Technical Sciences
Academy of Romania
www.jesi.astr.ro

Journal of Engineering Sciences and Innovation
Volume 7, Issue 1 / 2022, pp. 29 - 44

C. Chemical Engineering, Materials Science and Engineering

Received ***21 September 2021*** *Accepted* ***7 March 2022***
Received in revised form ***19 December 2021***

PRECIOUS METALS RECOVERED BY URBAN MINING

GEORGETA ALECU[*], WILHELM KAPPEL

National Institute of Research and Development for Electrical Engineering ICPE-CA,
313 Splaiul Unirii, 3, Bucharest, Romania

Abstract. The circular economy generates major environmental benefits, which result from the use of energy and renewable materials or from reuse and recycling. Being a complex mixture of materials and components, from an economic point of view, the separate collection and recycling of electronic and electric wastes can be cost-effective for products because they contain many hazardous substances, rare or precious metals.

This paper presents some aspects regarding the waste with high content of precious or non-ferrous metals contained in the electronic/electrical components. Their presence in electronic/electrical waste makes it necessary to recycle and treat them in an ecological way, generating a true industrial symbiosis. In the paper this fact is exemplified by the presentation of a reconditioning-recovery technology that allows the full recovery of all components of some types of electrical contacts widely used in economics. Disposable or defective electrical contact waste was used, as well as technological waste resulting from the manufacture of electrical contact pieces.

Key words: circular economy, e-waste, recycled materials, urban mining.

1. Introduction

Electrical and electronic equipment (EEE) is a rapidly developing sector (3-5% per year), [1], in which the characteristics of the equipment and materials used are constantly changing, leading to a growing trend in the production and sale of EEE, which contrasts with the decrease in their duration of use.

Case studies for four different groups of electronic products show that they all have a real average lifetime, which is at least 2.3 years shorter than the designed or desired lifetime, Fig. 1 [2].

---

[*] Correspondence address: georgeta.alecu@icpe-ca.ro

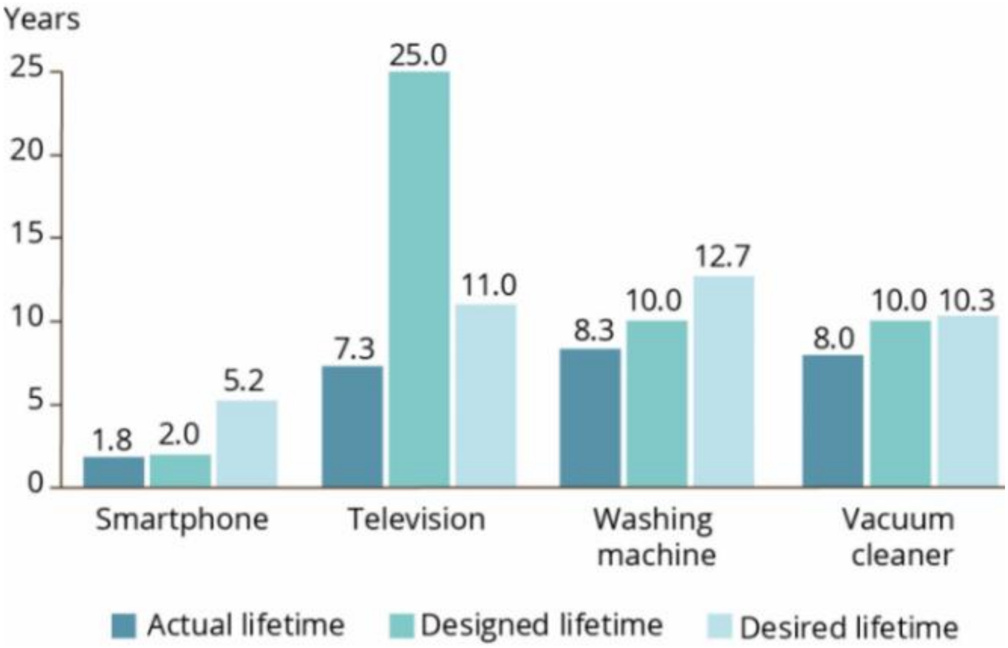


Fig. 1. Lifetime for smartphones, televisions, washing machines and vacuum cleaners, [2].

On average in the European Union (EU) each year, more than 20 kg of EEE per person are placed on the market, including large appliances such as washing machines, vacuum cleaners, refrigerators and freezers, as well as electronics and gadgets, such as computers, televisions and mobile phones. For example, in 2017, 20.6 kg per person of EEE were placed on the market, of which approximately 60% (11.8 kg) were produced in the EU and 40% (8.8 kg) were imported, [1, 3].

The increased rate of obsolescence and subsequent improvements in product quality have a psychological impact on the mentality of consumers, contributing to a faster change in the life cycle of the product. This applies in particular to devices that already have a short lifespan (for example, mobile phones, computers, televisions, digital cameras and laptops). This trend leads to the accumulation of an increasing amount of waste of electrical and electronic equipment (WEEE), also known as electronic waste (e-waste). The complexity of dismantling and recycling WEEE, as well as the various substances and / or materials in their composition is a threat to the environment and health.

E-waste generation is expected to increase in the future by requiring improvements in collection systems and consumer awareness to ensure increased recycling, which will lead to reduced losses of material resources. The stock of EEE, products that are used or stored in businesses, households and public space before being discarded, is significant and growing. In Europe, it is estimated that 129 million tonnes of EEE are in stock, constituting a real urban mine. In EU28 + 2 countries (Switzerland and Norway), the average per capita stock of EEE products is 44 and

248 kg- respectively, including all EEE in stock in enterprises, households and public space, [4].

