e-waste crisis calls for innovative solutions. This study explores the circular economy's potential to revolutionize mobile phone management by analysing extraction techniques, environmental impacts, and material optimization. Embracing a circular economy model, it advocates for resource reuse to reduce waste and promote sustainability. From the results, it concludes that, One ton of recycled mobile phones can yield approximately 150 grams of extracted gold, with recycling costs ranging from ₹5,586.54 to ₹28,014.85 and a recycling time of four to eight weeks for gold extraction. From one ton of recycled mobile phones, approximately 110 kilograms of plastic can be recovered, with recycling costs varying between ₹6,983.18 and ₹27,768.39. The recycling process for plastic typically takes around 20 to 40 days. By reusing and recycling components, the production cost of a new mobile phone can be reduced by approximately 36%, resulting in a new production cost of ₹15,622.51, compared to the original cost of ₹24,271.87. The total cost of recycled and reused components amounts to ₹8,649.36. Recycling one ton of mobile phones yields enough materials to manufacture approximately 4406 new mobile phones, resulting in a potential cost saving of approximately ₹3,80,74,899 for a large-scale production of the same quantity. By adopting this approach and promoting sustainable and ecologically friendly practices in the electronics industry, manufacturers can contribute to societal well-being and mitigate the environmental repercussions of discarded mobile phones.

Keywords
Sustainability, Circular Economy, Waste Management, E-Waste reduction, Cost Analysis

1. Introduction
In today's interconnected society, smartphones have become an indispensable and inseparable part of our everyday existence. Mobile phones, in particular, contribute significantly to the e-waste stream. The increasing research and development efforts, expanding distribution networks, rising consumer demand, and shorter product lifespans have fuelled the growth in mobile phone waste generation. As technological advancements continue, the disposal of outdated or non-functional mobile phones becomes a mounting concern. The disposal of electronic waste poses significant environmental and health risks. With mobile phone ownership surpassing 60% of the global population and smartphone adoption steadily increasing in developing nations, their significance is undeniable. Although different smartphone brands have their own unique components, the majority of smartphones contain approximately

© IEOM Society International

80% of the stable elements found on the periodic table. However, certain essential metals used in smartphone production are deemed vulnerable due to geological scarcity, geopolitical concerns, and other factors.

Based on the Central Pollution Control Board's inventory in 2005, it was estimated that India would generate 0.8 million tonnes of e-waste by 2010. However, recent studies suggest that the actual amount of e-waste generated could be much higher. According to the Global E-Waste Monitor of 2017, India produces approximately 2 million metric tonnes of e-waste annually, with personal devices accounting for about 82 percent of the total. In the financial year 2022, India collected and processed around 527 thousand metric tons of e-waste, marking a significant increase in comparison to the previous year .The country currently ranks as the fifth-largest e-waste producer globally. A study on Electronic Waste Management in India revealed that computer equipment constitutes nearly 70% of the e-waste. The rise in e-waste can be attributed to increased consumption and faster obsolescence of old computers, mobile devices, and other equipment. A study from 2017 estimated that the volume of e-waste is growing at a rate of about 21 percent annually.

E-waste encompasses hazardous substances like lead, mercury, cadmium, and brominated flame retardants. Improper handling and disposal of e-waste can result in pollution and have detrimental health effects on humans and wildlife alike. Mobile phones rely on various core materials such as rare earth metals, precious metals, and plastics. The extraction and mining of these materials can have detrimental environmental impacts, including habitat destruction and water pollution. Moreover, the future depletion of these finite resources raises concerns about the sustainability of mobile phone production. The circular economy offers a promising alternative to the linear economic model of "take-make-use-dispose." It aims to minimize waste, maximize resource efficiency, and promote the recycling and reuse of materials. In the context of the mobile phone industry, adopting a circular economy approach involves strategies like designing phones for longevity and ease of repair, implementing take-back programs for recycling, and promoting the use of recycled materials in manufacturing. Embracing a circular economy strategy in the mobile phone industry can yield several benefits. Leads to reduction in electronic waste generated, leading to less environmental pollution and resource depletion. It also promotes sustainable production and consumption patterns, encourages innovation in eco-friendly designs, and fosters the development of recycling and recovery infrastructure. Additionally, a circular economy approach can create economic opportunities, such as job creation in the recycling sector and the emergence of new business models centered on repair and refurbishment. The implementation of a circular economy in the mobile phone industry aligns with several SDGs, including Responsible Consumption and Production (SDG 12) and Sustainable Cities and Communities (SDG 11). By adopting sustainable practices, reducing waste, and promoting recycling, the industry contributes to the broader global agenda of achieving sustainable development and addressing environmental challenges.

The work on advancing sustainable practices in the mobile phone industry is a ground breaking approach towards achieving a circular economy. It focuses on promoting durability, repairability, and eco-friendly materials in mobile phone design and manufacturing. By maximizing resource recovery through efficient recycling processes, this research contributes to a sustainable future and addresses the concern of e-waste.

2. Literature Review

The rapid increase in the production and disposal of electronic waste, driven by the manufacturing and usage of electronic gadgets, has become a pressing environmental and health concern (Shahabuddin, et al., 2023). Research indicates that the impact of mobile phone waste generation is expanding due to factors such as research and development, distribution, consumer demand, and shorter product lifespans. Furthermore, there are concerns about the depletion of core materials used in mobile phones in the future (Yammiyavar, G. P., and Kumar, V. 2011).

