GOCE DELCEV UNIVERSITY - STIP
FACULTY OF COMPUTER SCIENCE

ISSN 2545-4803 on line

BALKAN JOURNAL OF APPLIED MATHEMATICS AND INFORMATICS (BJAMI)

BALKAN JOURNAL
OF APPLIED MATHEMATICS AND INFORMATICS

YEAR 2019

VOLUME II, Number 1

GOCE DELCEV UNIVERSITY - STIP, REPUBLIC OF NORTH MACEDONIA
FACULTY OF COMPUTER SCIENCE

ISSN 2545-4803 on line

BALKAN JOURNAL OF APPLIED MATHEMATICS AND INFORMATICS

(BJAMI)

YEAR 2019 VOLUME II, Number 1

AIMS AND SCOPE:
BJAMI publishes original research articles in the areas of applied mathematics and informatics.

Topics:
1. Computer science;
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Republic of North Macedonia

BALKAN JOURNAL
OF APPLIED MATHEMATICS AND INFORMATICS (BJAMI), Vol 2

ISSN 2545-4803 on line
Vol. 2, No. 1, Year 2019

EDITORIAL BOARD

CONTENT

UDC: 005.936.5
UDC: 628.477:621.3

GEO - MAPPING OPPORTUNITIES FOR DETECTING DIFFERENT TYPE OF WASTE AND TRANSFORMATION INTO ECO-BUSINESS SOLUTIONS

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Abstract: Waste electrical and electronic equipment (WEEE) is currently considered one of the fastest growing waste streams in the EU. The recycling of WEEE offers substantial opportunities in terms of making secondary raw materials such as refractory metals available on the market. This paper aims to identify applications and corresponding end-of-life waste products (urban mine) containing refractory metals, estimating the quantities and form of refractory metals in the end-of-life products, as well as to identify the existing collection infrastructures and the economic incentives for delivery of waste products to legal operators. The objective of urban mining is the safeguarding of the environment and the promotion of resource conservation through reuse, recycling, and recovery of secondary resources from waste. Urban mining maximizes the resource and economic value of the waste streams generated in urban spaces and will be a significant concept in the planning and designing of sustainable cities, making the process consistent with the sustainable development goals.

1. Introduction

1.1 The Challenges of Electronics Recycling

The treatment of waste from electrical and electronic equipment (WEEE) has been subject to growing concern in the last decade and has recently lead to vigorous action among legislation setting bodies across the globe. Waste from electrical and electronic equipment (WEEE) is among the fastest growing categories of municipal solid waste and constitutes approximately 4% of the overall municipal solid waste stream. Facing approximately 10 million tons of WEEE in the European Union, sound waste management has developed into a significant challenge for all institutions involved in the end-of-life management of electronic devices. The overwhelming WEEE mass contributes to a growing volume of toxic inputs into the local waste streams. Dependant on the treatment process, WEEE can have a considerably detrimental impact on ecosystems and their environment. Yet, e-waste or WEEE is not only "a problem to be solved". Indisputably, the materials contained in WEEE are of considerable value and, if e-waste as a supply stream was in its size comparable to the volumes processed in traditional mining operations, WEEE would represent one of the most attractive veins of ore to be located on the globe. Given its economic attractiveness as a source of valuable raw materials on the one hand and its potentially harmful impact on ecosystems on the other, a key concern for sound and well thought-out WEEE management are the flows of these materials in a cycle economy and treatment strategies applied to shape and influence these flows. A respective analysis must focus on end-of-life processes as well as on the upstream part of the value chain that includes logistics, sorting, and collection strategies.

The goal of this paper is to describe and quantify the flows of small waste electrical and electronic equipment (sWEEE) and, in particular, the flows of gold and palladium contained in this sWEEE. The term 'sWEEE' covers small household appliances, IT and telecommunication equipment, consumer electronics, tools and toys generated by households or similar to sWEEE generated by households. The material and substance flows are considered in the whole recycling chain (from the generation of sWEEE by the last user up to the exit of the end-of-life phase), so that the losses of precious metals are quantified and recommendations for more efficient recovery can be formulated.

