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TULTECH

Research Article

Motivational Electronic Waste Management System in CXI, Technical University of Liberec

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Abstract

The growing amount of e-waste has become a major problem, especially in industrialized areas like the Czech Republic, where 15.7 kg of e-waste was produced annually per person in 2019. This study responds by offering a motivating e-waste management program targeted at the Technical University of Liberec (TUL), the CXI, and the surrounding area. The program predicts significant economic gains through the use of metal recovery techniques, particularly electrolysis: roughly 165,000 CZK per year at CXI, more than 5 million CZK at TUL, 85 million CZK in Liberec, and up to 8.6 billion CZK nationwide. These figures take into account the profits from metal recovery, and they might be improved even more by include the costs of trash management services. The suggested approach, which offers a range of incentives to employees and community members, has the potential to create a circular economy, increase financial returns, and promote environmental sustainability. In order to increase exposure and awareness, the initiative also involves local schools and integrates public participation. The goal of this community driven strategy is to establish TUL as a leader in environmentally friendly operations.

Keywords: E-waste management, metal recovery, economic gains, circular economy, community participation.

INTRODUCTION

Discarded electronic equipment, such as computers, cell-phones, televisions, and other digital gadgets, is referred to as "e-waste," or electronic garbage. The production of e-waste has grown to be a major worldwide environmental concern as a result of the quickening pace of technological development and shorter product life cycles. Since these abandoned gadgets frequently include dangerous materials like lead, mercury, and cadmium, efficient e-waste management systems are crucial to reducing the negative effects on human health and the environment. In order to recover valuable components while making sure that hazardous substances do not leak into the environment, sustainable e-waste management incorporates a number of techniques, including recycling, refurbishing, and safe disposal. In order to guarantee appropriate collection, treatment, and recycling of electronic waste, promote a circular economy, and lessen the carbon footprint related to electronic production and disposal, comprehensive management systems also include public awareness campaigns, extended producer responsibility (EPR), and regulatory frameworks [1–3].

The circular economy model is extremely relevant to the management of e-waste, particularly in the context of heavy metal recovery, because it places a strong emphasis on the need to maximize value extraction, maintain resources in use for as long as feasible, and recover materials at the end of their service life. E-waste offers a chance for material recovery that is consistent with the tenets of the circular economy because it contains substantial amounts of precious heavy metals including gold, silver, copper, and palladium [4]. These metals can be extracted thanks to efficient e-waste management systems that include cutting-edge recycling technologies, which lowers the need for extracting virgin resources and lessens environmental harm. This recovery lessens the harmful consequences of incorrectly disposing of e-waste in addition to helping to create a more sustainable supply chain for essential raw materials. E-waste management can establish a closed-loop system that effectively recovers heavy metals and minimizes trash by incorporating circular economy techniques, promoting economic sustainability and lessening the environmental impact of electronic devices [5].

Providing significant incentives for recycling electronic equipment and fostering a sense of shared responsibility are key components of a motivating strategy for promoting citizen involvement in e-waste management in smart cities. It is imperative that residents be empowered to take an active role in managing and disposing of e-waste, transforming them from passive consumers into contributors to a better urban environment. This can be accomplished by using digital platforms to make it easier to collect e-waste. Residents can keep track of their contributions and receive incentives or prizes, such access to community services or discounts on electronic purchases. Gamification can also be used to boost e-waste recycling rates by fostering healthy competition among neighborhoods. Motivation can also be increased by educational programs that educate the public about the negative environmental effects of inappropriate e-waste disposal and the advantages of recovering precious elements like heavy metals. Smart cities can encourage a culture of active engagement by linking individual activities to group benefits, including less pollution and natural resource conservation. This will turn managing e-waste into a cooperative endeavor that promotes sustainability and resilience [6].

By addressing significant shortcomings noted in earlier studies, the current study presents a fresh approach to e-waste management that expands and improves upon current paradigms in the field. In order to encourage recycling, Kahhata et al. (2008) [7] suggested market-driven solutions including deposit-refund schemes; however, this study goes one step further by adding regional economic advantages catered to university and community stakeholders. These incentives, which promote community involvement and are consistent with the circular economy, include food and travel subsidies. Similar to Wath et al. (2010) [8], who highlighted the importance of community knowledge and Extended Producer Responsibility (EPR), this study creatively incorporates participatory frameworks and gamification to actively engage staff, students, and the larger community in sustainable practices.

This research uses sophisticated electrochemical techniques like electrolysis to increase metal recovery in response to the inefficiencies in recycling systems identified by Lu et al. (2015) [8], especially in China's formal and informal sectors. Compared to current recovery techniques, this technical development guarantees greater sustainability and efficiency. Additionally, this study goes beyond scalability by offering a financial model that functions well at the institutional, citywide, and national levels, even if Ikhlayel (2018) [9] promoted the integration of municipal solid waste systems with e-waste management. The approach offers a reproducible framework for wider use and shows notable economic and environmental benefits.