At the same time, the prevention, collection and management of e-waste is an important element of the circular economy through which precious resources are not lost. The production of modern electronics requires the use of scarce and expensive resources (for example, about 10% of total gold worldwide is used for their production). In order to contribute to a circular economy and improve the environmental management of e-waste, as well as to increase resource efficiency, it is essential to improve the collection, treatment and recycling of end-of-life EEE.

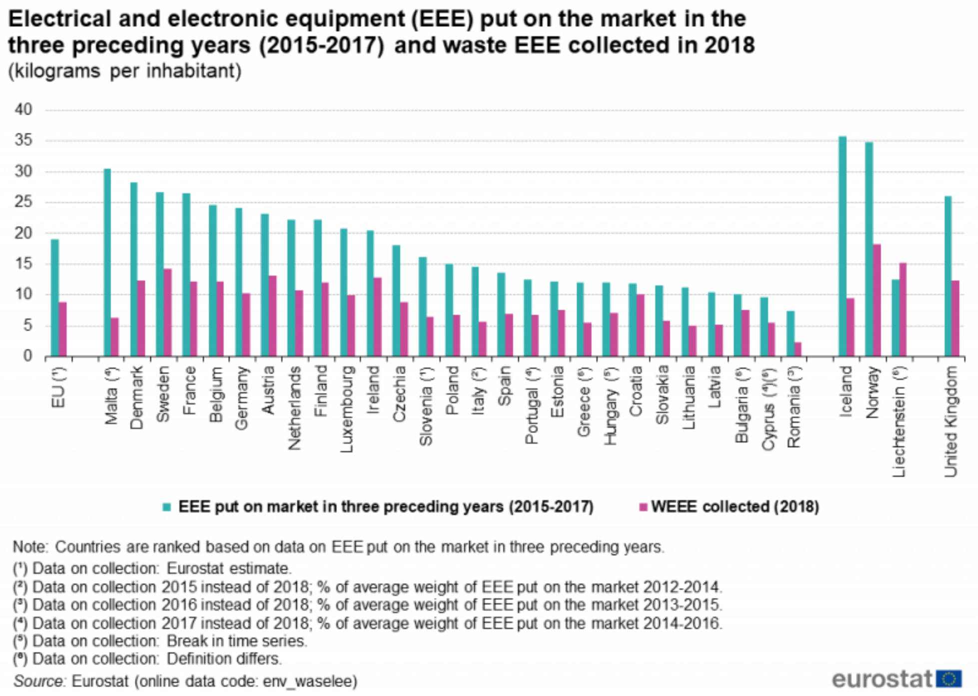
2. EU directives and consequences

To address these challenges more appropriately, the EU has introduced two pieces of legislation: the WEEE Directive (WEEE Directive) and the Directive on Restricting the Use of Certain Hazardous Substances in EEE (RoHS Directive).

The first WEEE Directive (Directive 2002/96 / EC), [5], provided for the creation of collection schemes in which consumers return their WEEE free of charge. These schemes aim to increase the recycling and / or reuse of WEEE. In 2008, the European Commission (EC) proposed a revision of the directive to address the rapid increase in waste stream. The main directive governing this waste stream is the WEEE Directive (2012/19 / EU), [6], which sets out a number of targets for collection, recovery / reuse and recycling according to the different categories of EEE. The first WEEE Directive (2002/96 / EC) grouped EEE into 10 primary categories for which statistics were to be compiled, while the amended WEEE Directive (2012/19 / EU) grouped EEE, starting with 15 August 2018, into six categories. However, both classification systems remain valid, [5, 6].

The WEEE Directive 2012/19 / EU, starting with the reference year 2016, sets as its objective the "Collection rate" as equal to the total weights of WEEE collected in the reference year divided by the average weight of EEE placed on the market in the last three years. previous ones (both expressed in units of mass). "Reuse and recycling rate" shall be calculated by dividing the weight of WEEE entering the recycling / preparation plant for reuse by the weight of all WEEE collected separately for each category (both expressed in units of mass) in accordance with Article 11 (2) of Directive, given that the total amount of WEEE collected is sent to treatment / recycling facilities. The same amended directive, starting in 2019, introduced a gradual increase in collection targets, coming into force for the reference years 2016 and 2019, respectively. This is set at 45% for the reference year 2016 (reported in 2018) and 65 % for the reference year 2019 (to be reported in 2021) or, alternatively, 85% of WEEE generated in that Member State, [1, 7].

Depending on the country, the amount of WEEE collected in 2018 compared to EEE placed on the market in the previous three years (2015-2017), both measured in kilograms per capita is shown in Fig. 2, [1]. In the EU, WEEE collected in 2018 was estimated at 8.9 kg per capita, while the average value of EEE placed on the market in 2015-2017 was estimated at 19.1 kg per capita. The variation in the masses collected reflects the differences in the level of consumption of EEE between countries, as well as the differences in the performance of their respective waste collection systems.