The effects of pandemics and war on e-waste generation and collection are crucial considerations in waste management discussions. During times of conflict or crisis, such as the COVID-19, disruptions in supply chains, logistical challenges, and changes in consumer behaviour can lead to significant fluctuations in e-waste. Research shows that during periods of upheaval, there is often a surge in electronic device purchases for communication, entertainment, and remote work, resulting in increased e-waste generation. Conversely, disruptions in manufacturing and distribution channels can impede the proper disposal of electronic devices, worsening the environmental and health risks associated with e-waste mismanagement. Therefore, it is essential to understand the nuanced impacts of pandemics and war on e-waste dynamics to develop effective waste management strategies that address these fluctuations and minimize their negative effects on public health and the environment.

© IEOM Society International

To address these challenges, there is a need to shift from the conventional linear economic model of "take-make-use-dispose" to a circular economy approach. The circular economy aims to improve resource efficiency, minimize waste generation, and promote recycling and reuse (Geissdoerfer et al. 2017). It has gained significant attention as a potential solution for global sustainability, particularly in the mobile phone sector, where it can reduce electronic waste, enhance resource efficiency, and foster sustainable production and consumption patterns (Althaf et al. 2019). Achieving this requires a multifaceted strategy involving sustainable business models, product design, and material recovery and recycling (Awasthi et al. 2019). This research paper focuses on the application of the circular economy concept to effectively manage e-waste in the mobile phone industry. It explores current manufacturing and usage practices of mobile phones, the challenges associated with e-waste management, and the potential benefits of adopting a circular economy approach. The study also examines techniques and tools for material recovery and recycling, with a specific focus on recyclable materials like plastic and gold due to their economic and environmental significance (Prokic et al. 2022). Furthermore, the paper aligns with the SDG's, particularly Responsible Consumption and Production and Sustainable Cities and Communities.

By analyzing production costs and establishing a circular economy, this research aims to provide manufacturers, industry experts, and stakeholders with a framework for promoting sustainable and environmentally friendly practices in the electronics industry (Valls-Val et al., 2023). Embracing a circular economy strategy will lead us towards a more sustainable and resource-efficient future, mitigating the adverse environmental impacts of e-waste and creating a healthier and safer environment for future generations. E-waste management presents a significant challenge in our efforts to achieve sustainability in 2021, the global e-waste processed amounted to 57.4 million metric tonnes (Mt), with an average annual increase of around 2 Mt. It is projected that by 2023, there will be approximately 347 Mt of unrecycled e-waste on Earth. Despite the growing production, only 17% of e-waste is collected and properly recycled worldwide. Asia is the largest generator of e-waste (24.9 Mt), followed by the Americas (13.1 Mt), while Europe leads in e-waste collection and recycling (42.5%), with Asia as the second-largest contributor (11.7%). The concept of the circular economy is ideally a goal to establish a system with closed-loop where waste materials are allowed to recycle and contribute towards manufacture of new items, thereby reducing waste generation and the consumption of raw materials. The circular economy also advocates for the use of alternative energy sources and the reduction of carbon emissions. Utilizing renewable energy to power e-waste recycling operations can minimize the carbon footprint of the recycling sector.

Mobile phone recycling plays a crucial role for several reasons. Firstly, it helps protect the environment by preventing the incineration or disposal of mobile phones, which releases hazardous elements like lead, cadmium, arsenic, mercury, and bromine-based flame retardants into the environment. Proper recycling and reuse of these materials can reduce toxic waste without endangering the ecosystem. Secondly, mobile phone recycling reduces the need for mining. Rare minerals used in mobile phones, such as copper, silver, gold, and palladium, can be recovered through recycling (Wu et al., 2008). Recycling one mobile phone can save enough energy to charge a laptop for 44 hours. If 130 million mobile phones were recycled annually, they could power approximately 24,000 homes for a year, highlighting the importance of mobile phone recycling for energy conservation and reducing the carbon footprint (Gu et al., 2019).

Mobile phones consist of various components, including the display, battery, and system on a chip, sensors, speakers, cameras, modems, storage, memory, and an operating system. The display is essential for the device's functioning. The battery serves as the power source for the device. The system on a chip houses crucial components like the CPU, GPU, LTE modem, and video processors. Storage and RAM are necessary for the device to operate, and a modem enables the transmission and reception of texts and calls. Mobile phones also feature front-facing and back-facing cameras, sensors such as a gyroscope, accelerometer, digital compass, ambient light, and proximity sensors, as well as speakers for voice generation and audio quality. The specific components needed can vary based on the type of mobile phone, and the device may require an operating system to carry out various functions (Awasthi et al., 2019). The second phase of waste reduction involves trade-in programs, where numerous companies eagerly purchase used mobile devices, even if they are faulty. Through this process, phones are given a second chance as they are repaired and resold. By encouraging trade-ins, the lifespan of mobile phones can be further extended, reducing the need for new device production.

Recycling represents the final phase of the waste management process. Mobile phones are composed of various recyclable materials, including 32% non-ferrous metal, 40% plastic, 3% iron-based metal, 20% glass and ceramics,

© IEOM Society International

and 5% other materials (Deng et al., 2017). During recycling, the glass touch screens are shattered and melted to create new glass products. Mobile phone components, including their aluminium casings, are highly recyclable. Valuable metals such as gold, copper, silver, palladium, and platinum are extracted from the circuit boards of mobile phones, treated, and reused. Additionally, metals like steel and a mixed metal composed of cobalt, nickel, graphene, and lithium are recovered during lithium battery production and can be utilized to manufacture fresh batteries. Recycled plastic from mobile phone cases and attachments can be processed into granules, reducing energy consumption compared to producing new plastic.

