**WEEE recyclinginGreece: estimate of critical metals and toxic compounds.**

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**SUMMARY:**Waste electrical and electronic equipment (WEEE) is among the fastest growing waste streams in the EU, currently representing 4% of municipal waste approximately. Recent provisions imposed a separate collection of WEEE from household waste, pursuing a specific treatment in order to exploit them where is needed for the achievement of a high level recycling. Greek legislation has identified WEEE as a priority waste stream due to the hazardousness, the rapid growth of the accumulated tumor and the significant effects caused on both environment and health. As a basis for discussion toward a better management of WEEE, this research characterizes various types of WEEE in terms of toxic, common and precious metal contents. The objective of this research is the registration of toxic (Ba, Be, Cd, Cr, Pb, Sb), common (Al, Cu, Fe, Sn, Zn) and precious (Ag, Au, Pd) metals. Collection of metal concentrations in different types of WEEE was made by reviewing existing literature. Thereafter, metal flows estimates were based on the amounted WEEE in Greece.Estimates of metal flows (i.e. metal amounts x contents ) constitute the methodology to be followed. The Hellenic Recycling Agencyprovided us with the aforesaid amounts “put on market” as well as the relevant amounts recycled in Greece. All those data though tabulated could not be properly evaluated by this study provided that they concerned every category of EEE provided by the EC Directives and the Greek Law without any distinctions per class of equipment (e.g telephones & mobile phones one category).

Keywords: WEEE, toxic metals, precious metals, recycling, characterization

## 1. INTRODUCTION

Due to the significant technological development during the last decades, Electrical and Electronic Equipment (EEE) has become an integral part of human life [1]. However, Waste Electrical and Electronic Equipment (WEEE) has become one of the fastest growing waste streams [2] and has recently received extensive attention as a secondary resource [3, 4]. For example, each year about 40 million tons of Electronic Wastes are produced in the world [5]. In Greece, according to the Hellenic Recycling Agency / HRA (ε.ο.αν in Greek) the annual production of WEEE from private

households in our country is estimated between 190,000 and 200,000 tones. The producedWEEE amounts on average to 18 Kg per inhabitant per year [6]. The importance of WEEE is not restrictedonly to its amounts, but also to its content. Waste Electrical and Electronic Equipment contains a variety of hazardous material, such as toxic metals [1, 7]. Generally, the final destination of such waste should be a landfill with a high level of environmental protection, due to the content of hazardous compounds [8].

European countries have increased their re-use, recycling and other forms recovery of WEEE under the EC Directive on WEEE, which covers all electrical and electronic equipment for consumer and professional use [3, 9, 10]. Particularly, in order to regulate the treatment and the reducing disposal of WEEE, the European Union has introduced two Directives, the no. 2002/96/EC, which is known by the title ‘‘Directive on Waste Electrical and Electronic equipment’’ (WEEE Directive) and the no. 2002/95/EC, which is known by the title ‘‘Directive on the restriction of the use of certain hazardous substances in electrical and electronic equipment’’ (RoHS Directive)and was recently renewed by the no. 2012/19/EU recast[1,11,12].

In parallel,Greek legislation has identified WEEE as a priority waste stream due to the hazardousness, the rapid growth of the accumulated tumor and the significant effects caused on both environment and health.More specifically, Presidential Decree (P.D.) no.117/2004 concerning measures to-be-taken, terms and an alternative management plan of WEEE (the article 11 defined the main targets for the collection/evaluation of WEEE) substituted by the new P.D. no.114/2013 (article 19) were issued in conformance with the EC Directive 2011/65. FinallythereistheMinisterialDecisionNo. 133480/2011 (FEK 2711/B/15.11.2011).

This research will focus on the assessmentof heavy & precious metal flowsof WEEE in Greece. Specifically, the main objective targeted in this work is the registration of toxic (Ba, Be, Cd, Cr, Pb, Sb), common (Al, Cu, Fe, Sn, Zn) and precious (Ag, Au, Pd) metals. Collection of metal concentrations in different types of WEEE was made by reviewing existing literature.In addition, will be assessed the situation of the amountedWEEE in Greece.

