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Device And System to Recycle E-Waste Resource with A Data-Driven Decision-Making Process

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ABSTRACT: Materials recycling is a key process to close the loop of materials in the direction of circular economy. However, the variability of waste and the high volatility of the price of recovered materials are posing serious challenges to the current rigid design of mechanical recycling systems. This is particularly true for Waste Electric and Electronic Equipment (WEEE), whose volume is growing more than other waste streams in Europe due to the diffusion of electronic products and to their short technology cycles. This study is aimed at the development of new flexible recycling systems through the implementation of a Hyper Spectral Imaging system and a simulation model enabling the real-time characterisation of shredded particles and the dynamic optimisation of process parameters for efficient sorting. A hardware and software prototype was realised and tested at the De- and Re-manufacturing pilot plant of CNR-STIIMA. The positive economic impact of flexible recycling systems enabled by new technologies was assessed through scenario analysis.

KEYWORDS: E-waste, environmental challenges, e-Electronic Scraps, e-waste management

I. INTRODUCTION

E-waste refers to repudiated electronic devices, such as computers, mobile phones and other electronic equipment, that are at the verge of their efficacious use. Owing to the unrelenting momentum of technological innovation, a growing multitude of individuals are procuring electronic devices with regularity; thus, this begets roughly 54 to 60 million metric tons of e-waste every year, averaging some 7 kg of e-waste per capita. Pursuant to the Global E-waste Statistics Partnership, this is expected to increase to 74.7 Mt by 2030. By 2025, it is estimated that Asia will generate the highest volume of e-waste, at 24.4 million metric tons, followed by the Americas (13.4 million metric tons) and Europe (12.8 million metric tons). Scarcely around 15 percent of global e-waste was collected and recycled in 2014, with the remaining 85 percent being discarded in landfills or incinerated [1].