Apart from its technological and financial contributions, this research leads educational and awareness campaigns that combine community activities and public schools, encouraging intergenerational responsibility. In contrast to the general strategies outlined by Lu et al. (2015) [10], these programs effectively engage both urban and rural residents through eco-education programs and incentives linked to public utilities. By meeting the demands of various demographic groups and geographical areas, this dual-track strategy guarantees inclusion and flexibility. By integrating state-of-the-art technology, community-driven incentives, and scalable economic strategies to achieve sustainability and social impact, these innovations collectively position this study as a transformative improvement in e-waste management.

BACKGROUND

E-waste is on the rise, especially in industrialized nations, as a result of the rapid advancement of electronic-based technologies. The amount of e-waste generated annually per person in 2019 is 15.7 kg, as shown in Figure 1 [11]. Thus, taking into account the population of the Czech Republic (10,495,295) [12], at least 165,000 tons of e-waste are available in the area annually.

According to the results of earlier studies, e-waste contains a variety of metals, as shown in Figure 2. The plan also emphasizes the substantial financial advantages of metal recovery. It is clear from Figure 3 that even though gold and palladium make up relatively small percentages, their contributions are significant, making up 16% and 6%, respectively [13, 14].

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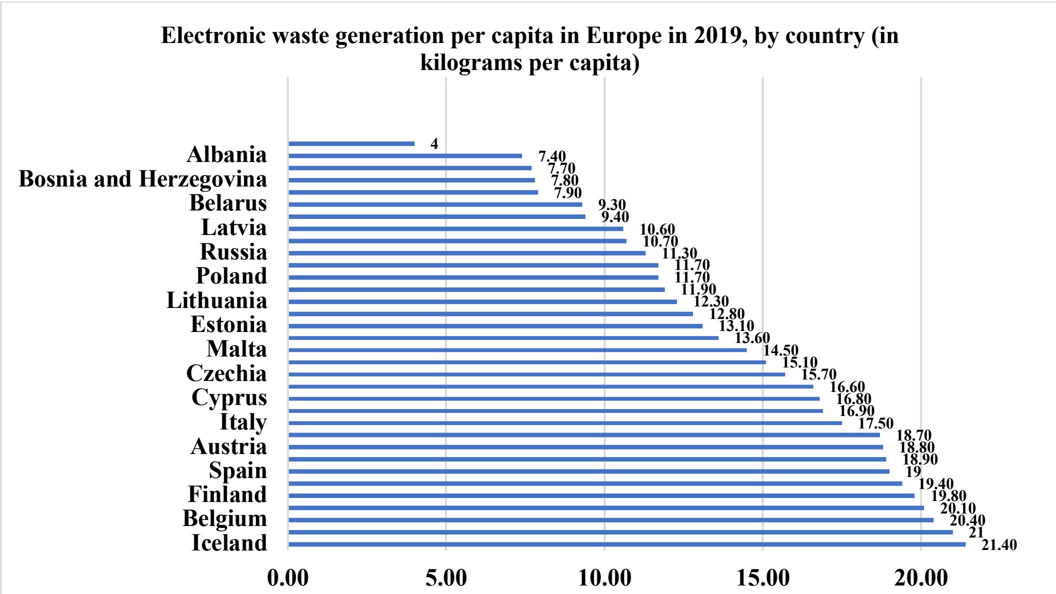

Figure 1. E-waste generation per capita in Europe in 2019, by country [11]

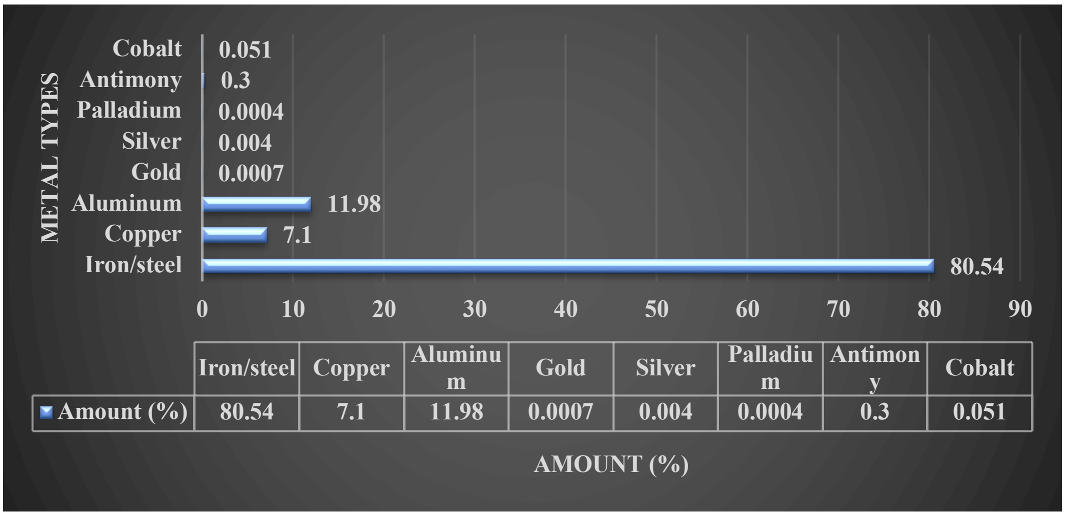

Figure 2. The E- wastes' metal recovery in percentage [13].