Various extraction methods are commonly used for recycling mobile phone components, with the goal of recovering valuable materials while minimizing waste and environmental harm. These methods include, Manual Disassembly: Skilled workers use specialized tools to carefully separate different components of the mobile phone, such as the display, battery, circuit boards, and connectors. This enables the retrieval of valuable components that can be repurposed or recycled. Mechanical Shredding: Mobile phones are shredded into small pieces using mechanical shredders. The resulting shredded material is then sorted and further processed to extract valuable components and materials. Hydrometallurgical Processes: Chemical solutions - acid leaching, for example, is commonly employed to extract precious metals like gold, silver, and palladium from circuit boards and connectors. It is crucial to take into account that the selection of extraction methods relies on the specific components and materials being targeted for recovery, alongside the scale and efficiency prerequisites of recycling operations. Recycling facilities may employ a combination of these methods to maximize resource recovery and minimize the environmental impact.

Furthermore, addressing the issue of mobile phone durability has become increasingly important as consumers demand more reliable and repairable devices. The products need to design by Manufacturers that are more dependable and easier to repair, thereby reducing the adverse effects of e-waste and prolonging the lifespan of mobile phones. This research contributes to advancing knowledge on creating more durable mobile devices while considering the technological aspects of mobile phones (Cordella et al., 2021).

It is evident from the literature examined and the data acquired that further high-quality study in various areas of the circular economy and e-waste management is still required. The annual production of electronic waste is frequently the emphasis of current research papers, articles, and publications, rather than the wastes produced by individual items. It's unusual to find analysis of the procedures involved in material recycling and reusability. Rarely are the costs of a mobile phone's constituent parts analysed, and nothing is known about how much material can be recovered from waste mobile phones.

The research will delve into various aspects of sustainable practices, with a particular focus on the design and manufacturing of mobile phones. This includes emphasizing durability, repairability, and upgradability, as well as adopting eco-friendly materials and energy consumption reduction during production. Additionally, responsible sourcing of virgin materials, fair labour practices, and considering the social implications of mobile phone production will be explored. Material recycling will also play a pivotal role in the research. The study will investigate the implementation of efficient collection systems for retrieving old devices and establishing robust recycling processes for extracting valuable materials. By recovering metals, plastics, and rare earth elements, the research aims to minimize the impact on environment connected with new material mining and manufacturing.

Also, extensive environmental impact assessments will be conducted throughout the life cycle of mobile phones. This includes evaluating the environmental consequences of raw material extraction, manufacturing processes, product use, and end-of-life treatment. The research will provide policymakers, manufacturers, and consumers with valuable insights to make informed decisions that minimize negative environmental impacts and enhance sustainability.

The research gap in the current study, lies in the need for comprehensive analysis bridging the theoretical framework of circular economy principles with practical implementation strategies specifically tailored to mobile phone e-waste management. While existing literature discusses various aspects of e-waste management and circular economy principles in separate contexts, there remains a notable lack of integrated research focusing on the intricate dynamics of mobile phone e-waste within a circular economy framework. Therefore, this research aims to fill this critical gap by providing a holistic understanding of the challenges, opportunities, and best practices associated with implementing a circular economy approach to mobile phone e-waste management.

© IEOM Society International

The work on advancing sustainable practices in the mobile phone industry represents a novel and groundbreaking approach towards achieving a circular economy. By embracing circular economy principles, this research aims to revolutionize the way mobile phones are designed, manufactured, used, and disposed of. The focus lies on promoting durability, repairability, and upgradability of devices, as well as adopting eco-friendly materials and reducing energy consumption during production. This comprehensive study also delves into efficient material recycling processes, aiming to extract valuable metals, plastics, and rare earth elements from discarded mobile phones. By minimizing waste generation and maximizing resource recovery, the research paves the way for a more sustainable and resource-efficient future in the mobile phone industry. Ultimately, the research strives towards a sustainable and resource-efficient future of the mobile phone industry. By promoting responsible consumption, reducing waste generation, and conserving natural resources, it aims to foster environmental protection and drive positive change in the sector.

3. Methodology

The research methodology employed in this study is depicted in Figure 1. The main focus of this study is to analyse the information regarding components of a mobile phone, specifically focusing on plastic and gold due to their significant economic and environmental implications (Geyer & Doctori Blass, 2010). In order to minimize e-waste and effectively implement a circular economy, a meticulous cost analysis was conducted. The researchers adopted a specific research methodology to gather detailed information about the various components of a mobile phone. The aim of the study was to make a meaningful contribution towards the mitigation of electronic waste while advocating for the adoption of a circular economy model. This model emphasizes the reuse and recycling of resources as a means to significantly reduce the environmental footprint. To achieve this, a thorough cost analysis was done. By evaluating the costs associated with the production, use, and disposal of mobile phones, they aimed to identify potential areas for improvement and cost optimization. It was a crucial component of the research methodology as it provided insights into the economic feasibility and viability of implementing a circular economy in the mobile phone industry. By identifying the financial implications of various stages in the product lifecycle, the researchers were able to propose strategies and recommendations for reducing waste generation and maximizing resource efficiency. Overall, this research methodology aimed to provide a comprehensive understanding of the materials used in mobile phone production and explore ways to minimize waste generation and promote a sustainable circular economy.

