Identification of Innovative End of Life Management Behaviours for the Sustainable Recovery of Valuable Products

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Abstract. This work aims at developing a sustainable End of Life strategy assessment tool for the definition of innovative business models in waste PCBs environments. Starting from an extensive literature review about current waste PCBs management strategies and business models, a series of sustainability drivers will be defined. These drivers will be used as performance indexes for the assessment of a series of selected case studies. Basing on the obtained results, a set of innovative waste PCBs management behaviours will be proposed. The final aim is to support European reverse logistics networks in the definition of innovative actions able, from one side, to counteract current waste PCBs volumes generation and, from another side, to support companies in reaching new recovery and recycling rates established by the updated versions of WEEEs and ELVs EU Directives.

Keywords: Waste Printed Circuit Boards (PCBs), Waste from Electrical and Electronic Equipments (WEEEs), End-of-Life Vehicles (ELVs), End-of-Life Strategies, Business Models.

1 Introduction

The critical materials demand is constantly growing in Europe, causing relevant problems to the entire economy. According to 2014 EU Commission data, their criticality depends on a series of elements:

- High supply risks due to mines concentrations in few countries;
- Low substitutability of materials with equally functional ones;
- Low recycling rates of current technologies;
- Extremely high variability of market prices.

The only way to counteract this criticality seems to be the recovery of resources from wastes, especially from technological ones. Waste from Electrical and Electronic Equipments (WEEEs) and End of Life Vehicles (ELVs) represent the two most important waste streams from this side, with high annual growth rates of 3-5% and 2-3%, respectively (Ongondo and Williams, 2011; Rotter and Chancerel, 2012). Given that, they are becoming a very important source of secondary resources for the near

future. In fact, both of them embed a series of different materials (metals, non-metals, plastics, ceramics, etc.) that can be recovered for the production of new products (UNEP report, 2013). Furthermore, they have in common an important component, or Printed Circuit Boards (PCBs), offering potential great advantages from the recovery point of view. Thanks to their composition (about 25-35% in weight) in valuable metals (e.g. Au, Ag, Pt, Cu), they are re-known by the experts as "urban mineral resources" (Graedel et al., 2011; UNU, 2012). Therefore, the development of sustainable strategies for the materials recovery from this kind of wastes is of outmost importance for the European and global economy (Wang and Chen, 2011). However, the feasibility of these strategies is necessarily linked to the current technological development into two main areas, or recycling and remanufacturing processes of electronic products. Recycling is a very challenging process that has not reached yet a good sustainability level, basing on various scientific findings (Kumar and Sutherland, 2008; Ellen McArthur Foundation, 2012; Berzi et al., 2013; Simic, 2013; Lu et al., 2014). Highly energy-consuming processes with low recovery rates of valuable materials (variable from one material to another), very few links among actors involved in reverse logistics chains and the lack of proven successful business models represent only some critical examples. Remanufacturing is another important process that needs to be improved. By considering recent literature reviews (CR&R, 2013), it is mainly applied in the automotive sector. However, there are many other industries interested in its application (e.g. aerospace, communication and medical equipments, printers, etc.). Again, there are many papers explaining the great advantages coming from this discipline (Ghazalli and Murata, 2008; Vasudevan et al., 2012; Giuntini, 2013). In fact, from a pure sustainability view, remanufacturing is better than recycling. The problem is that remanufacturing is more difficult to control from a managerial point of view (Mukherjee and Mondal, 2009; Atasu et al., 2010). If not controlled at all, it could cannibalize new products sales. Therefore, the positioning of remanufactured products in the market is yet too difficult to do in too many markets. This way, remanufacturing is currently limited to some specific products in market niches. Given all these issues, this research wants to assess the current state of the literature (and the industry) with the final aim to propose innovative (and feasible) sustainable business models able to exploit benefits coming from a mixed use of remanufacturing and recycling for the recovery of waste PCBs extracted from both WEEEs and ELVs.