2. Definitions of WEEE

'Waste electrical and electronic equipment' or 'WEEE' means EEE, which is waste, including all components, subassemblies and consumables that are part of the product at the time of discarding. According to the Waste Framework Directive 2008 of the European Union (Directive 2008/98/EC), 'waste' means "any substance or object which the holder discards or intends or is required to discard".

Other definitions of WEEE, also called e-waste or e-scrap, can be found in the literature. According to some investigations, “e-waste encompasses a broad and growing range of electronic devices ranging from large household devices such as refrigerators, air conditioners, cell phones, personal stereos, and consumer electronics to computers which have been discarded by their users”. OECD (2001) defines e-waste as “any appliance using an electric power supply that has reached its end-of-life”. E-waste is a term used to cover almost all types of electrical and electronic equipment that has or could enter the waste stream. Although e-waste is a general term, it can be often considered to cover TVs, computers, mobile phones, white goods (fridges, washing machines, cookers, etc.), home entertainment and stereo systems, toys, toasters, kettles – almost any household or business item with circuitry or electrical components with power or battery supply.” According to some researchers, “electronic waste, commonly known as e-waste, waste electrical and electronic equipment (WEEE), or end-of-life (EOL) electronics, denotes electronic and electrical equipment, including all components, sub-assemblies, and consumables, deemed obsolete or unwanted by a user”.

3. Objectives of WEEE management

End-of-life management of WEEE serves the following goals:

- Reduction of materials going to a landfill, and minimization of landfill-volumes.
- Recycling of materials in order to keep the maximum economic and environmental value and to avoid new material extraction.
- Reduction of emissions of environmentally relevant substances, for example through leaching from landfill sites, incineration slags and off-gases from combustion processes.

These objectives are partly interlinked; from a broader point of view, WEEE management aims at reducing environmental impacts by “developing a society that learns to balance rapid technological evolution with responsible product/material management” refers to separating and recycling materials after the use phase as a “step toward sustainability”, where materials are moved “through the human economy the way they move through nature – in closed cycles”.

4. Electronics Recycling Systems

A substantiated and concise assessment of regulatory policies requires a profound understanding of the regulated industry’s functioning. This chapter will provide a comprehensive picture of the electronics recycling industry, including players and stakeholders with their interests, tasks, and roles, EEE and WEEE characteristics, and the recycling value chain. Where appropriate, the reader will already be familiarized with the formalized modelling structures used for policy simulations and some data excerpts will be embedded to allow the reader to develop a sense of the magnitude of key variables and parameters.

5. The Recycling Value Chain

This chapter presents activities, material, and monetary flows involved in take-back and material recycling. Furthermore, the economics of the recycling value chain are analysed and put into a formalized structure, using activity-based costing as a method to allocate costs to products and services. Figure 1 shows the major steps of the recycling value chain that correspond to the constituents of the economic model.

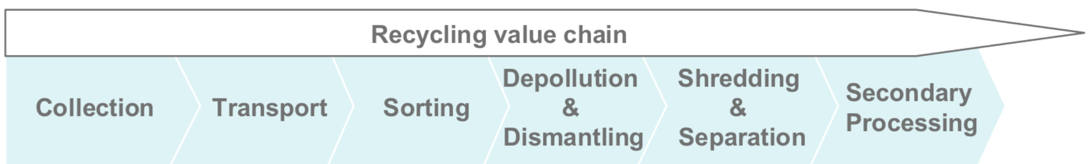


Figure 1. *Recycling value chain*

Each single step is subsequently portrayed, providing data and information on observed practice and the structure of the derived economic model. Some of the data presented has been generated during the research project with the support of different sources and research activities. The section contains a quick explanation of the data background since providing complete information would disturb a smooth reading.