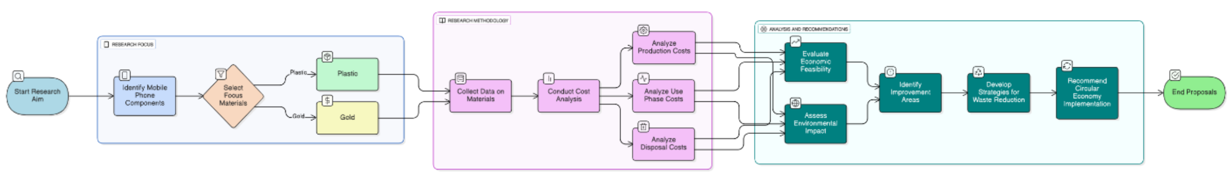

Figure 1. Methodology of the current work

3.1. Case Study

This study aimed to explore the feasibility of recycling used mobile phones as a means to mitigate the environmental impact of e-waste. However, accurately estimating the costs associated with mobile phone recycling poses a challenge due to varying charges imposed by different manufacturers for different materials and components. The cost analysis conducted in this research specifically focuses on the Indian market, recognizing that the practicality and viability of mobile phone recycling programs can be strongly influenced by the unique pricing systems and cost dynamics of specific locations. To ensure the accuracy and comprehensiveness of the analysis, it is essential to consider the local market dynamics when evaluating the costs and benefits of recycling used mobile phones (Garg & Adhana, 2019). The study examined the materials, components, recyclability, reusability, and pricing aspects of the iPhone 8+ as a reference model. While certain components, like the battery, may not be recyclable, the majority of other parts and materials have the potential for recycling and are generally reusable. The research encompassed an in-depth cost analysis and an evaluation of the environmental impact associated with various recycling methods. The recycling potential of materials such as plastic and gold was emphasised due to their commercial and ecological importance.

3.1.1. Materials Recovered - Gold

The process of recycling gold from mobile phones involves several stages used in recycling of mobile phones is presented in Figure 2 and also outlined below.

© IEOM Society International

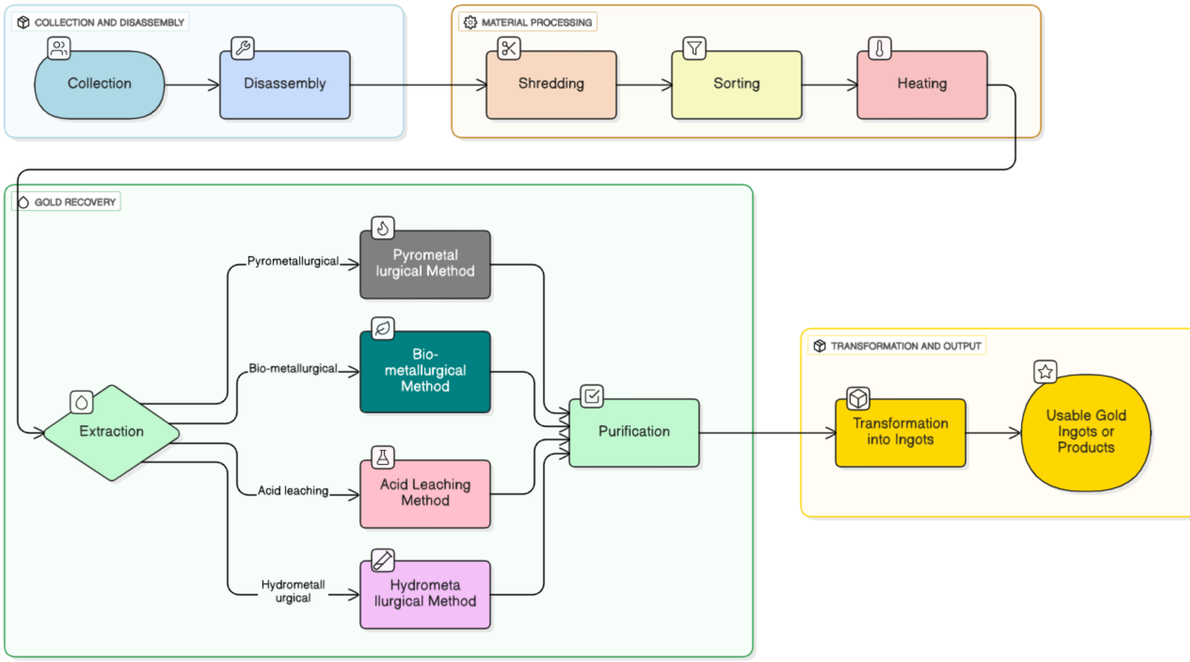

Figure 2. Recycling Process of Mobile Phones

In the acid leaching method, which is commonly used, the PCB (Printed Circuit Board) pieces are treated with a mixture of nitric acid and hydrochloric acid, known as aqua regia. This acidic solution dissolves the gold-containing components, leaving behind non-gold components. The resulting solution is filtered to remove any remaining solids, and a reducing agent, such as sodium metabisulfite, is introduced to precipitate the gold out of the solution. The precipitated gold is then dried, cleaned, and filtered to remove impurities and residual chemicals (Wang et al., 2021) and (Huang, Chou, & Lo, 2022). Choice of extraction method and the optimization of the recycling process may have significant environmental and cost implications. While bio-metallurgical techniques are environmentally beneficial, acid leaching is a less expensive option that can be made more sustainable by reducing chemical usage and using renewable energy power sources.

Quantity: Gold is commonly employed in various components of mobile phones, including connectors and circuit boards. The amount of gold present in a phone can vary depending on the model. On average, a mobile phone may contain around 0.034g of gold. This means that a ton of mobile phones could potentially hold approximately 227g of gold. When it comes to recycling, around 150g of gold can be extracted from one ton of recycled mobile phones.
Cost of Recycling Gold: The expense associated with recycling a ton of gold from mobile phones can vary due to several factors. These factors include the prevailing market price of gold, the quantity of gold present in the phones, the recycling method utilized, and the availability of materials and equipment. However, it is generally estimated that the cost of recycling one ton of mobile phones to extract gold falls within the range of ₹5,586.54 to ₹28,014.85. This cost encompasses the expenses for supplies, labour, and chemicals involved in the recycling procedure, as well as the costs associated with collecting, shipping, and processing the outdated devices.