Electrical and electronic equipment (EEE) put on the market in the three preceding years (2015-2017) and waste EEE collected in 2018
(kilograms per inhabitant)

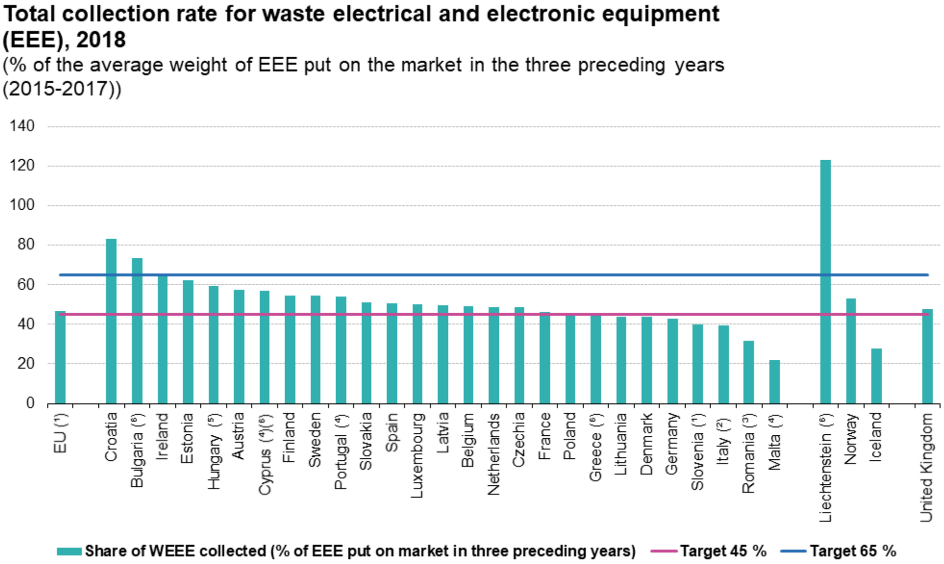
Note: Countries are ranked based on data on EEE put on the market in three preceding years.
(1) Data on collection: Eurostat estimate.
(2) Data on collection 2015 instead of 2018; % of average weight of EEE put on the market 2012-2014.
(3) Data on collection 2016 instead of 2018; % of average weight of EEE put on the market 2013-2015.
(4) Data on collection 2017 instead of 2018; % of average weight of EEE put on the market 2014-2016.
(5) Data on collection: Break in time series.
(6) Data on collection: Definition differs.
Source: Eurostat (online data code: env_waselee)

Fig. 2. EEE placed on the market and WEEE collected by country, [1].

In Fig. 3, WEEE collected are presented as a share of EEE placed on the market. The quota is calculated as the ratio of the mass of WEEE collected in 2018 to the average mass of EEE placed on the market in the previous three years, e.g. 2015-2017, [1]. These reports indicate how much WEEE must be collected by EU Member States in order to reach the collection targets of 45% and 65% respectively.

In 2018, 18 EU Member States exceeded the WEEE collection target by 45%. Seven Member States reported rates ranging from 39.4% to 44.7%, while two Member States were below 32%. However, two Member States have already reached the new target of the 65% collection rate for WEEE in 2018, which will take effect from the reference year 2019, and two Member States are close to reaching the future target of 65% in 2018.

Table 1 presents statistical data for the EU on waste collected from households and the rate of WEEE recycling, [1].



(¹) Eurostat estimate.
(²) Data on collection 2015 instead of 2018; % of average weight of EEE put on the market 2012-2014.
(³) Data on collection 2016 instead of 2018; % of average weight of EEE put on the market 2013-2015.
(⁴) Data on collection 2017 instead of 2018; % of average weight of EEE put on the market 2014-2016.
(⁵) Break in time series.
(⁶) Definition differs.
Source: Eurostat (online data code: env_waselee)

Fig. 3. Total collection rate for WEEE, [1].

Table 1. E-waste and their recycling rate in the EU and in Romania

E-waste through waste management operations (waste collected from households), kg / capita										
State/year	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
EU after 2020	*	*	5.88	5.74	5.87	5.96	6.45	7.05**	7.37**	7.13**
Romania	1.66	1.15	0.96	1.04	1.55	1.50	1.79	2.19	*	*
E-waste recycling rate, %										
EU after 2020	*	*	27.9**	29.5**	30**	30.9**	32.8	39.5**	39.5**	38.9**
Romania	17	12	10.3	14.5	21	21.3	22.5	25	*	*

* No data available
** Eurostat estimates

The WFD Framework Directive 2008/98 / EC, [8], is responsible for classifying waste as a valuable resource. This Directive, together with the Landfill Directive (2018/850 / EU), [9], have recently been amended to include, inter alia, a number of new targets and measures taken after 2020, with the main objective of approximating a circular economy in which waste is managed as a resource.

As increasing recycling is part of the transition to a circular economy, this area focuses on the share of waste that is recycled and actually returned to the business cycle to continue to create value. In this sense, Fig. 4 provides a brief overview of recycling rates for different waste streams, stating that only 39% of existing e-waste in 2017 was recycling, [1].

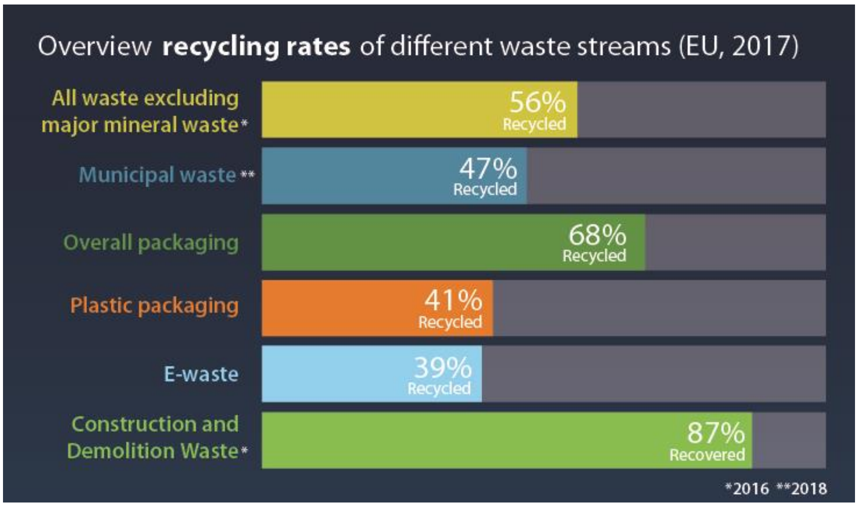


Fig. 4. Overview of recycling rates for different waste streams, [1].

