Eco-design opportunities for critical material supply risks

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Abstract

A number of recent publications point to the important role of eco-design approaches in risk mitigation for critical materials supply. The core of eco-design is life cycle thinking – usually as some form of Life Cycle Assessment (LCA) approach together with a set of generic guidelines such as checklists, etc. There has however been little appraisal of the extent to which eco-design offers opportunities in the context of critical material supply risks. It is this gap that this paper will tackle. Through research with 30 companies in The Netherlands, a small number see the phenomena of critical materials as an opportunity to seek competitive advantage via new product designs. There is also evidence that those companies see opportunities via an eco-design based approach but there are some issues that need to be addressed before such eco-design approaches could be more successful and used widely.

1 Introduction

Through the 20th century the extraction of material resources from the earth increased 34 times [1]. The electrical and electronics industry has seen rapid technological developments over the past 30 years using an ever increasing range of materials in order to meet the performance requirements in new products [2]. These connected activities have contributed to material supply issues which can be observed through disruptions to supply and price volatility.

This paper discusses what the current best practice in eco-design can offer to mitigate supply risks of critical materials. A material can said to be critical *"when it faces high supply risks or high environmental risks, and be of high economic importance"* [3]. An eco-design opportunity is in Life Cycle Assessment (LCA) together with associated generic eco-design guidelines. There are however some challenges with both approaches.

A review the literature via the topics of critical materials and eco-design has been conducted. Key aspects of the fields helped to develop the rationale for the company research that was undertaken. This, in turn, allowed for a position to be developed, where the proposals in the literature can be compared to actual activities in companies. This paper discusses the results and uses the evidence to suggest that there is indeed further work needed on eco-design approaches in order for them to be fully effective in a critical materials context.

2 Critical materials overview

This section discusses the state of the art regarding critical materials and some of the more pressing factors that affect material criticality and supply risks.

Although the extraction of material resources from the earth has dramatically increased, the prices of materials through that period, although at times volatile, generally had a downward trend and this was especially true over the period from the 1980 – 2000 [4]. One of the drivers for such price decreases were technological developments in mining and processing, and the discovery of new and relatively cheaper sources of supply driven by de-regulated and globalised markets.

The increase in use of previously rarely used elements can be graphically seen in figure 1 where the use is shown for printed circuit boards by Intel [5].

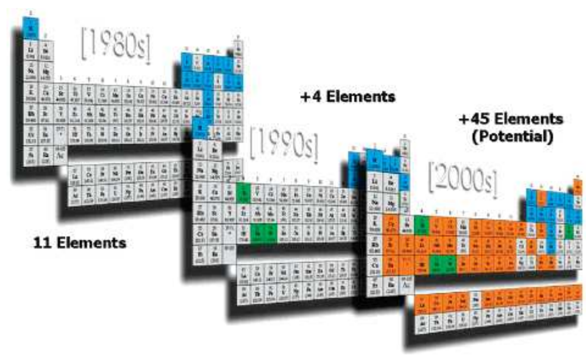

Figure 1: Use of elements in Intel circuit boards

Another example was given by GE when, in 2010, they stated the following: “To put GE’s material usage in perspective, we use at least 70 of the first 83 elements listed in the Periodic Table of Elements” [6]

2.1 Causes of material criticality

Criticality is not a metric which can easily be measured. There have been several proposals to quantify material criticality [3] [7], but to date no single internationally accepted and recognised approach exists. Critical materials can have different levels of criticality for different countries and organisations.

The lists of which materials are critical are many and varied. Much of the attention has been on a number of metals classified within the Rare Earth Elements, range such as Neodymium. For a basis upon which to engage in this research the list issued by the European Commission in 2010 was used.[3]

The main factors playing a part in the current critical materials phenomenon includes;

Increasing demand driven by product technological development. This is particularly true in the electronics sector and attention has also been given to renewable energy generation (wind, solar PV, etc) and electric mobility solutions. The societies who use such products have also been changing with rising population, prosperity, urbanization, and industrialization – all of which has generated higher demand. This has in turn all been driven by developments in info-tainment and communication systems.

Another factor is where the critical materials phenomenon has demonstrated an increasing inter-linkage between resources and economic growth with many regions expressing concerns over their dependency on imports of such materials.