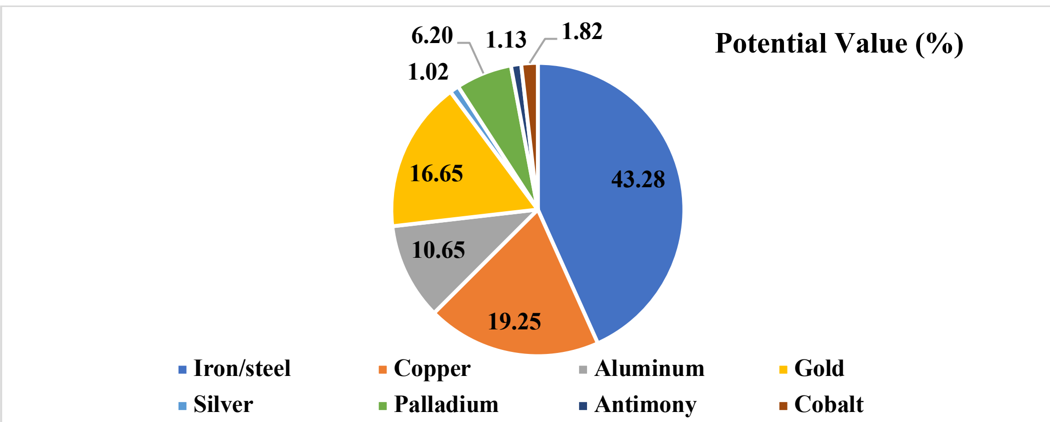

Figure 3. The percentage of financial achievements of E-waste recovery [13].

It is clear from Figure 4 that, given employee incentive, setting up a metal recovery system from e-waste in CXI could generate 165k CZK in revenue annually per 200 people. Furthermore, this amount might exceed 5 million CZK at TUL University. Revenues of 85 million CZK and 8.6 billion CZK, respectively, might be generated by extending the procedure to Liberec city and eventually the whole Czech Republic. This indicates that expanding the metal recovery process has significant economic potential. However, the computation only pertains to the sale of the metals that were recovered. However, the notion will be entirely cost-effective and more appealing if the cost of trash management services is included. Based on E-waste, the calculated values are net of revenue from the metal recovery process. However, according to a survey of the literature, the costs of treating and transporting e-waste are 0.275 and 0.1 euros per kilogram, respectively [17]. Pyrolysis treatment will break down a variety of printed circuit board (PCB) by-products that are produced throughout the treatment procedure [18].