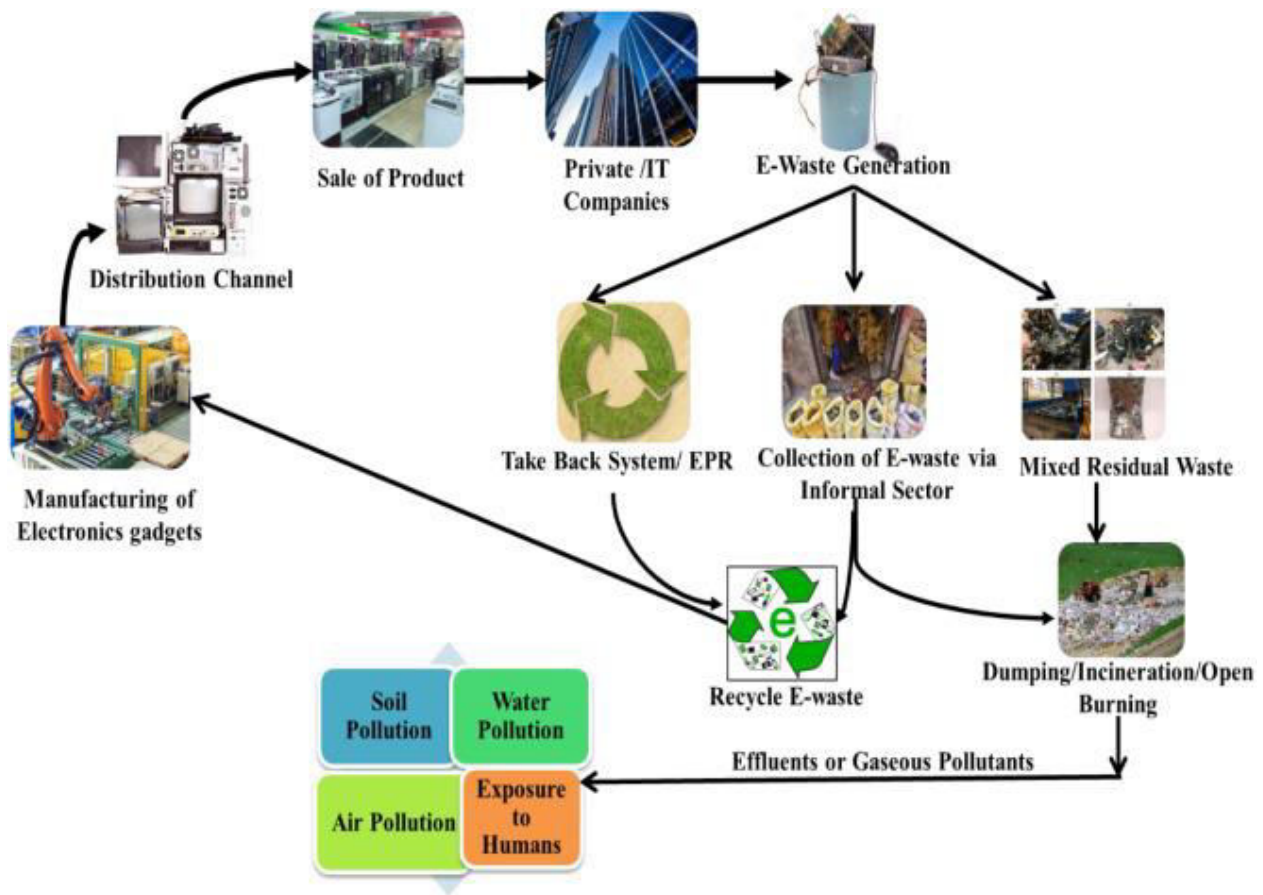


Fig 1: E-waste in Information and Communication

This situation gives rise to a profound disquietude and engenders a palpable sense of apprehension. It is incumbent upon us to take substantive action. The deleterious effects of electronic waste on the environment are manifold and unequivocal. It has been empirically demonstrated that the materials utilized in the construction of these devices, when containing high concentrations of lead and mercury, are capable of perniciously poisoning the surrounding soil in landfills. Once discarded, the components of e-waste become veritable toxins for the ecosystem, gradually seeping into the earth and causing damage to the atmosphere [2]. This process releases noxious chemicals into the air, thereby exacerbating air pollution. Furthermore, as these toxic materials are carried by rainwater or groundwater, they can affect both terrestrial and aquatic wildlife, rendering e-waste an omnipresent threat to environmental health. The identification and separation of e-waste from municipal solid waste (MSW) is a challenging task that requires significant resources. Moreover, the recycling of e-waste involves substantial costs and requires specialized techniques for sorting and processing [3]. Our study focuses on the separation and sorting of e-waste using machine learning and the recycling of plastic using pyrolysis, as well as the potential uses for the resulting bio-char by-product, and using metals to produce solar batteries. E-waste metals can be converted to solar batteries for achieving sustainable and renewable energy sources, and we propose the use of time series data [4] for the continuous monitoring of the garbage level in the cloud, employing the Auto-regressive Integrated Moving Average (ARIMA) to forecast and analyze the life cycle [5].

II. LITERATURE REVIEW

"Electronic waste" could also be outlined as discarded computers, workplace equipment, diversion device natural philosophy, mobile phones, TV sets, and refrigerators. This includes used natural philosophy that are destined for use, resale, salvage, recycling, or disposal. Others are re-usables (working and fixable electronics) and secondary scrap (copper, steel, plastic, etc.) to be "commodities", and reserve the term "waste" for residue or material that is drop by the

client instead of recycled, as well as residue from use and utilization operations. as a result of many surplus natural philosophy are oftentimes commingled (good, recyclable, and non-recyclable), many public policy advocates apply the term "e-waste" broadly speaking to any or all surplus natural philosophy. Electron beam tubes (CRTs) are thought about one in all the toughest varieties to recycle.

Developing review procedures for all material purchased is the initiative in establishing a listing management program. Procedures ought to need that each material should be approved before purchase. Within the approval method, all production materials area unit evaluated to look at, whether they contain venturous constituents or various hazardous materials area unit obtainable. Another inventory management procedure for waste reduction is to confirm that only required amount of a fabric is ordered. This can need the institution of a strict inventory pursuit system. Purchase procedures should be enforced to make sure that materials area unit ordered solely associate with need basis.