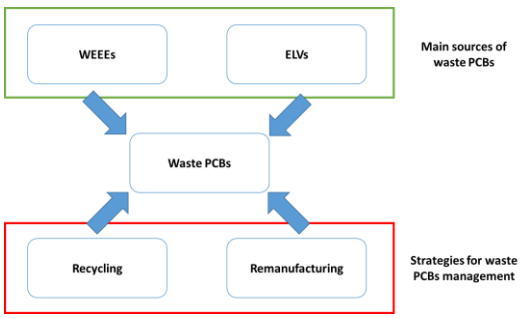


Figure 1. Research proposal's framework of analysis

Literature review

1.1 Selection of articles

Journal articles, published from 2000 up to early 2015, provided by the most popular academic search engines (e.g. Google™ Scholar, Sage™, Science Direct™, Springer™, Taylor&Francis™ Online and Wiley™ Online Libraries) were evaluated. Aim of the review was to capture a snapshot of the different researches conducted, during the last decades, in the waste PCBs management field. An initial set of keyword**s** (WEEEs, ELVs, automotive, automotive electronics, PCBs and ECUs) was combined with different terms (e.g. management, disassembly, recycling, remanufacturing, reuse, reverse logistics, technologies), and searched in titles, abstracts and keywords of scientific papers. Basing on the amount of available papers found, a refining of searching terms was subsequently conducted up to define a set of relevant papers directly related to the research topics. Furthermore, the literature search was extended to intra-national institutions and industrial reports, in order to create a comprehensive database of waste PCBs management literature.

1.2 Classification framework

The literature review was based on the classification framework developed by (Burgess et al., 2006), subsequently adapted to the specific needs of this research. The articles were divided into 3 groups, as shown in Table 1, starting with descriptive features of the literature, and progressively working through theoretical issues. The same process was replicated for both ELVs, WEEEs and waste PCBs topics.

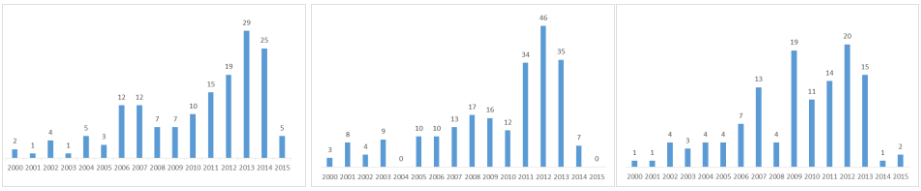
Grouping	**Content covered**
Descriptive features	Time distribution of publications, Journal names and Industry sectors
Waste PCBs issues	Management approaches, Conceptual framing and Discipline bases
Research methodological issues	Research methods

Table 1. Literature review classification framework (adapted from Burgess et al. 2006)

Descriptive features

Time distribution of publication of articles.

Fig. 1 displays results of the search process, in terms of number of papers per year, and publications trend. The total amount of papers (224 in mass electronics, 157 in automotive, and 123 in PCBs manufacturing sectors) reveals the relevant attention devoted to this topic (from 2000 up to early 2015) by the experts.



(a) (b) (c)

Fig. 1. Historical series of published papers: (a) ELVs, (b) WEEEs, (c) waste PCBs

Journal names

The journals' classification (by number of published papers between 2000 and early 2015) indicates Journal of Cleaner Production as the major information source in ELVs topics. From WEEEs point of view, the Waste Management Journal is the most cited information source. Finally, from waste PCBs point of view, the Journal of Hazardous Materials is the most cited – see Fig. 2.

(a) (b) (c)

Fig. 2. Top five journals: (a) ELVs, (b) WEEEs, (c) waste PCBs

Industry sectors

There are several industries speaking about waste PCBs management. In general terms, these industries are represented by the mass electronics sector, the automotive sector, and the PCBs manufacturing sector – see Fig. 3.

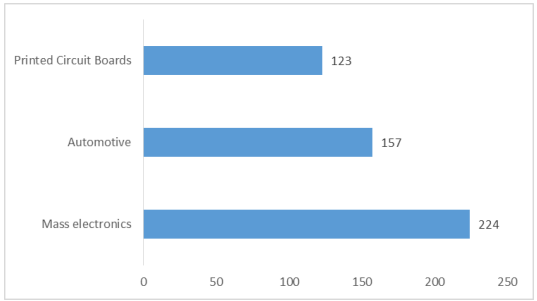


Fig. 3. Industry sectors

Waste PCBs issues

Waste PCBs management

The analysis highlighted a multi-disciplinarity of the topic. For this reason, journals pertain to various research fields and scientific areas. However, what seems to be clear is the lack of literature in waste PCBs management coming from both the three industrial sectors taken into account. From the ELV's and WEEE's literature views, there is a clear focus on recycling and remanufacturing processes and policies. Instead, the recycling of automotive electronic components is rarely analysed (almost 1.5% of cases). However, by considering only the waste PCB's literature, there is the same trend, and EoL management strategies are partially considered.