## 2. METHODOLOGY

The methodology of the present work is based on the registration of the concentration of the toxic and precious materials from WEEE. In other words, collection of metal concentrations in different types of WEEE was made by reviewing existing literature. In addition, the main object was the assessment of heavy & precious metal flows through the amounts of WEEE in Greece. More specifically, the way of the assessment of metal flows is the following: two (2) values of the metal concentration will be selected by each category of WEEE, the maximum and minimum figure of the total range. Furthermore, the assessment of the metal flow analyses will be effected from the total amounts of each category of WEEE in Greece mentioned in the provided tables through the following equation:

Metal Flows = Concentrationx Amount

## 3. RESULTS

Conducting literature review,metal composition data were gathered from twenty six (26) different types of WEEE. The most ten (10) importantrange of all them was the Mobile phones, Microwave oven, Cellular phones, Telephones, PCs, CRT TVs, VCRs, Laptops, Radios and TVs. The figures here in below nos. 1,2,3,4 show the maximum and minimum value of metal concentrations in Mobile Phones, PCs, Telephones and CRT TVs respectively.

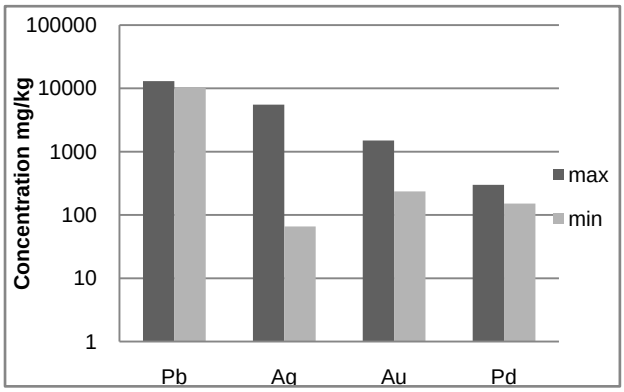


Figure 1. Metal concentrations (Pb, Ag, Au, Pd) in Mobile Phones

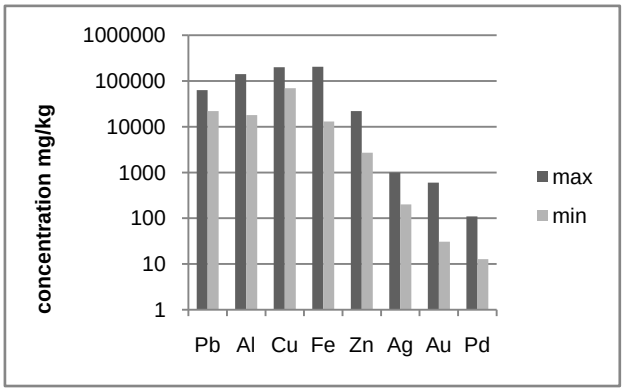


Figure 2. Metal concentrations (Pb, Al, Cu, Fe, Zn, Ag, Au, Pd) in PCs

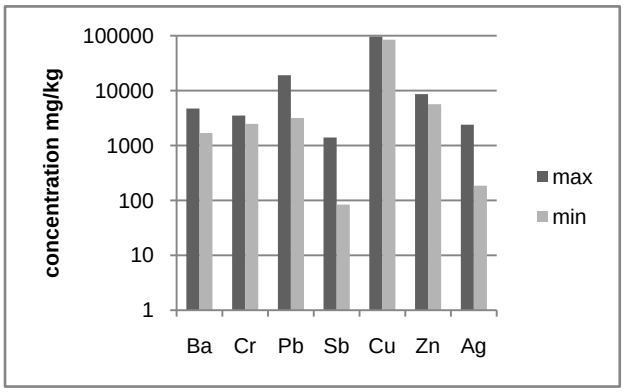


Figure 3.Metal concentrations (Ba, Cr, Sb, Cu, Zn, Ag) in Telephones

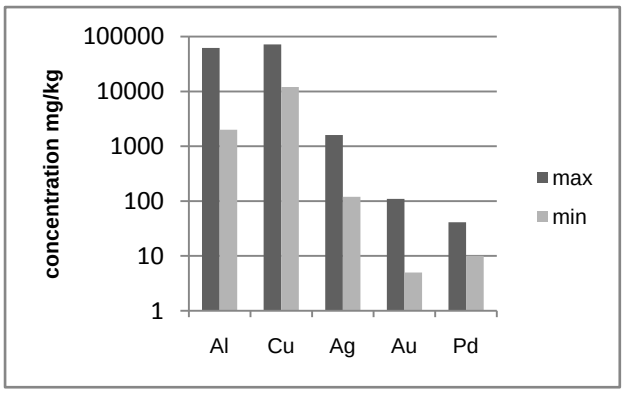


Figure 4.Metal concentrations (Al, Cu, Ag) inCRT TVs

In *Figure 1*is observed that,in the category of Mobile Phones, there is an important range at Ag with maximum value of 5.540 mg/kg and minimum value of 65.9 mg/kg. The same occurs with Au with maximum and minimum values 1500 mg/kg and 236mg/kg respectively. In the category of PCs, there is also an important range at Alwith maximum and minimum values of 141.700 mg/kg and 18.000 mg/kg respectively. The same occurs atFe with maximum and minimum values of 204.700 mg/kg and 13.000 mg/kg, atZn with maximum and minimum values of 22.000 mg/kg and 2.700 mg/kg, at Ag with maximum and minimum values of 1000 mg/kg and 200 mg/kg, at Au with maximum and minimum values of 600 mg/kg and 30,8 mg/kg and at Pd with maximum and minimum values of 150mg/kg and 12,8 respectively (*Figure 2*). In the *Figure 3*, regarding the category Telephones there is important range of values at Sb with 1400 mg/kg and 84 mg/kgand at Ag with maximum value 2400