3.1.2. Materials Recovered – Plastic

For mobile phone casings, thermoset plastics like phenol formaldehyde, polycarbonate, fluoropolymer, and polypropylene are commonly used due to their durability and heat resistance, which withstand the constant wear and heat generated during phone usage. Among these, polycarbonate (PC) is the most frequently used material in mobile phones. PC has great resistance to weak acids, alkalis, and neutral oil, and it is considered safe for human use.
In this particular study, the mechanical recycling method, which involves transforming plastic waste into raw materials or finished products without significant alteration of the material's chemical composition, was employed due to its

perceived advantages in terms of cost-effectiveness, and resource conservation. Thermoplastics, in particular, can be mechanically recycled with minimal to no loss of quality. Extracting plastic from mobile phones and other electronic devices involves several steps. Once the phones are disassembled post-collection from various sources, the plastic components are separated from other materials such as metals, circuit boards, and batteries. To facilitate the removal of contaminants like batteries or circuit boards that may still be attached to the plastic after disassembly, the plastic components are shredded or ground into smaller fragments. These fragments are then sorted by plastic type using techniques like optical sorting, where sensors identify and sort the different types of plastic accordingly. The plastic fragments are further processed, cleaned, and rinsed to eliminate any impurities. The cleaned plastic fragments are melted using extrusion machinery and transformed into pellets. These pellets serve as the primary ingredients for creating new plastic products. The recycled plastic pellets undergo quality control testing to ensure compliance with all necessary requirements (Cherrington & Makenji, 2019).

Challenges: Despite the benefits, there are challenges to overcome in the recycling process. Mobile phones contain a variety of plastics with different properties, making separation and sorting complex. Contamination from other materials, such as metals or electronic components, can also affect the quality of the recycled plastic. Additionally, ensuring a consistent supply of used mobile phones for recycling can be a logistical challenge. Efforts are underway to improve recycling technologies, enhance collection systems, and raise awareness about the importance of recycling mobile phone plastics. By implementing effective recycling practices, we can reduce plastic waste, conserve resources, and move towards a more sustainable future.

Quantity: A mobile phone typically weighs around 25g of plastic depending on each model. Therefore, it is estimated that 169kg of plastic make up one ton of mobile phones, from which about 110kg of plastic may be recovered.
Cost of Recycling Plastics: Several variables, including the specific recycling procedure employed, the number and quality of the phones being recycled, and the accessibility of resources and equipment, might affect the precise cost of recycling plastic from one ton of mobile phones. Typically, it costs between ₹6983.18 and ₹27768.39 to recycle one ton of mobile phones in order to extract the plastic. The calculation of operating cost of recycling of mobile phones is given in Eq (1).

$OPEX = Fixed\ Operating\ Costs + Variable\ Operating\ Costs$ ….. Eq.(1)

$C\mathrm{FOC} = C\mathrm{FL} + C\mathrm{D} + C\mathrm{MC}$ ….. Eq.(2)

$C\mathrm{VOC} = C\mathrm{VL} + C\mathrm{E} + C\mathrm{W} + C\mathrm{C}$….. Eq.(3)

CFL refers to cost of fixed labour, CD is the depreciation on machinery and equipment, CMC is the maintenance cost, and CVL is cost of variable labour, CE is electricity cost, CW is water consumption cost, CC is cost of consumable required for recycling.

From this, $Total\ Cost = C\mathrm{RL} + \sum OPEX$. This total cost is compared with Cmarket, the market value of all the materials obtained through recycling, to determine which is most cost-efficient, i.e., if $C_{\mathrm{market}} > Total\ Cost$, then recycling is profitable. However, if $C_{\mathrm{market}} < Total\ Cost$, then recycling is not profitable. Note: CAPEX is not included. CAPEX represents one-time costs that contribute to the assets of the recycling plant. By considering these costs, a more thorough perspective on the financial implications of setting up a recycling plant can be obtained.

3.2. Findings

The research data was analysed and calculated, and it was discovered that about 4406 phones could be made by recovering enough gold and plastic from recycling 1 ton (6667) of used mobile phones. As a result, it can be deduced that employing recycled gold and plastic might replace approximately 66% of the freshly mined gold and plastic used in new mobile phones. Note: Recycling cost of gold and plastic of 1 mobile phone is negligible

- Total cost of recycled and reused components = 8,649.36 ₹
- Production cost of a new mobile phone = 24,271.87 ₹
- Therefore, New production cost = 15,622.51 ₹

Hence, the cost of manufacturing a new mobile phone can be reduced by approximately 36%. For example, consider a large-scale manufacture of 4406 mobile phones.

- Manufacturing cost without recycling or reusing = 10,69,41,902.89 ₹
- Production cost after reusing and recycling = 6,88,32,827.36 ₹
- Total cost of recycling gold and plastic = 34,176.48 ₹
- Therefore, Total manufacturing cost after reusing and recycling = 6,88,67,003.84 ₹

Hence, approximately 3, 80, 74,899 ₹ of the manufacturing cost could be saved by reusing and recycling.

3.2.1. Sample Calculations

By recycling 1-ton mobile phones, approximately 150g of gold and 110kg of plastic could be recovered, and to make 1 mobile phone, .034g of gold and 25g of plastic are needed. Hence, with the quantity of materials recovered, approximately 4406 mobile phones could be made. Hence, it can be said that approximately 66% of the freshly mined gold and plastic used in new mobile phones could be replaced with recycled gold and plastic.