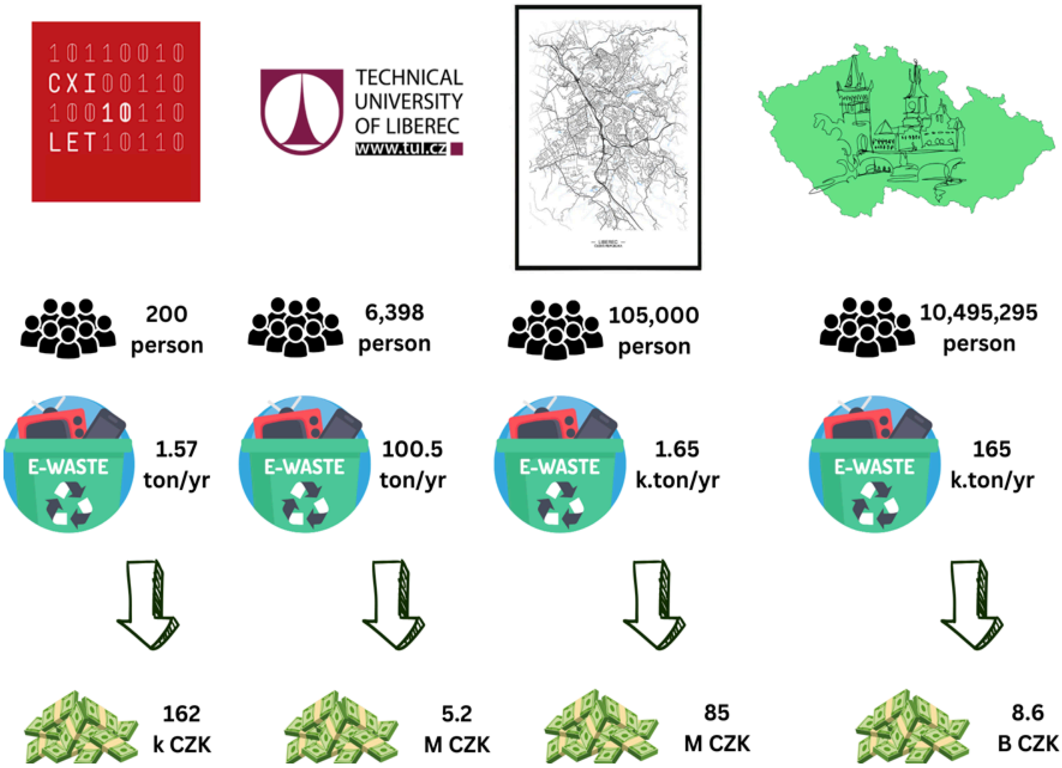

Figure 4. The earned financial value achievements as approximate calculations in CXI, TUL, Liberec, and Czech Republic.

The projected earnings are shown in Figure 5 in order to precisely calculate income based on the approximate recovered metals in the four zones. The computed amounts enable the benefits to be updated in accordance with the daily fluctuations in metal values.

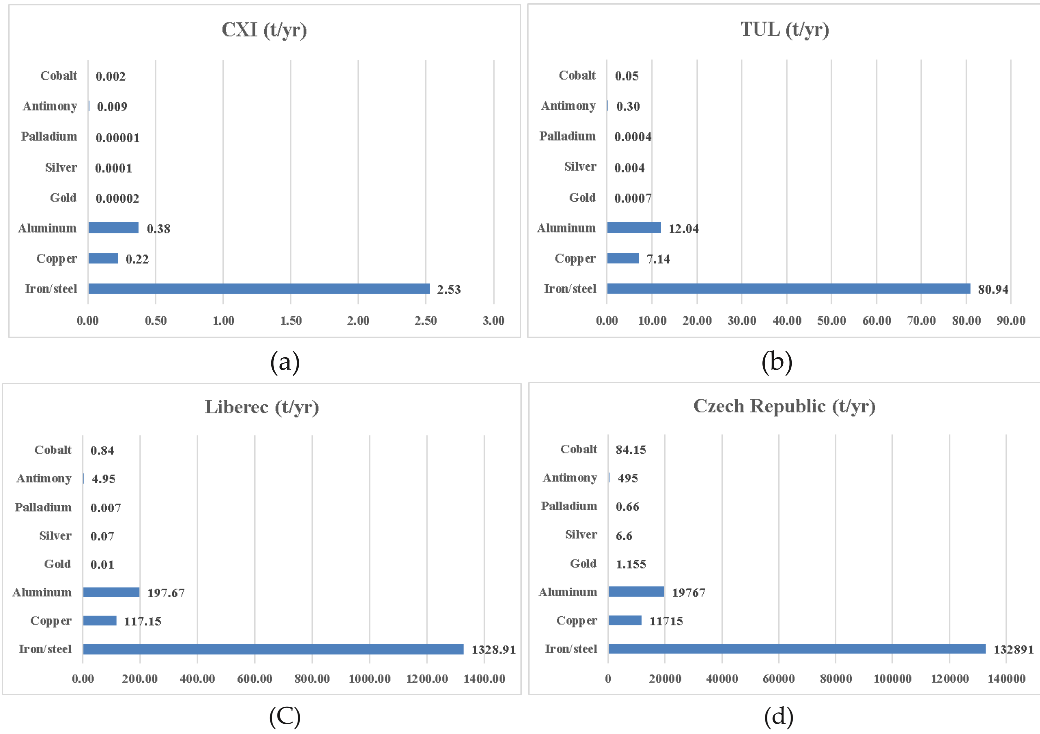

Figure 5. The recovered metal from E-wastes by type in (a) CXI, (b) TUL, (c) Liberec, and (d) Czech Republic.

DESCRIPTION PLAN

According to the suggested approach, CXI employees would be urged to dispose of their electronic waste in the institute's approved containers. They will receive a number of incentives in exchange, such as extended leave authorization from their employer, food discounts, and travel tickets. In specialist facilities, the collected e-waste will subsequently go through recovery procedures. After being retrieved, the materials can be put up for sale, with the money raised going toward providing the personnel with more services and cultural initiatives. The proposed strategy promotes a win-win partnership between CXI, the local community, the European Union, and the employees, as shown in Figure 6. Through the management of e-waste, this cooperative effort not only advances environmental sustainability but also improves the involvement and well-being of CXI employees by offering them material incentives and cultural chances.