6. WEEE and precious metals

As a consequence of continuous modifications of function and design of appliances, WEEE contains a highly heterogeneous mix of materials. Essential constituents of much EEE include precious metals (gold, silver, palladium) and special metals (indium, selenium, tellurium, tantalum, bismuth, antimony).

6.1. Precious metals

Precious metals (PM) include gold, silver and the platinum-group metals (PGM): platinum, palladium, rhodium, ruthenium, iridium and osmium. All precious metals belong to the transition elements. Precious metals are characterised by high economic value, beauty and particular chemical and physical properties, i.e. low electron affinity, high resistance to corrosion, and high density. Precious metals are all electrochemically noble metals, which means that their standard reduction-oxidation potential has a positive value. Silver has the highest electrical conductivity, the highest thermal conductivity, and the lowest electrical contact resistance of all metals. Table 1 summarizes the properties of some precious metals.

Table 1. *Properties of the precious metals gold, silver, palladium and platinum*

	Gold Au	Silver Ag	Palladium Pd	Platinum Pt
Atomic number	79	47	46	78
Atomic mass	196.96654	107.8682	106.42	195.08
Melting point	1064.43 °C	961.9 °C	1554 °C	1772 °C
Boiling point	2808 °C	2212 °C	2970 °C	3827 °C
Density at 20 ◦C	19.32 $g.cm^{-3}$	10.49 $g.cm^{-3}$	12.02 $g.cm^{-3}$	21.45 $g.cm^{-3}$
Electrical resistivity at 0 ◦C	2.06 µΩ.cm	1.465 µΩ.cm	9.725 µΩ.cm	9.825 µΩ.cm
Thermal conductivity at 0 ◦C	314 $W.m^{-1}K^{-1}$	418 $W.m^{-1}K^{-1}$	75 $W.m^{-1}K^{-1}$	73 $W.m^{-1}K^{-1}$
Average price in 2007[1]	21 701 US-$ per kg	431 US-$ per kg	11 574 US-$ per kg	40 509 US-$ per kg
World mine production in 2007[1]	2500 t	20 500 t	232 t	230 t
Reserve base[1]	90 000 t	570 000 t	80 000 t (including all PGM)	

7. Collection of WEEE and reuse possibilities

The separate collection of WEEE conditions the recycling and reuse of WEEE. WEEE can be collected on a voluntary basis or to fulfil legislative regulations driven by economic and/or idealist motivations (for environmental protection). Collecting large amounts of WEEE to divert it from being disposed of is one of the main objectives of the majority of the current legislations.

In practice, the channels used to collect WEEE differ in terms of both the applied models and the persons or organisations responsible for organising and/or financing the operations. The following models are available for collection:

- Bring systems, with permanent collection centres with fixed opening times, containers on the streets, or temporary collection events;
- Pick-up systems, where the WEEE is collected at the homes or offices of the last users, optionally together with other kinds of waste like packaging waste;
- Distance collection, where the user sends the WEEE by post to the collector.

The responsibility to finance and/or to organise the collection can be in the hands of the following stakeholders:

- Public authorities like municipalities and governments;
- Private commercial organisations like EEE manufacturers, EEE retailers or WEEE recyclers. Besides registered companies, the collection of WEEE by individuals or non-registered commercial organisations belonging to the ‘informal sector’;
- Private non-commercial organisations such as non-governmental organisations or citizen initiatives.

Benefits and barriers to various collection channels were presented by CIWMB (2004a). Seddigh et al. (1996) compared different collection options regarding the willingness of the citizens to use them. Nagel et al. (1998) analysed the collection systems used in Germany, the Netherlands and Sweden. The strengths of temporary collection events, especially the careful handling of the EEE and, therefore, the preservation of the reuse value, were presented by Legler (2009).

