Imperial College London

E14

IDENTIFICATION OF CRITICAL METAL PRIORITIES IN WEEE

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1. WEEE

The recovery of value from waste is being increasingly recognised as a vital step towards achieving a circular economy. Waste Electrical and Electronic Equipment (WEEE) is one of the fastest growing waste streams, and represents an important challenge to the material recovery industry. The materials contained in WEEE are usually heterogeneous, sometimes toxic, and often valuable; the highest value and recovery potential are concentrated in the metal fraction.

2. CRITICAL METALS

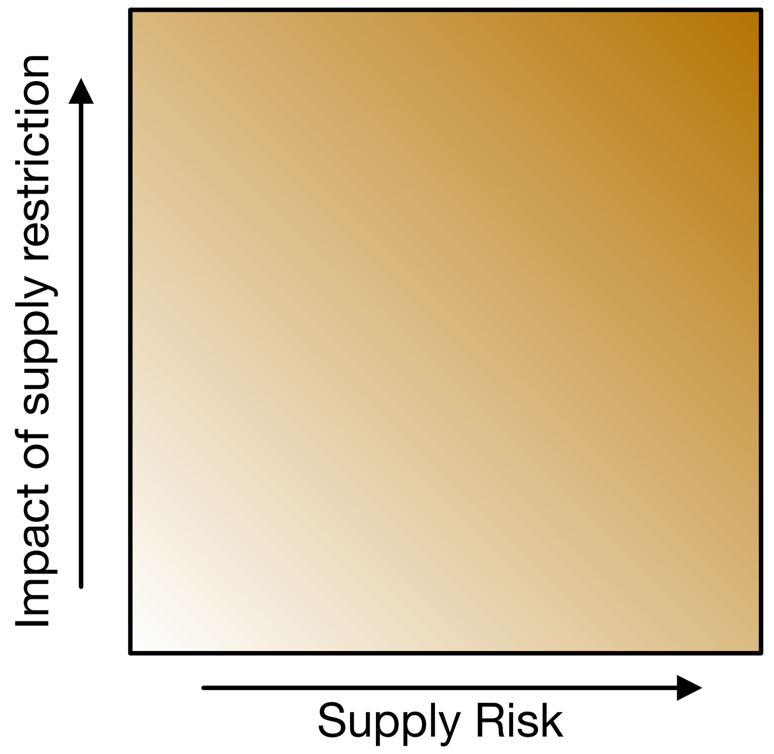

Figure 1: Criticality space

The European Commission published two reports, in 2010 and 2014, on Critical Raw Materials in the EU. These define a criticality space where supply risk is measured against the impact of supply restriction (Fig. 1). The critical metals in WEEE are listed below.

51 Sb Antimony	4 Be Beryllium	24 Cr Chromium	27 Co Cobalt	31 Ga Gallium	32 Ge Germanium	49 In Indium
12 Mg Magnesium	41 Nb Niobium	44-46, 76-78 PGM Platinum Group*	21, 39, 57, 58-71 REE Rare Earths**	73 Ta Tantalum	74 W Tungsten	

*Ruthenium, rhodium, palladium, osmium, iridium, platinum

**Cerium, dysprosium, erbium, europium, gadolinium, holmium, lanthanum, lutetium, neodymium, praseodymium, promethium, samarium, scandium, terbium, thulium, ytterbium, yttrium

3. MULTI-CRITERIA ANALYSIS

To identify the metals with the highest priority for recovery, a multi-criteria analysis method was developed. This allows the use of **conflicting criteria, incommensurable units**, and both **qualitative** and **quantitive scales**. Many of the criteria used (Fig. 2) were composed of several sub-criteria.

Figure 2: Criteria considered

4. ANALYTIC HIERARCHY PROCESS

$$\begin{matrix} 1 & a_{1,2} & a_{1,3} & \cdots & a_{1,n} \\ 1/a_{1,2} & 1 & a_{2,3} & \cdots & a_{2,n} \\ 1/a_{1,3} & 1/a_{2,3} & 1 & \cdots & a_{3,n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ 1/a_{1,n} & 1/a_{2,n} & 1/a_{3,n} & \cdots & 1 \end{matrix}$$

Figure 3: Comparison matrix

In order to assign weights to each criterion, the Analytic Hierarchy Process was used. Pairwise comparisons are made between criteria to establish a hierarchy, of the form: **"What is the importance of criteria 1 relative to criteria 2?"**. The importances are rated on a scale of 1 to 9 to construct the relative importance matrix. **Only the upper triangle of the matrix need be completed**, as the comparisons are internally consistent (Fig. 3). The weights for each criteria are calculated by taking the geometric mean of the relevant row.

ACKNOWLEDGEMENTS

I would like to thank Professor Sue Grimes for her kind support and continued encouragement throughout the project.

5. FUZZY UNCERTAINTY

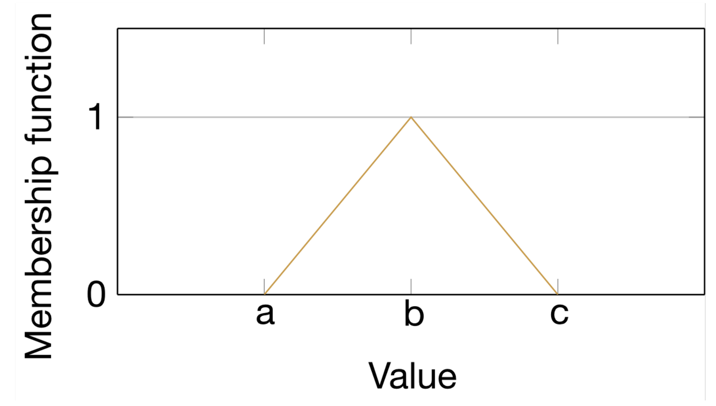

Figure 4: Triangular fuzzy number

Uncertainties were accommodated through the use of fuzzy numbers, which are sets with **non-binary membership functions**. Triangular fuzzy numbers (Fig. 4) are a simple way to characterise uncertainties where a measure of central tendency and an uncertainty is given. Both weights and scores were represented by fuzzy numbers.