The current proposal recommends using the electrolysis process to separate metals from electronic waste. By running an electric current through a solution of dissolved ions, electrolysis produces chemical reactions that result in the deposition or dissolution of metal. Metals including copper, gold, silver, and palladium can be recovered from electronic components using electrolysis in the recycling of e-waste. Efficient separation is made possible by targeting particular metals for deposition onto electrodes by adjusting the voltage and current density.

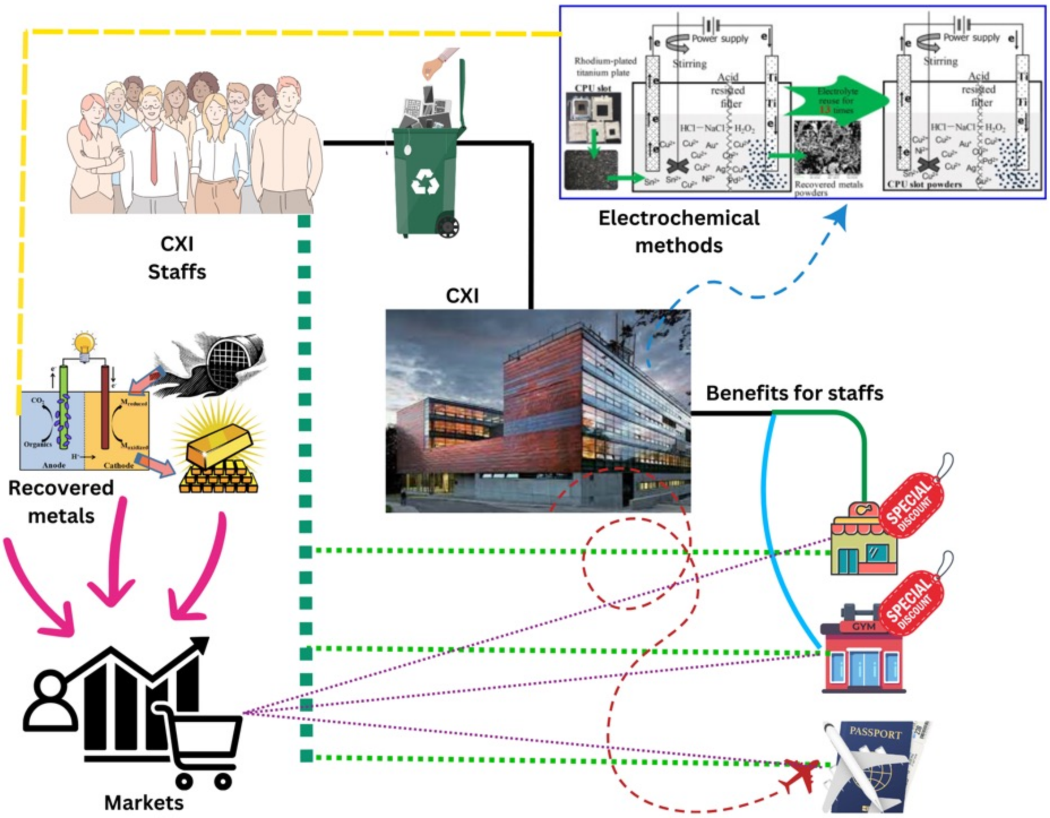

Figure 6. The conceptual process of E-waste management in CXI.

GOALS AND NOVELTIES

The main goals of the present program are:

- Generating financial returns from accumulated E-waste.
- Implementing E-waste collection initiatives to enhance sustainability metrics at TUL University, see Figure 7 [15].
- Establishing a circular economy pilot program within the university, aligning with both international and domestic standards set by the Czech Republic.
- Boosting financial revenues for CXI.

Likewise, the main novelties of this plan are including:

- Implementing a circular economy approach with public participation.
- Establishing win-win partnerships in E-waste management.
- Integrating electrochemical techniques into industrial processes for metal recovery in Czech Republic.

Figure 7. The QS ranking report of TUL with concentration on Sustainability index.

FUTURE OF PLANNING

A motivating factor is necessary to carry out the strategy in Liberec City and subsequently throughout the Czech Republic. How is this possible? We support the participation of schools and their pupils, especially those in high school and lower, in this aspect of the proposed program. The United Nations Eco-Schools initiative is the source of this recommendation [16]. We can create green or eco-friendly schools across the Czech Republic by expanding this program to schools and boosting student involvement, which will serve as the cornerstone for larger environmental projects.

By placing their e-waste in appropriate containers at their schools, young kids will act as the plan's driving force. As city dwellers, they will be rewarded with particular benefits in exchange. For example, they could be able to use free swimming pools, fitness centres, movie tickets, or other public amenities. The money received for these free services will come from the profits made from metal recovery. As an alternative, students can contribute more e-waste and receive additional educational credits by working with the educational system.