Improvements within the operation and maintenance of method instrumentality may result in vital waste reduction. This will be accomplished by reviewing current operational procedures and examination of the assembly method for methods to boost its potency. Instituting normal operation procedures will optimise the employment of raw materials within the production method and scale back the potential for materials to be lost through leaks and spills. A strict maintenance program, that stresses corrective maintenance, will scale back waste generation caused by failure. Nursing employee-training program may be a key component of any waste reduction program. Training ought to embrace correct operational and handling procedures, correct instrumentality use, counselled maintenance and examination schedules, correct method management specifications and correct management of waste materials.

Volume reduction includes those techniques that take away the venturesome portion of a waste from a non-hazardous portion. These techniques area unit typically to scale back the quantity, and therefore the value of eliminating a waste product. The techniques that may be wont to cut back waste-stream volume may be divided into two general categories: supply segregation and waste concentration. Segregation of wastes is in several cases an easy and economical technique for waste reduction. Wastes containing differing types of metals may be treated one by one so the metal worth within the sludge may be recovered. Concentration of a waste stream might increase the probability that the fabric may be recycled or reused.

III. METHODS

From a technological point of view, the main challenge consisted in the development of a robust and flexible imaging system for the in-line characterization of the metal and non-metal fraction of waste. The underpinning knowledge regarding spectral signatures of pure materials is derived from end-member collections, with cross-check performed by Scanning Electron Microscope (SEM) measurements. The information about composition and geometry of the particles in the mixture made available by the developed vision system is used to feed a multi-body simulation model and an optimization and control module to get optimal separation parameters and improve the configurability of the recycling system.

The implemented vision system includes three main elements: (1) the hyperspectral camera, (2) the illumination system and (3) the transportation system. The conveyor speed, the image frame rate and binning are mutually aligned for the effective performance of the system. For the purpose of the simulation developments, granular flows involved in waste processing exhibit complex dynamical phenomena. Therefore, a custom simulation software based on multi-body dynamics was developed. Such a tool simulates the trajectory of thousands of processed particles, including mutual collision effects and their interaction with electric and magnetic fields in the CES and Eddy Current Separation (ECS) machines.

Thanks to the new hardware and software technologies, the resulting flexible recycling systems are able to dynamically adapt the implemented recycling strategy to business conditions. This means that it will be possible not only to adapt process parameters to variations of volumes and characteristics of waste that will be required to treat over time, but also to select strategically—and source accordingly—the type of waste that should be treated to maximise the profit based on material pricing and availability of waste. However, a wider range of options and the uncertainty that is typical of the recycling context makes difficult to companies to fast decide what is the best strategy to be pursued. Thus, decision support tools able to indicate suitable business models and to predict economic performance under uncertain conditions are needed to dynamically address business operations and maximise profit.

Circular Economy represents an innovative paradigm for sustainable manufacturing [42]. Relying on technology and business model innovation, the Circular Economy concept aims at maximising the use of products and materials. Recycling is one of the strategies that can be pursued in circular economy, together with re-use and re-manufacturing. Through recycling, critical materials and key-metals can be recovered from post-use products when they can not be re-used or remanufactured.

Recycling systems are nowadays very rigid in their design and they do not allow dynamic adaptation of process parameters to different types of waste. For this reason, the performance of recycling plants is often sub-optimal. With the goal of developing a new generation of flexible recycling systems, new hardware and software solutions were developed in this study for the dynamic adaptation of process parameters to different type of waste. The Hyper Spectral Imaging (HSI) system and the software tool for the control of the sorting parameters based on a multi-body simulation model were demonstrated in a prototype at the De- and Re-manufacturing pilot plant of CNR-STIIMA (ex CNR-ITIA).

IV. RESULT ANALYSIS

Based on interviews to recycling companies and experts, two variables were selected as the main determinants of recycling economic performance: the relative volume of waste products to be treated in a time period (waste mix) and the market price of materials. Waste volume and mix may vary unpredictably due to fast products technology cycles, success (or failure) in regional tenders for treating specific waste over fixed time periods, new regulation, etc. Different types of waste contain different percentages of valuable materials and require different type of treatment processes which impact on costs. On the other hand, the market price of materials depends on their periodic demand and availability, thus determining the revenue that is made by selling recycled materials on the market. Scenarios were designed by making the hypothesis of average, favourable and unfavourable waste mixes according to their content of precious materials and of recycling cost.