There have been environmental concerns being expressed over the critical materials mining and processing industry. This factor has been used by China as their rationale for restricting exports of Rare Earth Metals in recent years. In turn there are ethical and social concerns, an example of which is the way materials are mined and processed in countries such as the Democratic Republic of Congo.

There is another factor where there is a lack of transparent information in the supply chain, such as agreed data on reserves. This factor allied with the restriction of exports has given rise to defence and security concerns where defence technology systems are reliant on critical materials.

All of the above factors have resulted in difficulty for supply to meet demand, which in turn has caused price volatility. All of which has fuelled concerns over shortages threatening economic growth in the current global financial situation.[8]

2.2 Materials criticality literature frames eco-design as an opportunity

There have, over the past few years, been governmental and research think tank publications on the topic of critical materials which have raised the opportunities provided through product design and in particular eco-design, playing an important role [9].

An example of this approach is the optimisation of disassembly and access to materials in order to facilitate economically efficient processes for reuse, recycling, recovering or substituting materials. The topic of new material design and substitution is proposed in terms of seeking to replace current materials with new ones that are less critical (direct substitution). It is also proposed that a product could be completely redesigned to use a completely different material to do a similar function (indirect substitution) [9].

The connection between critical materials and eco-design can be seen in the current review of the EU Eco-Design Directive. A study document published by Van Elburg [10], proposes using critical materials as a scoring metric to determine if a product class should rank higher in relation to possible future eco-design requirements. The work points out that electronic and electrical equipment would come under the spotlight.

Of note has been the growing interest in, proposing to companies, the development of so called ‘new business models’ around a circular economy [11]. This would mean companies retain ownership or incentivise take back of products or materials for re-use or remanufacture. Such an approach could mean seeking to extend the life of products, which could lead to new sources of revenue through repair, refurbishment and maintenance. Such product life extension can lead to lower material usage through fewer new products being manufactured.

3 The eco-design approach

The core of eco-design is life cycle thinking – usually as some form of Life Cycle Assessment (LCA) approach together with a set of generic guidelines such as checklists.

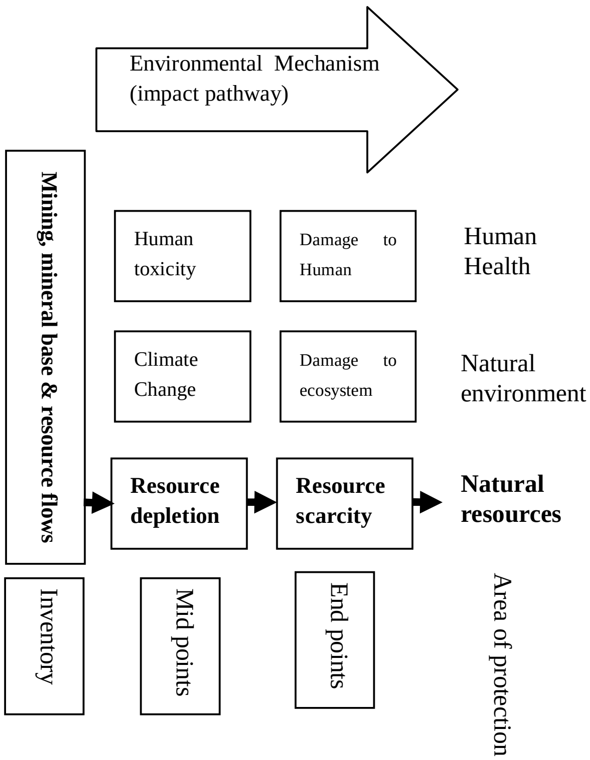

Figure 2: Life cycle impact assessment adapted from the ILCD Handbook (for ISO 14040 series) diagram

The LCA process is a formal method and has been standardised in ISO 14040 series:2006. It is usually a time consuming and complex process and is heavily reliant on accurate material data. One of the direct applications of the life cycle assessment framework is in product development and improvement.[12]

ISO 14040 series is comprehensively supported by the ILCD Handbook: General guide for lifecycle assessment [13]. In this detailed guide there is an introductory diagram which shows the life cycle impact assessment and the schematic steps from inventory to category endpoints. This shows how the LCA approach can address the critical materials issue and this is demonstrated in the adapted diagram shown in Figure 2. This has, as one of the impact pathways, the issue of resource depletion leading to resource scarcity.