EU legislation restricts the use of hazardous substances in EEE in the RoHS Directive 2002/95 / EC, [10], and its new amendment, which entered into force in 2013, RoHS 2011/65 / EU, [11]. The legislation requires that heavy metals such as lead, mercury, cadmium and hexavalent chromium and flame retardants be replaced with safer alternatives.

Better environmental design, prevention of waste generation and reuse could bring net annual savings of up to EUR 600 billion to the EU's business environment, while reducing total annual greenhouse gas emissions, [1].

3. Aspects regarding the recovery and recycling of WEEE materials

Urban mining in the EEE refers to the recovery of used materials from e-waste, the recovery of metals incorporated in buildings (e.g. cables). Most products at the end of their life cycle contain metals and minerals in higher concentrations than primary resources. These stocks of resources used are the urban mines of the future.

The main benefits of urban mining and recycling are related to the conservation of natural resources and energy, to the reduction of pollution in the production process resulting from the use of recycled raw materials (RM) instead of virgin RM. The recycled materials have already been processed once, so this time the process is cleaner and less energy consuming compared to the original process. Urban mining can provide significant economic gains and employment opportunities in the recycling and metallurgy industry, the emergence of so-called "green jobs", [12]. Recycling provides the manufacturing industry with cheaper resources, long-term economic benefits that translate into value for consumers, who spend less on products and packaging. However, the most important barrier to increasing the recycling of these waste streams is the low market price of virgin natural resources / RM. Another disadvantage is the mixed and complex composition of some residual products, which makes it difficult to recover and reuse waste materials, [13].

The EU Circular Economy Action Plan provides that, in a circular economy, recyclable materials are to be reintroduced into the economy as new RMs, contributing substantially to security of supply. Thus, the materials are kept in the economy for as long as possible and at the highest possible value. This production of "secondary raw materials" (SRM) can be generated in a national economy and can also be marketed and shipped in the same way as primary RMs resulting from traditional extractive resource industries, [1].

The materials contained in the products at the end of their life cycle should be recovered by dismantling and recycling. The reintegration of these materials, as SRM, at the beginning of the product life cycle reduces the environmental footprint of production and consumption, as well as production costs. It is known that the environmental footprint is generally lower for recycling processes compared to primary production. Recycling is also expected to contribute to increasing the EU's competitiveness, as set out in the EC Circular Economy Action Plan, [14]. Few data are available at European and international level on the amount of SRM produced. In the EU, the level of demand for RM exceeds the volume that could be supplied even if all waste were transformed into SRM. Therefore, the supply of primary RM will remain necessary. Due to problems related to primary mining, fluctuations in market prices, lack of materials, availability and access to resources, it has become necessary to improve the exploitation of secondary resources and reduce the pressure on virgin materials.

By improving global e-waste collection and recycling practices, a considerable amount of SRM - valuable, critical and non-critical - could be made available to re-enter the manufacturing process, while reducing extraction of new materials. On average, recycled materials meet only around 10% of EU material demand, despite a continuous improvement in recycling processes since 2004. For a range of bulk materials, SRM meets more than 30% of total material demand. (for example, for copper and nickel). However, for many materials, including almost all critical raw materials (CRM), the contribution of recycled materials to meeting the demand for MP is still small. Possible causes are the lack of cost-effectiveness of their recycling, the lack of recycling technologies or the fact that the materials are incorporated into products kept in use for a long time (for example, permanent magnets with rare earths used in wind turbines). EEE contains a complex mixture of materials, ranging from base metals to plastics, including various substances that pose risks to the environment and health. EEE contains precious metals and several CRMs, which are essential for their operation in key industrial sectors as well as in other applications. As is known, EEE also contains hazardous substances, usually heavy metals such as mercury, cadmium or lead, and chemicals such as chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs) and fire retardants. Approximately 71 kt of plastic containing BFR (brominated flame retardants) comes from e-waste generated in 2019 in the EU, [15]. In particular, BFRs are used in appliances to reduce the flammability of the product, occurring, for example, in the outer casings of computers, printed wiring boards, connectors, relays, wires and cables.

Although base metals such as ferrous metals, Al and Cu in e-waste are already largely recycled, many CRMs (e.g. rare earths (REEs)) cannot be recovered effectively due to low prices on the market that does not cover recycling costs, lack of recycling technologies or limits on the recovery of metallurgical processes, [16], Table 2.

The most important parameter to measure the efficiency of a global recycling system is the functional recycling rate ((EOL) - recycling rate at the end of the life cycle). EOL excludes non-functional recycling flows of discarded products and depends on the efficiency of all stages in the recycling chain: collection, separation, sorting and, finally, metal recovery. Recycling is considered "functional" when the recycled material has a quality equivalent to that of the primary materials and can be used for the same (or similar) applications.