The separation workstation integrates a Corona Electrostatic Separator Hamos KWS. The quality of the separation process is influenced by five controllable parameters: (i) electrode voltage and position; (ii) drum speed; (iii) output stream splitters position; (iv) material feed rate; and (v) feeder vibration. However, due to the complexity of the process, non-controllable effects, such as particle-particle interactions and impacts among particles and machine, influence the efficiency of the process, providing contaminated output flows. For this reason, a multi-body simulation model of electrostatic separator process, considering particles attributes, trajectories, interaction and collision, has been developed. The whole system has been validated with experimental analyses, under different operational conditions (i.e. mixture type, machine working parameters).

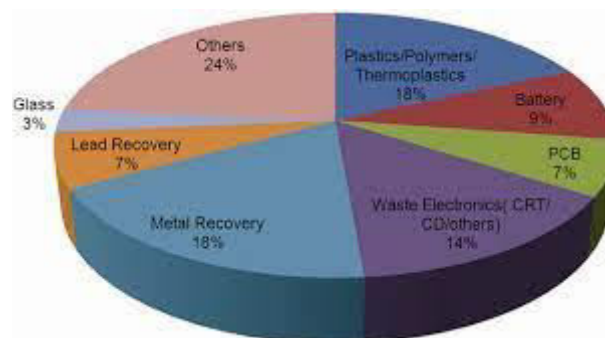


Fig 2: E Waste Result analysis

One of the most challenging modern recycling applications is the treatment of Waste from Electric and Electronic Equipment (WEEE) that represents the European waste with highest yearly average increase rate (5%). Such an increase was even higher in some European nations, e.g. in Italy the increase amounted to 30% in 2010 compared to the previous year (in terms of collected WEEE). Due to its material composition, WEEE represents an important source of recycled key-metals to be used for the production of advanced technological products. E-waste is a highly variable waste flow because of the wide range of products and material mixtures, which are in continue evolution due to fast technology cycles. For example, in small WEEEs (which in Italy are identified as “RAEE class 4”), Cathode Ray Tube (CRT) TVs, cellular phones and traditional HDD are rapidly being replaced by LCD/LED TVs, smart phones and SSD

(Solid State Disks), respectively. Other new waste flows are rapidly entering the recycling streams, such as for example solar panels and tablet PCs. For the successful treatment of WEEE, besides being flexible, recycling systems must guarantee a high efficiency, since critical metals are present in small quantities (e.g. indium, palladium, ruthenium, gallium, tantalum, and platinum). For instance, indium is found in WEEE with an average weight of 39 mg in Notebooks, 79 mg in computer monitors and 254 mg in LCD TVs.

V. CONCLUSIONS

The IoT- and cloud-based waste management and recycling system we have implemented successfully addresses the pressing issue of e-waste. Our study focused on the efficient separation and quick disposal of e-waste using the IoT, cloud computing, and machine learning. Our research results showcased numerous advantages, including enhanced efficiency, cost reductions, improved monitoring capabilities, and increased sustainability. Real-time data collection and analysis facilitated optimized waste collection routes, minimized the environmental impact, and successfully produced bio-fuel and solar batteries. Our research objectives were achieved through the implementation and evaluation of an IoT- and cloud-based waste management system, resulting in improved waste monitoring, optimized collection routes, and turning waste into assets by producing bio-fuel through pyrolysis and converting e-waste metal into solar batteries. Our study's outcomes align seamlessly with our initial research objectives, demonstrating the system's ability to overcome challenges associated with traditional waste management practices. However, there are some limitations, such as security and privacy concerns related to IoT devices and cloud infrastructure that must be addressed with robust measures to ensure data protection. In addition, the performance of the GAN algorithm can be affected by issues such as mode collapse, where the generator produces limited varieties of output, instability during training, and difficulty in evaluating the generated images. To sum up, the implementation of our IoT- and cloud-based waste management system has immense potential to revolutionize waste management practices. Its real-time data gathering, operational optimization, resource allocation, and production of recycled products offer substantial cost savings, a reduced environmental impact, and improved sustainability. However, addressing security concerns and conducting further research to ensure widespread adoption are necessary tasks for the successful implementation of such systems in the future.

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