- As per the earlier findings,
  Average Cost of recycling gold from 1-ton mobile phones = 16,801 ₹
  Average Cost of recycling plastic from 1-ton mobile phones = 17,376 ₹
  Cost of gold required to manufacture 1 mobile phone = 5593 * .034 = 190.162 ₹
  Cost of plastic required to manufacture 1 mobile phone = 100/1000 * 25 = 2.5 ₹
- Cost of other reusable components,
  Display = 4316.65 ₹. Speaker & Microphone = 927.46 ₹. Camera = 2672.21 ₹. Sensors = 546.78 ₹

- So, total cost of recycled and reused components = 8,656.4 ₹
- Production cost of a new mobile phone = 24,271.87 ₹
- Therefore, New production cost = 24,271.87 ₹ - 8,656.4 ₹ = 15,615.47 ₹ (Note: Recycling cost of gold and plastic of 1 mobile phone is negligible)
- Hence, the cost of manufacturing a new mobile phone can be reduced by approximately 36%.
- Quantity of gold and plastic recovered are enough for 4406 mobile phones. Hence, for 4406 mobile phones,
  Production cost after reusing and recycling = 15,622.51 ₹ * 4406 = 6,88,32,779 ₹
- By adding recycling costs,
  Total Production cost after reusing and recycling = 34,176.48 ₹ + 6,88,32,779 ₹ = 6,88,66,956 ₹
  Manufacturing cost without recycling or reusing = 24,271.87 ₹ * 4406 = 10,69,41,859 ₹
- Hence, approximately 3, 80, 74,899 ₹ of the manufacturing cost could be saved by reusing and recycling.

3.3. Circular Economy Approach

The implementation of a circular economy strategy involves the integration of three distinct cycles to address waste generation and reduce the environmental impact caused by unrecycled mobile phones, while also minimizing the cost of manufacturing new devices. The concept of a circular economy revolves around the objective of minimizing waste and optimizing resource efficiency by prolonging the utilization of materials. When applied to mobile phones, this strategy entails the establishment of a closed-loop system, wherein materials from old devices are recycled and repurposed in the production of new ones. By doing so, the reliance on extracting fresh resources is diminished, resulting in a more sustainable approach to mobile phone manufacturing.

Cycle 1: The first cycle begins with the supply of raw materials necessary for mobile phone production. Once manufactured, the mobile phone is delivered to the customer (Figure 3). After its useful life, the mobile phone is collected and subjected to a dismantling process where valuable components such as gold and plastic are separated and recycled. These recycled materials are then utilized as raw materials for manufacturing new mobile phones, thereby initiating a continuous cycle.

© IEOM Society International

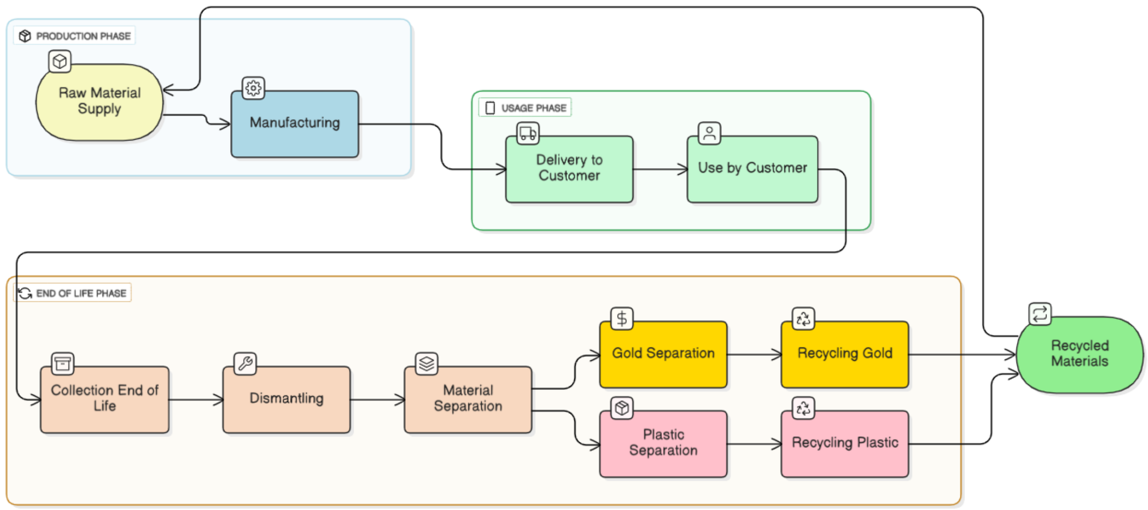

Figure 3. First cycle in the circular economy model

Cycle 2: When the mobile phone reaches its end-of-life stage, it can either be traded or have its lifespan extended. When a mobile phone reaches the end of its life or becomes obsolete, it needs to be collected for recycling. Collection methods such as drop-off points, recycling programs, or reverse logistics systems where customers return their old devices to manufacturers or designated recycling centres can be used. If it is traded, a new customer is brought in to ensure that the mobile phone is reused. On the other hand, if the lifespan is to be extended, the mobile phone is serviced by identifying and repairing the defective individual components. Once the mobile phone is repaired, it is then sold to a new customer, ensuring its reuse. And this cycle continues.

Cycle 3: After the production process, the mobile phone reaches the customer, and when it reaches the end of its useful life, it is collected and disassembled. Once collected, the mobile phones are subjected to a meticulous dismantling procedure. Competent technicians disassemble the devices (for metal extraction), meticulously segregating distinct components like circuit boards, batteries, screens, and casings. Subsequently, the separated materials, such as plastics and metals, are directed towards recycling and material recovery. Plastics undergo a series of treatments like shredding, and purification to be converted into plastic pellets, while metals are commonly smelted and purified for reuse across industries. After dismantling, the recyclable and reusable materials are separated, and the reusable components are again used in the manufacture of a new mobile phone and the cycle repeats

Manufacturing New Phones: The recycled materials, including plastics and metals, serve as raw materials for manufacturing new mobile phones. These materials go through quality control checks to ensure they meet the required standards. The recycled plastics can be used for casings, while the recovered metals can be used for connectors and circuitry. By incorporating recycled materials into the manufacturing process, the circular economy strategy creates a continuous cycle. The goal is to minimize the extraction of new resources, reduce waste generation, and extend the lifespan of materials by reusing them in new products. The implementation of a circular economy strategy for mobile phones helps conserve natural resources, reduce energy consumption, and decrease the environmental impact associated with the production and disposal of electronic devices.