Table 2. Metals, from waste, difficult to recycle, [16]

Metal	Main manufacturers	Recycle
Sb	China (87%), Vietnam (11%)	28%
Bi	China (82%), Mexico (11%),	1%
Co	DR Congo (64%), China (5%)	0%
Ge	China (67%), Finland (11%), Canada (9%), USA (9%)	2%
In	China (57%), South Korea (15%), Japan (10%)	0%
Mg	China (87%), USA (5%)	9%
Nb	Thailand (32%), Indonesia (26%), Vietnam (8%), India (8%)	1%
Sc	China (66%), Russia (26%), Ukraine (7%)	0%
Ta	Rwanda (31%), DR Congo (19%), Brazil (14%)	1%
W	China (84%), Russia (4%)	42%
V	China (53%), South Africa (25%), Russia (20%)	44%
PGM* (-Pd)	South Africa (83%)	14%
REE	China (95%)	< 5%
*platinum-group metals: Ru, Rh, Pd, Os, Ir and Pt		

From the set of indicators for the circular economy, the end-of-life recycling input rate (EOL-RIR) is used to monitor progress towards the SRM thematic area. In contrast to the indicators of the waste management monitoring framework, which focuses on the collection or recycling rates of certain waste streams, EOL-RIR measures the contribution of recycling to the demand for materials by type of material.

The indicator measures, for a given raw material, how much of its contribution to the production system comes from the recycling of 'old waste' (or 'end-of-life waste'), e.g. waste and end-of-life waste. EOL-RIR does not take into account residues from manufacturing processes (e.g. "new residues" or "process residues"). Indeed, processing residues have a known composition and are generally more homogeneous and not contaminated with other substances, being easier and more economically convenient to collect and recycle.

EOL-RIR values are still relatively low, mainly because they are incorporated into long-term goods and may only be available for recycling in the future. Other materials, on the other hand, have very high EOL-RIR values, as use and demand have been drastically reduced by legislative bans. For a large number of materials (including many CRMs) EOL-RIR is zero or very low because they have only recently been introduced in innovative and complex products (e.g. electric vehicles, renewable energy installations, electronics), [1].

Fig. 5 shows EOL-RIR for several materials, including metals (e.g. Al, W), non-metallic minerals (e.g. borate and phosphate rock), REEs that are used in specialized applications (e.g., Tb and Dy) and biotic materials (e.g. natural rubber, cellulose wood), [17].

Fig. 5. End-of-life recycling entry rates (EOL-RIR) for some metals, [17].

The contribution of recycled materials to the demand for RM, meaning how much of the total material introduced into the production system comes from recycling, reveals two interesting aspects. The first is that, in general, SRM represents a relatively small proportion of inputs in production processes. Very few materials have an EOL-RIR greater than 30%: Co (35%), cellulose wood (54%) and W (42%).

EOL-RIR for a number of bulk metals (e.g. Fe, Ni) and a limited number of special metals (such as Au and Ag) range from 20% to 30%. Even though many of these materials have EOL of over 50%, mainly because they are used in sufficiently large quantities in easily recoverable applications (e.g. steel in automobiles), their EOL-RIR are much lower because the demand for these materials is higher than what can be ensured by recycling.

The second aspect shows that, for most special metals and REE, as well as for natural rubber, secondary production represents only a marginal proportion (often less than 1%) in meeting the demand for materials. This is mainly due to the fact that primary extraction is often more economical than recycling, because these materials are used in very small quantities (which makes their collection and separation expensive) and / or because it is often difficult to recycle these materials. at sufficient degrees of purity.

Globally, only 17.4% of WEEE is formally documented for collection and recycling, [15]. On the other hand, the recycling sector is often faced with high recycling costs and challenges in recycling materials. For example, the recovery of materials, such as Ge and In, is difficult due to their dispersed use in products that are neither designed nor assembled on the basis of recycling principles.

On the other hand, base metals (e.g. Au) used in certain devices, such as mobile phones and computers, have a relatively high level of concentration: 280 grams per tonne of e-waste. The methods used for the separation and recycling of e-waste can be economically viable, especially if they are performed manually, in which case the material losses are less than 5%, [18]. Thus, for products containing high concentrations of precious metals, separate collection and recycling of e-waste can become economically viable. However, the recycling rate of most CRMs is still very low. It can be improved for precious metals by better collection and pre-treatment of e-waste.

In 2019, Fe, Cu and Al accounted for the majority of the total mass of raw waste identified in WEEE. These quantities could only be recovered in an ideal scenario where all globally generated e-waste is recycled and the recycling of all selected RMs is economically viable or even feasible with currently available recycling technologies. In the same year, the demand for Fe, Al and Cu for the production of new electronics was about 39 Mt. Even in an ideal scenario where all Fe, Cu and Al resulting from e-waste (25 Mt) are recycled, the world would need about 14 Mt of Fe, Al and Cu from primary resources to manufacture new electronics. This is a consequence of the continuous increase in EEE sales. With the current collection and recycling rate of 17.4%, a potential raw material value of USD 10 billion can be recovered from e-waste, and 4 Mt of SRM would become available for recycling. By focusing only on Fe, Al and Cu and comparing emissions from their use as virgin RM or SRM, their recycling has helped save up to 15 Mt of CO_2 equivalent emissions in 2019, [15].

4. Recycling of valuable metals from certain types of WEEE

When electronic devices are at the end of their life cycle, they become WEEE. This is one of the fastest growing waste streams in the world, with an annual growth rate of 4% or 44.7 million tonnes in 2016, [19]. It is well known that, in terms of mass, e-waste is the smallest waste stream, but it contains valuable resources (e.g. metals, CRM).