They can be combined relatively simply, and *defuzzified* to give values which can be compared and ranked. The method used in this analysis is adapted from that developed by Fu (2008), and considers distances from the **ideal and anti-ideal points** (the best and worst scores possible across criteria) to obtain a final priority value.

6. RESULTS

The results of the analysis (Fig. 5) clearly show **gallium** as the highest priority metal, followed by **indium**, **germanium** and the **rare earth elements**. Reasons for the high priority of gallium include:

- Gallium demand for emerging technologies in 2030 is predicted to be almost four times the current total world production
- No effective substitutes are available
- Production is heavily concentrated in China
- It is vital to the defence, low carbon energy and ICT sectors

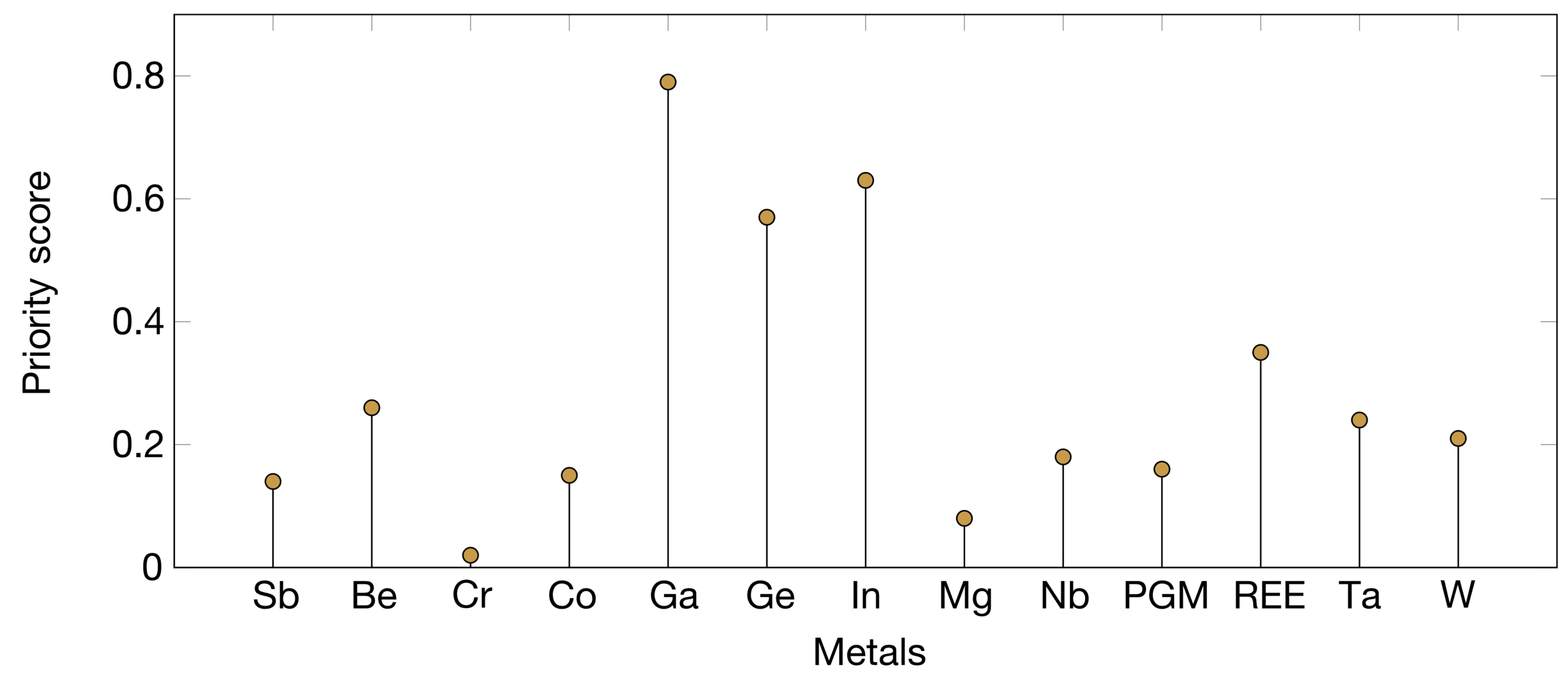

Figure 5: Priority scores of critical metals

7. SENSITIVITY ANALYSIS

'Priority profiles' were constructed in order to test the robustness of the results, with different sets of concerns which affected the pairwise comparison results and hence the weightings:

1. **Long-term policy consultant**: Criticality change, substitutability, recovery, sector importance.
2. **International affairs Minister**: Monopolies, supply reliability, supplier stability, market behaviour.
3. **EU economist**: Criticality change, monopolies, importance to EU economy, substitutability.
4. **Social/environmental activist:** Humanitarian credentials, clean energy, recovery, monopolies.
5. **Military logistics adviser**: Defence, import reliance, recovery, substitutability.

Gallium was consistently identified as the highest priority metal. Beyond this, the rankings shifted, although indium was most often identified as having the second highest priority.

8. CONCLUSIONS

Although gallium and indium are high priority metals in the context of recovery from WEEE, the results of the multi-criteria analysis method are evidently highly preference dependent.

REFERENCES

Fu, G. (2008) A fuzzy optimization method for multicriteria decision making: An application to reservoir flood control operation. *Expert systems with applications*, 34 (2008), 145-149.