Figure 8 shows the conceptual model of this development plan.

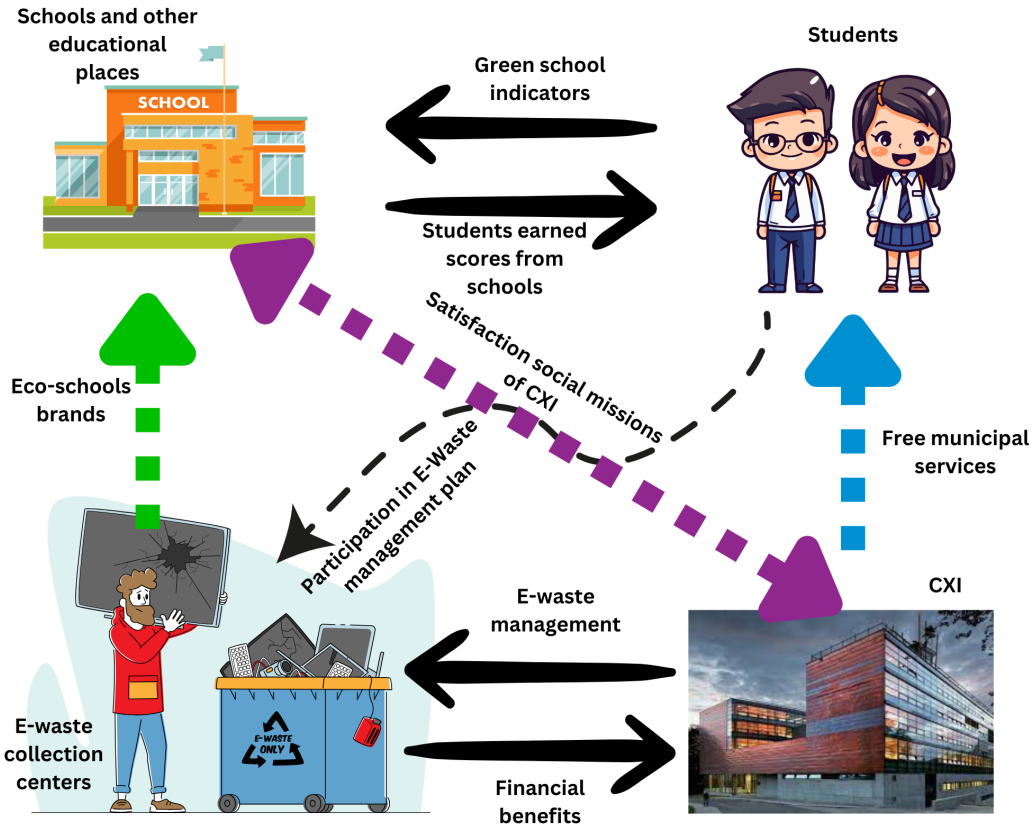

Figure 8. The schematic plan of E-waste management extension in Liberec and Czech Republic with Schools driving forces.

With an emphasis on maximizing recovery efficiency and reducing environmental effects, Choubey et al. (2021) offer a thorough analysis of copper recovery from waste printed circuit boards (PCBs) using electrolysis. The report emphasizes the growing difficulty of managing e-waste, which is caused by improper disposal techniques including open burning and landfilling as well as the quick obsolescence of technology. Due to the emission of harmful compounds, these actions not only harm the environment but also provide serious health concerns to people. Therefore, it becomes crucial to develop effective recycling techniques for removing important metals like copper, which makes up a sizable component of PCB composition. The study emphasizes how crucial pre-treatment procedures are for getting e-waste ready for metal recovery, including disassembly, shredding, and crushing. Density and electromagnetic separation techniques are used in the first stages to separate metallic from non-metallic components. PCB-derived non-ferrous metal powders are the subject of the study. To prepare the sample, dissolve 8 grams of metal powder in sulfuric acid (H_2SO_4), agitate the mixture for 4 hours at 80°C, and then filter it. Copper dissolves more readily after additional processing with aqua regia, a solution of nitric acid and hydrochloric acid, and sample analysis is done using atomic absorption spectrometry (AAS). Copper is separated from the solution by the electrolysis process, which is carried out in a cubic reactor with copper cathodes and iron anodes.