mg/kg and minimum value 186 mg/kg. Finally, in category of CRT TVs there is also an important range at Al with maximum value 62.000 mg/kg and minimum value 2.0000mg/kg, at Cu with maximum 72.000 mg/kg and minimum 12.000 mg/kg and at Ag with maximum 1.600 mg/kg and minimum 120 mg/kg respectively (*Figure 4*).

In theTables 1 & 2, the Collective Alternative Management Systems "APPLIANCES RECYCLING SA" and "FOTOKYKLOSI SA"in the year 2012contain information on the alternative management of WEEE. Inparticular, Table 1 presents the figures in tons of the total WEEE (per category) collected in Greece in the domestic and non-domestic sector compared to the amounts put on the market. Table 2 presents the relevant amounts in tons as well as the percentages (%) of the Recovery and Recycling of WEEE(per category) in Greece in the year 2012. For all categories of WEEE – according to the aforementioned Collective Alternative Management Systems – it is ascertained that the procedure and re-use of WEEE beyond Municipal Departments is practically zero.

Table 1: Disposal and collection of WEEE in Greece (2012).

| Category EEE | Putonthemarket* | domestic sector | non domestic sector | Total WEEE collected |
|---|---|---|---|---|
| **1. Largehouseholdappliances** | 73.281,34 | 19.103,70 | 913,97 | 20.017,67 |
| **2. Smallhouseholdappliances** | 9.555,30 | 2.635,54 | 2,61 | 2.638,14 |
| **3. IT andtelecommunicationsequipment** | 9.770,52 | 4.830,77 | 216,29 | 5.047,06 |
| **4. Consumerequipment** | 7.625,80 | 7.576,12 | 0,48 | 7.576,61 |
| **5. Lightingequipment** | 3.330,07 | 202,13 | 108,62 | 310,75 |
| **5α. Gasdischargelamps** | 1.907,63 | 300,55 | 38,27 | 338,82 |
| **6. Electrical and electronic tools** | 2.932,20 | 70,29 | 4,35 | 74,64 |
| **7. Toys, leisure and sports equipment** | 1.197,56 | 282,26 | 0,00 | 282,26 |
| **8. Medicaldevices** | 611,43 | 123,48 | 14,63 | 138,11 |
| **9. Monitoringandcontrolinstruments** | 1.241,64 | 591,28 | 2,19 | 593,48 |
| **10. Automaticdispensers** | 92,20 | 183,73 | 34,14 | 217,87 |
| **TOTAL Systems WEEE** | 111.545,68 | 35.899,85 | 1.335,56 | 37.235,41 |