Research methodological issues

From a first analysis of research methodologies used in studying waste PCBs management in the three different industries previously presented there is a clear lack in action research and case studies. Theoretical research is widely used both for environmental and economic purposes, and to analyse the application of EU directives in practice. Instead, empirical research is adopted to present innovative ideas, especially from a technological point of view.

1.3 Evidences

The wide literature analysis on waste PCBs management into different sectors evidenced, as already explained, a clear lack of studies focused on innovative strategies and business models able to cope with the increasing amount (and different typologies) of wastes generated annually around the world. The concurrent limited innovativeness of the adopted technologies and issues in relationships among different actors acting in the reverse logistic chain are only worsening the situation. Hence, there is a clear need of new efforts coming from the research. This work tries to answer to some of these needs.

2 Research questions, methodology and project plan

A theory is an attempt to explain how a system or phenomenon works by identifying the constituent elements of the system and how they interact and relate to each other. Since the waste PCBs management is a quite relatively new topic, this project is based on an *exploratory approach*, appropriate when the objective is to explore an area where there is little known. In particular, this research project follows a *theory building process*, in which research begins with observations and uses inductive reasoning to derive a theory from these observations. Given the lacks of the literature focusing on waste PCBs management, two research questions can be defined:

1. ***Which of the existing End-of-Life strategies (or a mix of them) is preferable to manage waste PCBs in a better – and sustainable – way?***

2. ***How much is the potential profit coming from the recovery of this type of electronic wastes, both for ELVs and WEEEs contexts?***

The first one is focused on the definition of sustainable strategies for a better management of waste PCBs. The second one wants to assess the economic feasibility of waste PCBs recycling practices, even with cores coming from different waste streams.

From the project plan point of view, the following graph can summarize the main activities that will be implemented during the PhD course:

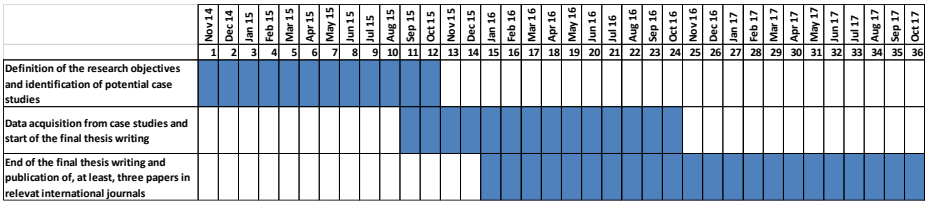


Fig. 4. Project plan schematics

3 Conclusions

3.1 Contribution to theory

This work aims at contributing to research in the field of waste PCBs management, which is a still a quite relatively new topic, not yet consolidated. More in detail, the project aims at:

- Propose innovative sustainable business model;
- Define a strategy assessment tool supporting decision-making processes.

3.2 Contribution to practice

Although the concept of waste PCBs management has been discussed in the literature for over a decade, its actual implementation is limited. This is because the transformation from an unbundled to an integrated business model requires not only modifications in company offering, but also changes in its internal organisation and in its relationships with customers and suppliers. Significant challenges exist to implement these changes (Kuo et al., 2009). The objective of this work is to support companies at different levels, from a strategic to an operative perspective. The use of a waste PCBs strategy assessment tool could help managers easily communicate and share their understanding of a business among other stakeholders (Fensel et al., 2001). Moreover, it can be used as a foundation for discussion, facilitating change and enabling the reuse of knowledge. In particular, the theoretical constructs correspond to the fundamental elements that affect the success of a business, while the empirical variables represent the levers on which companies should act to improve their performances. Consequently, the strategic assessment tool could help managers to define the business strategy, while the conceptual framework can assist in the identification of the practices to implement, in order to operationalise the corporate sustainability concept within the company.

4 Acknowledgements

This work is partly funded by the European Commission through the ELICiT Project (ENV-2013-603885, www.elicit-project.eu). In any case, the present work cannot be considered as an official position of the supporting organizations (EU Commission), but it reports just the point of view of the author.

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