The scheme of the materials used is circular in theory, a kind of perpetual motion. RMs are extracted and processed or are collected in the form of recyclable resources from waste and transformed into products and then recycled through a manufacturing process. Without recycling, the circuit of natural materials, Fig. 6, would become a series of events without a logical resolution. Any materials resulting from recycling would become dispensable and would not be kept as a possible resource. Thus, recycling and urban mining are much more efficient than traditional mining.

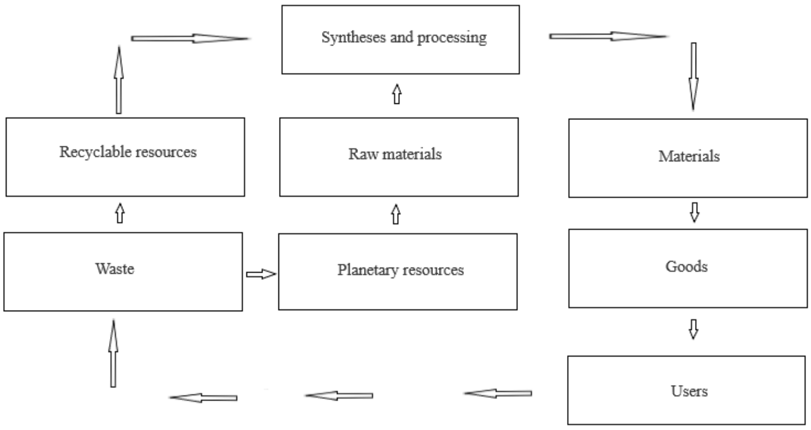


Fig. 6. Total circuit of materials.

Closing the material loop means reducing the need for new RMs and eliminating waste, while creating economic growth, new "green" jobs and business opportunities. The use of already processed materials involves substantial energy savings compared to the use of raw materials.

From the perspective of using materials, EEE contains about 69 elements from the periodic table. These include precious metals (e.g., Au, Ag, Cu, Pt, Pd, Ru, Rh, Ir and Os), CRM (Co, Pd, In, Ge, REE, Bi and Sb), and non-critical metals, such as Fe and Al, [15]. Within the paradigm of a circular economy, e-waste should be considered an important source of SRM. These include valuable precious materials whose recycling should be improved.

Au, as a key factor in material recycling, comes mainly from printed circuit boards in LCD TVs, laptops, tablets, desktops and mobile phones and totals up to 230 tons, representing about 8% of world annual gold production. Other significant metals are Cu (4.1 million tonnes), Nd (12,000 tonnes), In (300 tonnes) and Ag (1,300 tonnes), [20]. Many critical metals, such as In, Ga, Ta or REE, are not recycled, for example, due to the low content of these materials in EEE, low market prices or high recycling costs, lack of recycling technologies. commercial recycling and the limitations of metallurgical recovery processes, [21].

Electrical contacts are used in all EEE designed and manufactured today: electronic switches, thermostats, stoves, electric forklifts, elevators, washing machines, heaters, etc. They can be found in electrical switches, relays. Electrical contacts are installed in moving and permanent components in many technological devices, such as automotive and aerospace components, high and low power contact joints, sliding and breaking contacts, and electromechanical systems. Both electrical and mechanical wear contribute to the loss of contact material. To increase the corrosion resistance and service life of electrical contacts, manufacturers use precious and semi-precious metal alloys.

In electrical appliances there are many materials that can be used for electrical contacts: pure metals (Cu, Ag, Au, W, Pt, Pd, Mo), alloys (AgCdO, AgNi, $AgSnO_2$, AgPd, AgW, AuPt, AuAg, AuNi, PtIr, PtNi, PdCr, PdNi, CuW, AgNiW, CuCr, Ag-graphite).

Cu, although a soft metal that oxidizes easily, is widely used due to its high electrical conductivity and low cost. Gold, a soft metal that does not corrode in general, has excellent conductivity, but high costs. Ag, Pt and Pd can also be used, depending on the application and the desired level of conductivity. Resistant to corrosion, making them an excellent choice for contacts that will be installed in hot or hostile environments. For example, for riveted contacts there are few commonly used contact materials: AgNi, AgCdO and $AgSnO_2$.

AgCdO contacts belong to the most used material in the field of low voltage electrical appliances (general relays, communication relays, car relays, microswitches, switches, contactors, wall switches, stamped electronic assemblies, etc.). It is mainly used for resistive and inductive loads, such as motor load, heating elements, lamps, switches, relays and electrical contacts. But it is also found in the materials used to make these items - materials such as AgCdO wire, sheets, strips. They combine a satisfactory resistance to contact welding with a good resistance to arc erosion and a rather low contact resistance over the entire life. Old industrial AgCd components are not difficult to find because they have been used for years in many manufacturing processes: metal foundries, medical devices and other testing devices, various types of electronic devices. Cd and CdO are considered to be dangerous to health and the environment. For this reason, the use of AgCdO materials is banned in several countries where Ag-CdO electrical contact parts, toxic and carcinogenic, have been replaced with Ag-SnO_2, while maintaining good final properties, [22].

In order to ensure proper working conditions of the electrical contacts, they must be replaced regularly, as electrical and mechanical wear occurs. Each device has its own maintenance program recommended by the manufacturer. To avoid disposing of used electrical contact, it must be collected for recycling.