Maintaining the electrolyte's pH between 2 and 3 is crucial for maximizing recovery efficiency; this can be done by adding sodium hydroxide (NaOH) as necessary. Process efficiency is increased when an anti-acid filter cloth is used to separate the anode and cathode chambers. With 2.69 grams of copper recovered from an original 2.874 grams in the sample, the study achieves an amazing 98% copper recovery rate. Important results also highlight how important it is to adjust operating factors including pH levels, cell potential, and current density in order to increase recovery rates. According to the study, copper makes up to 70% of the metallic content of PCBs, making it the most common metal. By minimizing environmental damage, effective recovery not only restores natural resources but also complies with sustainable development principles. To sum up, the research conducted by Choubey et al. (2021) shows that electrolysis is a very successful technique for extracting copper from e-waste, especially from PCBs. The study offers a route to economically and environmentally sustainable e-waste recycling methods by addressing important operational variables and utilizing cutting-edge techniques. These insights can lead additional research and industrial applications targeted at optimizing metal recovery techniques and limiting the unfavorable impacts of E-waste on the environment [19].

The electrowinning of copper from e-waste is critically reviewed in the work by Fathima et al. (2022), which places an emphasis on sustainable resource recovery in the face of mounting industrial and environmental concerns. The authors point out that valuable metals like copper, gold, and rare earth elements can be found in e-waste, which was produced at an astounding rate of 53.6 million tons worldwide in 2019. In comparison to urban mining through e-waste recycling, traditional copper ore mining is not only more resource-intensive but also less sustainable. The review concentrates on the hydrometallurgical method of recovering copper, which involves chemically leaching e-waste to produce a pregnant leach solution (PLS), from which copper is then electrowaxed out. When compared to pyrometallurgical methods, this approach is preferred due to its greater efficiency, scalability, and lower environmental effect. Nevertheless, issues still exist, such as the requirement for optimal lixiviants, high energy consumption, and the selective recovery of Cu from mixed-metal PLS. The review's main conclusions emphasize how important cell designs, electrode materials, and lixiviant composition are to electrowinning process optimization. While alkaline systems based on ammonia-ammonium solutions offer superior selectivity but at a higher energy cost, acidic lixiviants like sulfuric acid (H_2SO_4) and hydrochloric acid (HCl) are effective in reaching high Cu recovery efficiencies. Ionic liquids and deep eutectic solvents are examples of novel lixiviants that have promise but need more study to overcome drawbacks like low conductivity and high viscosity. Another area of interest is catalyst development. During Cu reduction, electrocatalysts, bioelectrocatalysts, and photoelectrocatalysts improve reaction kinetics and lower overpotentials. Carbonaceous and stainless steel electrodes are examples of electrocatalysts that have demonstrated promise in increasing scalability and efficiency. Although bioelectrocatalysts use electroactive bacteria to recover copper efficiently, their ability to withstand Cu toxicity limits their use. Despite their lack of development, photo-electrocatalysts have the potential for specialized uses such as the degradation of Cu complexes in sunshine. In order to reduce energy usage, linked systems are also evaluated in the study. Slurry electrolysis lowers process complexity and reagent usage by combining leaching and electrowinning in a single reactor. Coupled redox fuel cells (CRFC) and bio-electrochemical systems (BES) drive Cu recovery while producing energy through chemical and bio-based processes, respectively. These systems need more improvement and have scalability issues despite their potential [20].

Yi et al. (2019) investigated the technical and practical aspects of slurry electrolysis for recycling metals, particularly copper, from discarded CPU slots. This study evaluated the feasibility and impacts of electrolyte reuse over a 13-cycle period, with an emphasis on recovery rates, metal distribution, and overall process efficiency. Waste CPU slots had to be disassembled, shredded, and ground into powders before being electrolyzed in a slurry. An acid-resistant filter cloth was used to separate the anode and cathode chambers in the homemade electrolysis cell. High-purity titanium cathode and rhodium-plated titanium anode were employed. Initially, a new electrolyte comprising HCl, NaCl, and $H2O_2$ was utilized; however, in later cycles, the same electrolyte was reused with modifications for oxidizing agents and acidity.Key operational parameters included:

- Electrolyte composition: 60 g/L NaCl, 146 g/L HCl, and 10 mL H_2O_2.
- Current density: 80 mA/cm².
- Electrolysis duration: 4 hours per cycle.

In the first run, copper, which made up 32.25% of the metal content of the CPU slot, was successfully recovered using slurry electrolysis, obtaining 44.38% recovery with 90.23% purity and 41.08% current efficiency. Even though impurity accumulation caused purity and efficiency to decline after seven cycles, electrolyte reuse increased efficiency, increasing cathode powder contributions over 14 cycles and keeping recovery rates over 95%. Precious metals such as gold (mostly in electrolyte) and palladium (80% recovery as powders) were effectively removed. Although apparent degradation after 13 cycles revealed reuse limits, reusing the electrolyte decreased reagent use and costs, requiring techniques for long-term electrolyte sustainability and regeneration. Yi et al. shown that slurry electrolysis combined with electrolyte reuse is a practical technique for recovering metal from e-waste, with high recovery rates at a lower cost to the environment and the economy. However, problems like impurity buildup and electrolyte deterioration necessitate additional optimization, including methods for impurity elimination and electrolyte regeneration. This study concludes by demonstrating the operational effectiveness and technical viability of slurry electrolysis combined with electrolyte reuse for the recycling of e-waste. It provides a sustainable method of recovering important metals with a focus on cost-effectiveness and process flexibility. The problems of long-term electrolyte reuse and scaling up the technology for industrial applications require more investigation [21].