Circular Economy Model: The raw materials needed to build the mobile phone are given to the manufacturer, who then delivers the finished product to the consumer. The first cycle then starts to move. When the mobile phone reaches the end of its useful life, the second cycle begins, guaranteeing the reuse of the device. Following disassembly, the recyclable and reusable components are separated, and the individual reusable parts are then employed again throughout the manufacturing process. After the third cycle is finished, recycling takes place, and waste materials and some elements that can't be recycled are classified as residual waste. The recycled materials are used as fresh raw materials to make a new mobile phone, and the cycle is repeated (Figure 4).

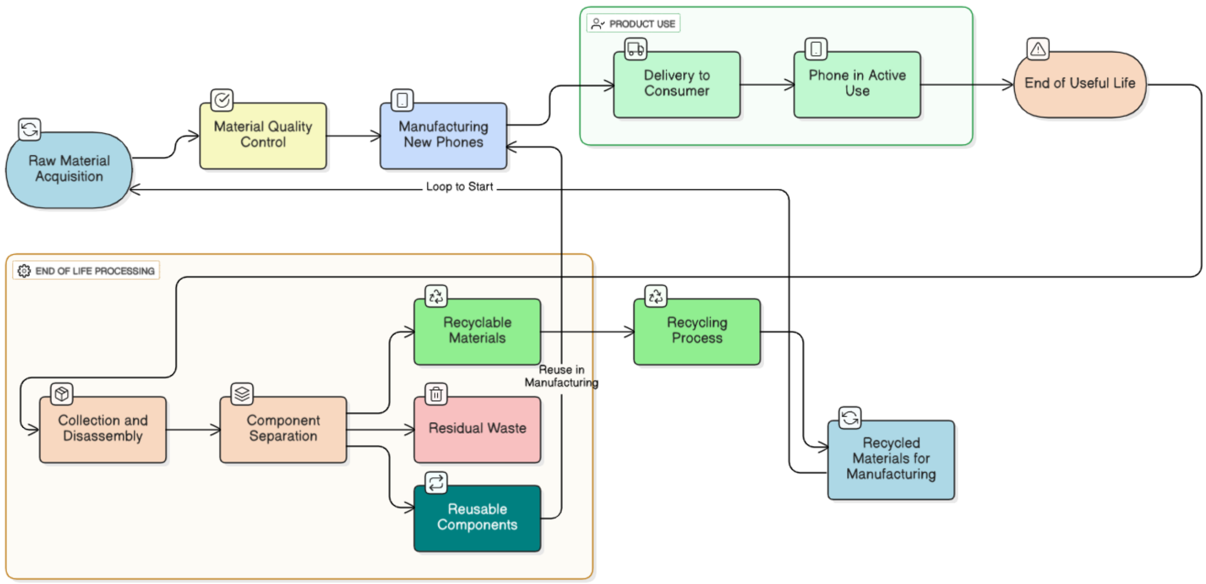

Figure 4. Final Circular Economy Model

4. Results and Discussion

4.1. Recycling

Gold: Approximately 150 grams of gold can be extracted from one ton of recycled mobile phones. The cost of recycling one ton of mobile phones to extract gold ranges from ₹5,586.54 to ₹28,014.85. The time required to recycle gold from mobile phones varies from four to eight weeks.

Plastic: About 110 kilograms of plastic can be recovered from one ton of recycled mobile phones. The cost of recycling one ton of mobile phones to extract plastic ranges from ₹6,983.18 to ₹27,768.39. The recycling process for plastic takes several weeks, typically 20 to 40 days.

Environmental Impact: Recycling plastic from mobile phones reduces the demand for virgin plastic production and minimizes plastic waste sent to landfills or incinerators. Challenges include the complex separation and sorting of plastics, contamination from other materials, and logistical issues in ensuring a consistent supply of used mobiles.

4.2. Cost Analysis

The total cost of recycled and reused components is ₹8,649.36, while the production cost of a new mobile phone is ₹24,271.87, resulting in a new production cost of ₹15,622.51. By reusing and recycling components, the cost of manufacturing a new mobile phone can be reduced by approximately 36%. Sample Calculations: With materials recovered from recycling one ton of mobile phones, approximately 4406 mobile phones could be made. Reusing and recycling components could save approximately ₹3,80,74,899 of the manufacturing cost for a large-scale manufacture of 4406 mobile phones. Overall, the study demonstrates significant potential for cost savings and environmental benefits through the recycling and reuse of materials from used mobile phones, emphasizing the importance of sustainable practices in the electronics industry.

5. Conclusions

A key finding of the study is the potential cost savings achieved through recycling and reusing mobile phone materials and parts. By adopting these practices, manufacturers can significantly reduce the manufacturing cost of new mobile phones. The research also highlighted the environmental benefits of implementing a circular economy approach. Improper disposal and management of mobile phone waste have negative ecological consequences. Through the adoption of recycling practices and the implementation of the circular economy model, it is possible to significantly

© IEOM Society International

mitigate the detrimental effects of mobile phone waste on the environment. This includes reducing waste generation, minimizing pollution, and conserving valuable resources.
Based on the study, it concludes that, One ton of recycled mobile phones can yield approximately 150g of extracted gold, with recycling costs ranging from ₹5,586.54 to ₹28,014.85 and a recycling time of 4 to 8 weeks for gold extraction. From one ton of recycled mobile phones, approximately 110kgs of plastic can be recovered, with recycling costs varying between ₹6,983.18 and ₹27,768.39. The recycling process for plastic typically takes around 20 to 40 days. By reusing and recycling components, the production cost of a new mobile phone can be reduced by approximately 36%, resulting in a new production cost of ₹15,622.51, compared to the original cost of ₹24,271.87. The total cost of recycled and reused components amounts to ₹8,649.36. Recycling one ton of mobile phones yields enough materials to manufacture approximately 4406 new mobile phones, resulting in a potential cost saving of approximately ₹3,80,74,899 for a large-scale production of the same quantity.