A good example of generic guidelines is provided by Brezet and van Hemel with the eco-design checklist. Questions such as: *"What problems can arise in the production and supply of materials and components?"* provides an example [14].

Rodrigo and Castells in their book Electrical and Electronic practical eco-design guide, show general guidelines to advice designers *'Try to minimize the use of scarce non-renewable resources'*.
In their comments they say that the consequences of extracting scarce non-renwable resources can be severe and they give the example of copper that *'..may become extinct'*. They go on to propose that such valuable materials should have a well established recovery and recycling system in place. More generally they propose designers should *'Pressure and motivate suppliers to design and produce more energy efficient components and parts'* [15].

This section has demonstrated there is the possibility to address critical materials risks using an eco-design approach.

3.1 A gap between theory and practice?

There is a growing view that eco-design approaches will have a significant role to play in the critical materials context – but there has been little evidence of detailed examples in practice. As Knight and Jenkins put it for eco-design *"evidence of actual implementation is sparse: The literature is full of examples of pilot DfE (Design for Environment) projects on the corporate level, but of few examples of the introduction into product development"* [16].

The next section indicates that the same could also be said of eco-design in the critical materials context.

4 The research with 30 companies

In order to understand further if companies are using eco-design approaches in response to critical materials risks it was decided to conduct research on them.

FME–CWM (FME) is an industry representative organisation for companies in the technological industry in The Netherlands. Together with research organisations M2i, TNO and Delft University of Technology, a research objective to gain a better understanding of company awareness of and responses to, the critical materials phenomena, was developed.

With a view to acquire a representative sample, a spread of companies over various sectors and different places in the supply chain, were selected.

Company type	Description	Product examples
Material producers	Processed raw materi-als	Copper (bar, wire)
Component producers	Producing components (mostly B2B market), using metals, basic metals and intermedi-ate goods	Electronics, LED's
Sub-assemblers	Producing subassem-blies: more complex assemblies	Computing, lighting
Producers	Producing relatively simple products, with relatively simple sup-ply chain	Domestic appliances, electric tools
Integrators	Producing complex products and equip-ment (OEM) with a complex supply chain	Medical equipment, production systems

Table 1: Table showing the company type, description and examples of their products.

As part of a mixed methods approach, 30 companies were interviewed.

The interview participants were mostly employees of either a procurement or R&D department. During the interviews the EU list of critical materials [3] was used and additional space was left for the companies to indicate other materials that they consider as critical.

It can be seen in table 1 that there was a significant number of companies with some form of electronics involvement in their product offering.

5 The research results

In terms of general awareness over three quarter of the companies said they are familiar with the term critical materials. Most of the companies are following the developments around the critical materials subject to varying degrees with only six companies not doing so at all.

The respondents indicated that of the 35 different critical materials on the EU list, 12 are being used by them. One of those most often named was Neodymium, as an element used in permanent magnets. From the EU list of critical materials Cobalt, Germanium, Indium, Niobium, Tantalum and Lanthanum were also named as being critical. One of the most frequently named non-EU critical list materials was Copper.

Over 80% percent of participating companies have had difficulties with supply of the critical materials (from both the EU list and non EU list) over the last five years. In most cases it appeared that the supply chain was sensitive to disruptions and there were insufficient secondary sourcing opportunities available. The activity was mainly undertaken by purchasing departments. Re-designing the product was done by only a few companies. In figure 3 the actions undertaken are shown and they are divided into product changes (green), company stock management (blue) and actions focussed towards suppliers (red).

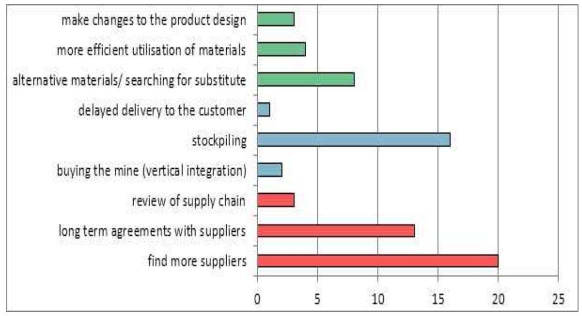

Figure 3: Action as a response to critical materials issues taken by the companies

Most of the companies interviewed, who accept that critical materials are a risk, were pro-active towards critical materials. The dominant approaches are stockpiling for short term future production, setting up long term agreements with suppliers (up to 12 months) and finding more suppliers to allow more switching. Some are seeking to limit waste as part of material efficiency activity. Others are looking for alternative materials that could perform the same or closely similar function.