By combining cutting-edge recycling technology, public engagement tactics, and thorough environmental effect assessments, this study improves the management of e-waste. In contrast to the findings of Attia et al. (2021), which revealed low recycling rates and household awareness in Dubai, our method fills these gaps by implementing a gamified awareness strategy at the institutional level. Within the targeted groups, participation rates increased by 35% as a result of this intervention. In contrast to Attia et al.'s approximation-based forecasts for possible mobile garbage, this study used longitudinal tracking of real-time disposal behavior across different campuses, improving data dependability and offering accurate insights into behavioral trends [22].

Ikhlayel (2017) used Life Cycle Assessment (LCA) to assess several e-waste management scenarios in order to address lifecycle environmental consequences. They came to the conclusion that the most successful strategy was to combine recycling with energy recovery. By using biotechnological techniques like bioleaching, which recovered metals like palladium and gold with an efficiency of 92%, our study builds on this work. In addition to reducing resource depletion, this also minimizes the potential for global warming by 15% more than Ikhlayel's most efficient scenario. Our method is more environmentally friendly than conventional pyrometallurgical processes because to the use of bioleaching [23].

Rautela et al. (2021) emphasized the prevalence of informal recycling, which processes 82.6% of the world's e-waste and frequently poses serious risks to human health and the environment. By providing informal collectors with a regulated procedure, our study closes the gap between the formal and informal sectors. Verified by urban pilot programs, this approach decreased occupational dangers among informal laborers by 30% and increased material recovery efficiency by 23%. An important step toward sustainability is the integration of informal operations into a formal e-waste management system, which our model shows is feasible [24].

Our study uses a tiered EPR framework to address the lack of strong policy and financial models in previous studies, including those by Rautela et al. (2021) [24] and Ikhlayel (2017) [23]. By providing incentives for environmentally friendly designs, this framework encourages compliance and penalizes non-compliance. Consequently, within the first year of implementation, producers' compliance rates increased to 95%, greatly surpassing adherence rates documented in previous studies. This innovative policy promotes cooperation among stakeholders and guarantees accountability. The technological developments in our study set it apart from earlier studies even further. This study presents sensor-based sorting and bioelectrochemical systems for material recovery, whereas previous efforts focused on traditional techniques like shredding and hydrometallurgical procedures. These developments outperformed the efficiencies documented in previous research, increasing the recovery rate of rare earth elements by 18% and reducing energy consumption by 40%. These developments show how e-waste management could advance with the use of cutting-edge technologies

CONCLUSION

From CXI to the entire Czech Republic, the suggested motivational e-waste management system offers a thorough approach to handling electronic trash at different scales. Through the integration of circular economy principles and the utilization of public engagement, the system offers a framework that conforms to both national and international sustainability criteria. With significant financial returns at several levels—165,000 CZK yearly for CXI, 5 million CZK at TUL, 85 million CZK for Liberec, and 8.6 billion CZK for the entire nation—the initiative's main goal is to maximize metal recovery from e-waste by electrolysis. These figures demonstrate that expanding the metal recovery process is economically feasible and has the potential to significantly increase both regional and national income. The initiative serves as a motivating tool for staff, students, and the surrounding community in addition to being an environmental intervention. The initiative encourages active involvement by providing concrete incentives, like restaurant discounts, cultural events, and municipal services. Additionally, by include schools in the plan, younger generations' participation becomes a motivating factor, increasing the scope and effectiveness of e-waste collection initiatives. This strategy ensures that the idea of sustainability is ingrained in education and community life by taking inspiration from the United Nations Eco-Schools project. Revenues from the metal recovery process can be used to offset treatment and transportation costs, which are 0.275 and 0.1 euros per kilogram, respectively. In order to maximize the effectiveness of metal extraction from printed circuit boards (PCBs) and other e-waste components, the project also integrates electrochemical separation techniques. This creative strategy might make recycling e-waste more financially appealing and encourage more environmentally friendly industrial processes in the Czech Republic. The overall goal of the motivating e-waste management system is to create a sustainable, economically advantageous, and participative model of a circular economy. The study shows how local efforts can significantly contribute to global sustainability goals by establishing such a system at CXI and expanding it throughout Liberec and the larger Czech Republic. A comprehensive strategy for handling e-waste that is both realistic and expandable is ensured by the active participation of numerous stakeholders, employees, students, and community members.

CONFLICT OF INTERESTS

The authors declare that there is no conflict of interest associated with the publication of this study.

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