In order to verify whether the recovery of metals is economically feasible, the market value of the metals present in the electrical contacts should be estimated. Table 3 shows the prices of some precious and non-ferrous metals on the largest metal commodity exchange in the world, the London Metal Exchange (LME), on September 22, 2021, [23]:

Table 3. Prices of precious and non-ferrous metals at the London Metal Exchange (LME)

Metal	**Unit price, $/kg**
Au	57,154.382
Ag	735.93
Pt	34,215.743
Pd	68,678.403
Al	2.887
Ni	19.075
Cu	9.255

In INCDIE ICPE-CA there has been a constant concern in the field of recycling materials researched and processed in the institute, [24, 25, 26, 27]. There were many challenges in recycling to separate components and recover materials because many EEEs are not properly designed for recycling: for example, miniaturization and structurally integrated materials make disassembly and recovery more difficult.

In this sense, researchers from the institute have developed a technology applicable to AgCdO contacts. The technology, efficient and ecological, allows the complete recovery of all the components of the electrical contacts, until the final contact. The method is based on an original chemical process by coprecipitation that is suitable for the reintroduction of waste in the industrial circuit specific to the production of sintered tablets from ICPE-CA. The scheme of the technological flow of reconditioning-recovery of waste and disused contacts or defects is presented in Fig. 7.

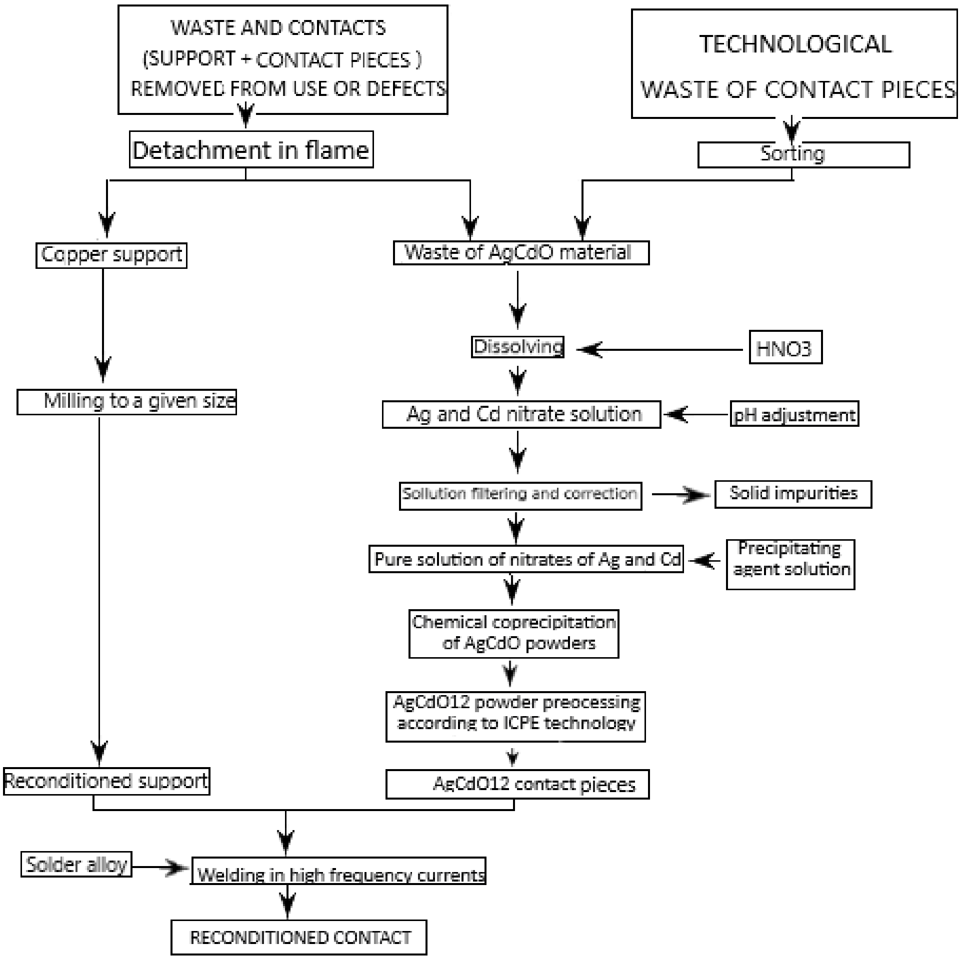


Fig. 7. Scheme of the technological flow of reconditioning – recovery.

Disposal of electrical contact waste (e.g., AgCdO contact pieces mounted on supports) or defects together with various technological wastes of AgCdO contact pieces has been collected. Disassembly, as a first step in the recycling process, can help ensure the recycling of EEE and the reuse of whole components. A good environmental alternative for waste management, reuse means using the products for the same purpose or for different purposes, without changing their main properties. Reuse involves a greater emphasis on product repair and maintenance which requires rethinking product design for longevity and maintainability. Sometimes reuse is only possible for product components and not for the product as a whole.

The separation of devices for reuse, as well as the improvement of metal-specific recovery rates is achieved by pre-sorting the equipment at the end of its life cycle. Pre-sorting requires knowledge of the metal content of the different groups of equipment and consideration of this information during the design and operation of pre-processing facilities.

The AgCdO pellets were peeled off the supports on which they were mounted. These supports were milled to the correct dimensions, requiring new reconditioned supports. Detached electrical contact pieces have been introduced into the flow of technological waste tablets along with other wastes of this type. After manual selection of the metal parts, they were subjected to dissolution with acids and acid mixtures. Then, chemical co-precipitations were performed followed by powder processing in order to obtain new electrical contact pieces. The new contact pads were welded on reconditioned supports.