Various authors reported that only a small fraction of the generated WEEE is collected (Huisman et al. 2007; US EPA 2008) and that the majority of WEEE still finds its way to landfill (Barba-Gutiérrez et al. 2008). In Germany WEEE is also often disposed of together with residual waste, even though the ElektroG requires separate collection of WEEE (Janz & Bilitewski 2007; 2009). Rotter (2002) estimated that 47% of the lead, over 50% of the cadmium and 31% of the mercury in residual household waste is from WEEE. Musson et al. (2006) investigated the leaching of heavy metals, especially lead, due to WEEE disposal on landfills and found lead concentrations in the leachates above the legal limit. Townsend et al. (1999; 2003; 2008) provided data on the environmental impacts of WEEE disposal on landfills and waste-to-energy facilities in Florida, regarding especially the concentrations of heavy metals and brominated flame retardants in the leachates. Especially cathode ray tubes can cause environmental problems when disposed to landfill, in particular due to the leaching of lead and other heavy metals into ground water (Greenpeace 2005; ICER 2003). Janz & Bilitewski (2009) investigated the transmission of heavy metals contained in WEEE and in batteries to other material fractions and to the leachates during mechanical-biological treatment and landfilling. They concluded that 65% of the WEEE and the batteries contained in the waste treated with mechanical-biological processes should be removed before treatment for the produced residue-derived fuel to fulfil quality requirements. Moreover, valuable materials and substances contained in WEEE cannot be recycled if WEEE is disposed of.

8. Reuse of WEEE

The term reuse has several definitions in international legislations, standards, academia and re-use practice, all embracing different contexts. According to the WEEE Directive, 'Reuse' means any operation by which WEEE or components thereof are used for the same purpose for which they were conceived, including the continued use of the equipment or components thereof which are returned to collection facilities, distributors, recyclers or manufacturers.

Reuse brings economic and environmental advantages, because a large fraction of the economic value of the EEE is preserved, the waste generation is reduced and virgin materials and energy are conserved. However, reuse can also have environmental disadvantages. Thus, the reuse of devices from countries with a large recycling infrastructure in countries with a weak recycling infrastructure raises questions about resource conservation, since the shifting of the devices for reuse probably prevents the resources from being recycled after the use phase. Reuse is sometimes used as pretence for illegal waste export.

In this paper, reuse refers to reuse of WEEE, which implies that EEE has first become waste. According to the European legislation, EEE becomes WEEE if its holder discards it, or intends or is required to discard it. The characteristics listed in Revised Correspondents' Guidelines N°1 on Shipments of Waste Electrical and Electronic Equipment can be used to distinguish EEE from WEEE. Anyway, it is necessary to examine the history of an item on a case-by-case basis to determine if it is EEE or WEEE.

There are several methods of reuse: (1) sell the product to another user, (2) donate the product to another user, (3) if the product is damaged, restore the product prior to moving it to another user and (4) harvest components from it. Regarding reuse of WEEE in practice, three kinds of reuse activities can be distinguished:

- Re-use of working equipment,
- Re-use of equipment after repair and/or refurbishment, and
- Re-use of parts or components.

9. Solving the e-waste problem

The e-waste issue is hard to grasp due to a lack of comprehensive data. Though there is considerable knowledge about negative environmental and health impacts through primitive recycling methods, better information about the quantitative and qualitative dimensions associated with the e-waste problem would make it more understandable and be more useful in order to better inform policy making at the private and public levels.