Table 2: Recovery and Recycling of WEEE in Greece (2012).

| Category EEE | Recovery | Recoveryrate ** | Recycling*** | Recyclingrate *** |
|---|---|---|---|---|
| **1. Largehouseholdappliances** | 18.285,68 | 90,2% | 18.285,68 | 90,2% |
| **2. Smallhouseholdappliances** | 2.124,58 | 79,4% | 2.124,58 | 79,4% |
| **3. IT andtelecommunicationsequipment** | 4.750,82 | 96% | 4.750,82 | 96,0% |
| **4. Consumerequipment** | 6.599,90 | 91,8% | 6.599,90 | 91,8% |
| **5. Lightingequipment** | 267,89 | 83,4% | 267,89 | 83,4% |
| **5α. Gasdischargelamps** | 333,45 **** | 98,6% **** | 333,45 | 98,6% |
| **6. Electrical and electronic tools** | 70,31 | 95,6% | 70,31 | 95,6% |
| **7. Toys, leisure and sports equipment** | 241,66 | 85% | 241,66 | 85,0% |
| **8. Medicaldevices** | 116,42 | 94,9% | 116,42 | 94,9% |
| **9. Monitoringandcontrolinstruments** | 588,00 | 99,3% | 588,00 | 99,3% |
| **10. Automaticdispensers** | 225,15 | 95,8% | 225,15 | 95,8% |
| **TOTAL Systems WEEE** | 33.603,87 | 90,7% | 33.603,87 | 90,7% |

Notes:

* Categories of EEE declared in the Collective Alternative Management Systems

** WeightintonsoftherecoveredmaterialsΒάροςvsthe Inflow in the processing units (="Recovery"/" TotallyProcessed")

*** TheRecyclingisidentifiedwiththeRecoveryduetothefactthattherewasnoenergyrecovery. PercentageofRecycling=Weightofrecycledmaterials vsthe Inflow in the processing units (="Recycling"/" TotallyProcessed"). TheRecycling percentageisidentifiedwiththeRecovery percentage

**** In the waste of Gas discharge lamps recycling is implemented. Nevertheless, therecoveryfigures in the Table 2 (tons&relevantpercentages) were not eliminated for calculation purposes.

## 4. CONCLUSIONS

Present research registers data from the international bibliography regarding concentrations of toxic, common and precious metals in various electrical/electronic products from the ten (10) categories of WEEE. The specific data could be further evaluated in futures researches for the assessment of heavy & precious metal flow analyses in Greece. Fundamental prerequisite in order to be implemented such an assessment of metal flows constitutes the availability of data from the amounts of the various classes of the EEE in Greece.

The particular research could not achieved to evaluate the data transmitted by the Collective Alternative Management Systems (ΣΣΕΔ in Greek) «Recycling of Equipment – elecrocycleSA/ΑνακυκλωσηΣυσκευωνΑΕ» and the «Fotokyklosi SA/ΦωτοκυκλωσηΑΕ» for the assessment of flow analyses of toxic, common & precious metals, provided that they concerned every category of EEE provided by the EC Directives and the Greek Law without any distinctions per class of equipment.

The objective of this specific procedure of the present research is to contribute to a better management of toxic & precious metals contained in WEEE, in order to be recovered recycled precious metals and materials and to be minimized the leakage of hazardous substances into the environment as well.

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