This technological flow is an efficient management system to avoid the formation of e-waste. It is thus possible to promote reuse, repair, redistribution, reconditioning, before recycling materials. Solutions similar to the one presented should be combined with an optimized EEE design to allow the disassembly and reuse of components or the recovery of valuable and precious materials.

5. Conclusions

EEE urban mining refers to the recovery of used e-waste materials. In a circular economy, in an economic symbiosis that brings added value in terms of recycling and improving the quality of the environment, reducing CO_2 from the atmosphere, we recover waste products and turn waste into "raw materials". Poor or inadequate collection is a serious challenge, related to almost all waste streams analysed. An important factor in increasing the collection rates of different waste fractions is related to the low level of awareness among consumers and traders about their rights and obligations, which varies considerably from one EU Member State to another. The quality of waste materials, their heterogeneity and the presence of hazardous substances that prevent recycling are challenges that need to be addressed. In this view, recyclability needs to be extended to include manufacturability, so that waste becomes a raw material for the manufacture of new materials. The resulting new value-added products are commercially relevant and have access to markets. The technology presented in the paper demonstrates that, in many cases, all components of certain types of EEE can be fully recovered. In the present case, obsolete or defective electrical contact waste was used, as well as technological waste resulting from the manufacture of electrical contact pieces. The technology is efficient and ecological and allows the complete recovery of all the components of the contacts, until the final contact.

References

[1] https://ec.europa.eu/eurostat.
[2] https://www.eea.europa.eu/publications/europe2019s-consumption-in-a-circular/benefits-of-longer-lasting-electronics.
[3] Baldé, C.P., Forti V., Gray, V., Kuehr, R., Stegmann, P., The Global E-waste Monitor – 2017, United Nations University (UNU), International Telecommunication Union (ITU) & International Solid Waste Association (ISWA), Bonn/Geneva/Vienna, 2017.
[4] https://www.eea.europa.eu/themes/waste/waste-management/reducing-loss-of-resources-from.
[5] DIRECTIVE 2002/96/EC of the European Parliament and of the Council of 27 January 2003 on waste electrical and electronic equipment (WEEE).
[6] DIRECTIVE 2012/19/EU of the European Parliament and of the Council of 4 July 2012 on waste electrical and electronic equipment (WEEE).
[7] Eionet Report - ETC/WMGE 2019/3.
[8] DIRECTIVE 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives.
[9] DIRECTIVE (EU) 2018/850 of the European Parliament and of the Council of 30 May 2018 amending Directive 1999/31/EC on the landfill of waste.
[10] DIRECTIVE 2002/95/EC of the European Parliament and of the Council of 27 January 2003 on the restriction of the use of certain hazardous substances in electrical and electronic equipment.
[11] DIRECTIVE 2011/65/EU of the European Parliament and of the Council, 8 June 2018.
[12] Jurate Miliute-Plepiene, Lena Youhanan, *E-waste and raw materials: From environmental issues to business models*, IVL Swedish Environmental Research Institute, January 2019.
[13] https://www.eea.europa.eu/themes/waste/waste-management/the-case-for-increasing-recycling.
[14] http://ec.europa.eu/environment/circular-economy/index_en.htm.
[15] The Global E-waste Monitor 2020, pg. 58.
[16] Materials innovation for the global circular economy and sustainable society, *Council of Europe, Strasbourg — 20th & 21st November 2017,* VI World materials summit, recycling materials: an absolute necessity.
[17] https://rmis.jrc.ec.europa.eu/?page=scoreboard2016.
[18] Otmar Deubzer, Explorative Study into the Sustainable Use and Substitution of Soldering Metals in Electronics, Ecological and Economical Consequences of the the Ban of Lead in Electronics and Lessons to Be Learned for the Future, 2007.
[19] https://www.eea.europa.eu/themes/waste/resource-efficiency/benefits-of-longer-lasting-electronics.
[20] http://www.prosumproject.eu/sites/default/files/DIGITAL_Final_Report.pdf.
[21] Esther Thiébaud, Lorenz M. Hilty, Mathias Schluep, Heinz W. Böni, Martin Faulstich, *Where Do Our Resources Go? Indium, Neodymium, and Gold Flows Connected to the Use of Electronic Equipment in Switzerland*, Sustainability 2018, 10, 2658; doi:10.3390/su10082658.
[22] Gavriliu Stefania, Lungu M., Enescu E., Lucaci M. - Procedeu de obtinere a contactelor electrice sinterizate din argint-oxid de staniu cu microstructura optimizata, RO122445B1, 2005.
[23] https://www.lme.com/en/Metals.
[24] Project PN 04-43-04-03/NUCLEU 2004-2005, *Ecological technologies for recycling electrical equipment waste.*
[25] RO Bi 115996/1998, *Procedure of recycling of magnetic NdFeB alloys scrap*.

[26] A. Lixandru, P. Venkatesan, C. Jönsson, I. Poenaru, B. Hall, Y. Yang, A. Walton, K. Güth, R. Gauß, O. Gutfleisch, *Identification and recovery of rare-earth permanent magnets from waste electrical and electronic equipment*, Waste management, **68**, 2017, p. 482-489.
[27] Georgeta Alecu**,** Wilhelm Kappel, *Elements of circular economy in the manufacture of NdFeB permanent magnets in ICPE-CA*, Journal of Engineering Sciences and Innovation, **6**, 2, 2021, p. 175-188.