In addition, the research highlighted the crucial connection between circular economy approach and SDGs, particularly those pertaining to responsible consumption and production, as well as the development of sustainable cities and communities. By adopting sustainable and responsible methods of production and consumption, manufacturers can contribute to achieving these goals.

References

Althaf, S., Babbitt, C. W., and Chen, R., Forecasting electronic waste flows for effective circular economy planning, Resources, Conservation and Recycling, vol. 151, Article 104362, 2019.

Awasthi, A. K., Li, J., Koh, L., and Ogunseitan, O. A., Circular economy and electronic waste, Nature Electronics, vol. 2, no. 3, pp. 86–89, 2019.

Barapatre, S., and Rastogi, M., E-waste management: A transition towards a circular economy, in Handbook of Solid Waste Management: Sustainability through Circular Economy, Springer Nature, Singapore, pp. 1499–1521, 2022.

Cherrington, R., and Makenji, K., Mechanical methods of recycling plastics from WEEE, in Waste Electrical and Electronic Equipment (WEEE) Handbook, Woodhead Publishing, pp. 283–310, 2019.

Cordella, M., Alfieri, F., Clemm, C., and Berwald, A., Durability of smartphones: A technical analysis of reliability and repairability aspects, Journal of Cleaner Production, vol. 286, Article 125388, 2021.

Deng, W. J., Giesy, J. P., So, C. S., and Zheng, H. L., End-of-life (EoL) mobile phone management in Hong Kong households, Journal of Environmental Management, vol. 200, pp. 22–28, 2017.

Fontana, D., Pietrantonio, M., Pucciarmati, S., Rao, C., and Forte, F., A comprehensive characterization of end-of-life mobile phones for secondary material resources identification, Waste Management, vol. 99, pp. 22–30, 2019.

Garg, N., and Adhana, D., E-waste management in India: A study of current scenario, International Journal of Management, Technology and Engineering, vol. 9, 2019.

Geissdoerfer, M., Savaget, P., Bocken, N. M., and Hultink, E. J., The circular economy – A new sustainability paradigm?, Journal of Cleaner Production, vol. 143, pp. 757–768, 2017.

Geyer, R., and Doctori Blass, V., The economics of cell phone reuse and recycling, The International Journal of Advanced Manufacturing Technology, vol. 47, pp. 515–525, 2010.

Gu, F., Summers, P. A., and Hall, P., Recovering materials from waste mobile phones: Recent technological developments, Journal of Cleaner Production, vol. 237, Article 117657, 2019.

Huang, Y. F., Chou, S. L., and Lo, S. L., Gold recovery from waste printed circuit boards of mobile phones using microwave pyrolysis and hydrometallurgical methods, Sustainable Environment Research, vol. 32, no. 1, Article 6, 2022.

Prokic, D., Stepanov, J., Curcic, L., Stojic, N., and Pucarevic, M., The role of circular economy in food waste management in fulfilling the United Nations' sustainable development goals, Acta Universitatis Sapientiae, Alimentaria, vol. 15, no. 1, pp. 51–66, 2022.

Sarath, P., Bonda, S., Mohanty, S., and Nayak, S. K., Mobile phone waste management and recycling: Views and trends, Waste Management, vol. 46, pp. 536–545, 2015.

Shahabuddin, M., Uddin, M. N., Chowdhury, J. I., Ahmed, S. F., Uddin, M. N., Mofijur, M., and Uddin, M. A., A review of the recent development, challenges, and opportunities of electronic waste (e-waste), International Journal of Environmental Science and Technology, vol. 20, no. 4, pp. 4513–4520, 2023.

Singh, N., Duan, H., Ogunseitan, O. A., Li, J., and Tang, Y., Toxicity trends in e-waste: A comparative analysis of metals in discarded mobile phones, Journal of Hazardous Materials, vol. 380, Article 120898, 2019.

© IEOM Society International

Valls-Val, K., Ibáñez-Forés, V., and Bovea, M. D., Tools for assessing qualitatively the level of circularity of organisations: Applicability to different sectors, Sustainable Production and Consumption, vol. 36, pp. 513–525, 2023.

Wang, R., Zhang, C., Zhao, Y., Zhou, Y., Ma, E., Bai, J., and Wang, J., Recycling gold from printed circuit boards gold-plated layer of waste mobile phones in "mild aqua regia" system, Journal of Cleaner Production, vol. 278, Article 123597, 2021.

Wu, B. Y., Chan, Y. C., Middendorf, A., Gu, X., and Zhong, H. W., Assessment of toxicity potential of metallic elements in discarded electronics: A case study of mobile phones in China, Journal of Environmental Sciences, vol. 20, no. 11, pp. 1403–1408, 2008.

Bibliographies

Sangeeth Kirushika C is currently a junior undergraduate student in B.Tech. Mechanical Engineering at Vellore Institute of Technology.

Dr. Rajyalakshmi G is a recognized leader in engineering education. With her extensive years of experience in research, she is now serving as Head of Department of Mechanical engineering at Vellore Institute of Technology, Vellore. She boasts numerous paper publications and citations, working primarily in the field of Operations Research and Optimization.