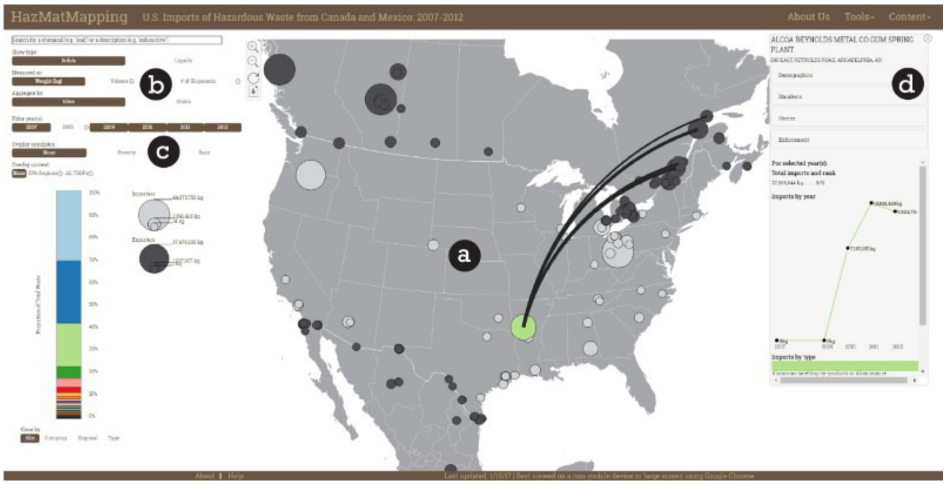
This first-of-a-kind e-waste world-map provides comparable, country-level data on the amount of electrical and electronic equipment put on the market and the resulting amount of e-waste generated in most countries around the world. In order to ensure comparability of data across countries, the data upon which this map is based has been assembled according to a common definition of electrical and electronic equipment, as well as of e-waste. The data will be updated regularly to incorporate additional data (e.g. imports and exports) and enable up-to-date comparisons. Additionally, as a supplement to the primary data, this e-waste world-map also provides links to relevant e-waste rules, regulations, policies, and other useful resources.

Yet, mapping is often a crucial component of understanding waste flows and identifying potential environmental justice (EJ) research and interventions including questions related to locations producing, processing, and depositing hazardous waste. Despite progress in theorizing, the main drivers of waste flows existing studies and interactive mapping applications of the hazardous waste trade are limited to country-level datasets. Such *methodological nationalism* means that attention to trade between nations has come at the expense of analyses of *specific sites within nations* (i.e. communities, cities, or municipalities) that receive hazardous waste from foreign destinations. Furthermore, while several online utilities exist for mapping waste at multiple scales, these tools rarely bring together demographics and waste flows in a way that clarifies site-to-site transactions of specific materials.

In this paper, we use the HazMatMapper to show how we can use an online and interactive geographic visualization tool designed to facilitate exploration of transnational flows of hazardous waste in North America, specifically, US imports from Canada and Mexico. To move beyond anecdotal discussions and national-level analyses, we assembled a novel geographic dataset tracking transnational hazardous waste shipments from documents collected through Freedom of Information Act (FOIA) requests to the US Environmental Protection Agency (EPA). We obtained records for nearly 18,000 import shipments from Canada and Mexico to over 60 US processors between 2007 and 2012. HazMatMapper supports multiscale and site-specific visual exploration of US imports, enabling academic researchers, waste regulators, and the general public to construct a data-supported understanding of regional clustering, transnational corporate structuring, and EJ concerns, as well as to understand limitations of the existing regulatory data collection itself.

HazMatMapper cannot statistically ‘confirm’ environmental injustices and does not support sophisticated geospatial analysis. For researchers interested in investigating hazardous waste trade relationships and patterns using spatial analysis techniques, we have made our compiled data available in a user-friendly format for download within HazMatMapper. Using HazMatMapper, we identified key geographic hypotheses for examination in a larger research project on the international waste trade. We have obtained data on US exports to Canada and Mexico over a similar timeframe, but these data are not available in sufficient quality to be mapped alongside imports.

Figure 2. *HazMatMapper in action: (a) central map; (b) configuration controls; (c) advanced context controls; and (d) information panel.*



10. Conclusion

The demand for precious metals by manufacturers of electrical and electronic equipment has increased significantly over the past few years. Although precious metal concentrations in appliances are very low, these metals have a high economic and environmental relevance compared to other substances present at much higher levels (for example iron, copper, plastics). This paper aims at describing and quantifying the flows of small waste electrical and electronic equipment (sWEEE) in EU and in the USA, as well as the flows of gold and palladium associated with the sWEEE. Although collection systems have been set up, in many cases sWEEE is not collected separately for recycling, but instead is disposed of. Regarding treatment of sWEEE, the model differentiates between reuse and treatments carried out by the formal and informal sector (including illegal export of sWEEE).

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