Twenty two of the companies (73%) expect that the role and price of critical materials will grow. An often quoted reason was an expected increase in the volumes of high-tech electronics & electrical appliances production.

In terms of threats and opportunities sixteen companies (53%) do not expect to have problems, due to their own good supply chain management and new (external) developments in recycling and production of critical materials. Six companies (20%) do, however, expect problems with critical materials over the next five years. One of the key reasons for this was because there is not enough capacity in the companies for effective product innovation.

Seven companies (23%) see opportunities as a result of the increasing role of critical materials. Critical materials phenomenon was perceived to be a stimulus to a raised awareness of material applications & use and to explore cradle-to-cradle design approaches. LCA was not discussed by any of the companies in the context of critical materials. Terms that were used included 'seeking materials efficiencies' and 'risk management'.

None of the companies mentioned the new business models typified by the circular economy or the corresponding longer product life.

6 Discussion

It is clear that both the fields of 'eco-design' and 'critical materials' are complex and that this paper has only been able to present certain aspects of these domains. A range of publications see eco-design as an approach that has the potential to provide a solutions space to the challenges and opportunities that the critical materials phenomenon presents. With respect to LCA, it can be seen that the quality of input data is an important factor and in the case of many critical materials, such as Rare Earth Elements, such data is either inadequate or missing. Added to this is the lack of knowledge and awareness of the presence of such critical materials in the supplied parts and assemblies, which makes the task of deploying an LCA even more difficult.

In the case of the more generic guidelines there are often contradictions. For example where the literature proposes that the designer '*Try to minimize the use of scarce non-renewable resources'*, it should be borne in mind that in many cases the materials in question are used in very small amounts to start with as alloying agents, and that changing their amount could adversely affect the final material performance – this is often true in the electronics sector. This is brought into sharper focus when the proposal for designers to '*Pressure and motivate suppliers to design and produce more energy efficient components and parts'* often results in the increased use of critical materials – again especially true in the electronics sector.

This view of the literature appears to be reflected in the company research results. None of the companies discussed the use of LCA as an approach they were taking. The role of eco-design more generally was referred to by only a few companies as a 'stimulus' at this stage.

It can be proposed that eco-design, as it is currently positioned, does not seem to be accepted by companies as either a critical materials solutions space, or a critical materials risk management opportunity. This is a result that is not a surprise to researchers in the eco-design field where companies more generally have not felt able to take up eco-design comprehensively. It is however an indicator that, at this time, the phenomenon of critical materials has not changed the situation and it could be argued it has made it even more challenging. It is becoming clear that the pressure for change is rising both in terms of risk and regulation.

Suggestions for a way forwards include; greater support to companies to allow them to access data and knowledge they need to make eco-design approaches work. As part of this, knowledge institutions need to engage in practice based research to develop eco-design further. Specific examples include the further understanding of materials flows and impacts, improved design for recycling methods, LCA tools developed for specific sectors, materials researchers and product designers to join forces to find innovative solutions, networks of excellence to be formed across Europe, develop with companies alternative strategies such as inspiration from nature, deepen our understanding of the meanings of materials and develop business models with companies that can facilitate longer lasting products.

7 Conclusions

This paper has shown how the domain of eco-design has a number of areas where direct reference to the challenge of critical materials is made. More specifically within LCA or more generic guidelines there is scope to address critical materials risks. In addition to that however, it has been suggested that LCA approaches are difficult to deploy in the context of critical materials because of data issues and lack of knowledge. The more generic guidelines are also difficult to apply because of their sometimes paradoxical and contradictory nature.

The critical materials literature demonstrates that the phenomenon is complex and even determining a list of critical materials is difficult and controversial. This literature does see eco-design as an important approach – particularly in relation to re-use, remanufacture and recycling. It goes on to propose new business models and a circular economy approach.

The practice in the companies interviewed tends towards much more traditional business approaches to supply chain difficulties. Re-design of products is on the agenda for a few but the use of eco-design and in particular LCA does not appear to be being considered.

Risk management is widely used and the use of resource efficiency is deployed. Cradle to Cradle was mentioned but new business models and the circular economy was not.

A range of possible solution fields has been outlined for further work.

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