A Review on Upcycling: Current Body of Literature, Knowledge Gaps and a Way Forward

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***Abstract*—**Upcycling is a process in which used materials are converted into something of higher value and/or quality in their second life. It has been increasingly recognised as one promising means to reduce material and energy use, and to engender sustainable production and consumption. For this reason and other foreseeable benefits, the concept of upcycling has received more attention from numerous researchers and business practitioners in recent years. This has been seen in the growing number of publications on this topic since the 1990s. However, the overall volume of literature dealing with upcycling is still low and no major review has been presented. Therefore, in order to further establish this field, this paper analyses and summarises the current body of literature on upcycling, focusing on different definitions, trends in practices, benefits, drawbacks and barriers in a number of subject areas, and gives suggestions for future research by illuminating knowledge gaps in the area of upcycling.

***Keywords*—**circular economy, cradle to cradle, sustainable production and consumption, upcycling, waste management

I. Introduction

UPCYCLING is often considered as a process in which waste materials are converted into something of higher value and/or quality in their second life. It has been increasingly recognised as a promising means to reduce material and energy use. For example, Braungart and McDonough [1] pioneers of industrial upcycling (i.e. Cradle to Cradle), have advocated radical innovations for perpetually circular material reutilisation as opposed to current recycling practice, and helped a number of companies to incorporate upcycling in their businesses (e.g., Steelcase, Herman Miller, Ford). Szaky [2] sees object upcycling as one of the most sustainable circular solutions since upcycling typically requires little energy input and can eliminate the need for a new product from virgin materials. Such object level upcycling has been actively promoted and practiced by increasing number of entrepreneurs including TerraCycle, FREITAG, Reclaimed, The Upcycling Trading Company and Hipcycle to name a few.

The growing number of publications on upcycling in various subject areas also shows that the concept of upcycling has received more attention from numerous business practitioners, researchers, and craft professionals and hobbyists in recent years. According to the Google Books search done by the author in September, 2014, upcycling-related books have been published since 1999.[1] Most books (96%; 115 out of 120 books) in the sample were published between 2008 and 2014 with higher publication rate between 2012 and 2014 as 62.5% of all samples (75 books between 2012 and 2014; 21 books in 2012; 28 in 2013; and 26 in 2014). 53% (64/120) of the sampled books are categorised as 'craft and hobbies' whereas the other book categories show similar percentages (art & design: 10%; house & home DIY: 10%; science & technology: 9%; business & economics: 8%; and the rest as miscellaneous).[2] The theses search on Google Scholar simultaneously conducted by the author showed a similar recent surge of publication: 90% (37/41) of these in the sample (since 2001) were published between 2009 and 2014.[3] Subject areas in them include architecture, art, business & management, design engineering, engineering, environmental study, textiles & clothing, among others.

Despite the rising interest in upcycling manifested by industrial interest along with increased publication levels, surprisingly, no major academic review has yet been presented to my knowledge. This might be partially attributed to the fact that the term, upcycling, is a neologism. The first recorded use of the term has been traced back to an interview with Reiner Pilz [3]. For this reason, the overall volume of literature dealing with upcycling is still low. Therefore, in order to further establish this field, this paper analyses and summarises the current body of literature on upcycling, focusing on different definitions, trends in practices, benefits, drawbacks and barriers in a number of subject areas.

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[1] Search keyword combination, "upcycle" OR "upcycling", was used. Total of about 9,290 pages were seen available (with about 92,900 books with overlapping search items). Including only English materials, and excluding fictions and the books not dealing with upcycling as main contents, 120 books were identified as relevant among 310 books (within 31 pages). Given the sorting method by relevance and the proportionally reducing number of relevant books accordingly page by page, further search result after page 31 was considered to be irrelevant.

[2] Book categories come from Google Books category system. Miscellaneous book categories include juvenile nonfiction, social science, literary criticism, humour, sports & recreation, capitalism, and reference.

[3] Search keyword combination, ["upcycle" OR "upcycling"] AND ["dissertation" OR "thesis"], was used. Total of about 423 pages were seen available (with about 4,230 theses/dissertations with overlapping search items). Given the sorting method by relevance and the proportionally reducing number of relevant thesis/dissertations accordingly, further search result after page 25 was considered to be irrelevant. Excluding non-English materials and checking the relevancy by skimming the abstract, 41 documents were considered relevant.

II. Research Methodology

This paper is based on the concept and systematic approach of literature review suggested by Fink [4]. Her systematic approach consists of seven tasks: (1) selecting research questions; (2) selecting bibliographic databases; (3) choosing search terms; (4) applying practical screening criteria; (5) applying methodological screening criteria; (6) doing the review; and (7) synthesising the results [4]. The following sub-sections describe how these tasks have been conducted. Methodological screening criteria were not applied in this study since some literature (e.g. book chapters) is not based on scientific research.

A. Selecting Research Questions

The research questions include: (1) what has been the trend in upcycling publication over time? – in terms of publication frequency, methodologies and approaches used, subject areas, industries involved, and country of origin; (2) what is the definition of upcycling?; (3) what are the trends in practices?; and (4) what are the known benefits, drawbacks and barriers of upcycling?

B. Selecting Bibliographic Databases

Acknowledging the relative newness of the term, upcycling, a wide range of major digital academic databases were selected for search, including Elsevier, Emerald, Google Scholar, IEEE, Metapress, Scopus, Springer, Taylor & Francis, Web of Science, and Wiley.

C. Applying Practical Screening Criteria Including Search Terms

A search keyword combination of "upcycle" or "upcycling" was used to identify literature. Only English publications were considered for selection. The selection was focused upon journal articles, conference proceedings, academic books and book chapters, and research institute reports. Theses, book reviews, editorials, working papers, self-published books and practical books (e.g. how to upcycle clothes, furniture, etc.) were excluded.

D. Doing the Review and Synthesising the Results

The database search was conducted in July, 2014. The search yielded a total of 297 items dating from 1994 to 2014 with overlapping results.[4] Duplicate results were removed before practical screening followed by content screening. Each article was examined to assess the content relevance, mainly by reading abstracts. This process resulted in 48 relevant pieces of literature. Eight highly relevant materials were manually added later on [1], [2], [3], [5], [6], [7], [8], [9]. Including this addition, a total of 55 (=n) relevant publications were used for both descriptive analysis, and synthesis of the results.

[4] 111 from Springer; 110 from Google Scholar; 45 from Scopus; 21 from Web of Science; 7 from Metapress; 2 from Taylor & Francis; 1 from IEEE; and 0 from Elsevier, Emerald and Wiley.

III. Results

A. Descriptive Analysis: Trends in Upcycling Publication

The reviewed publications (n=55) include 26 journal articles, 11 conference proceedings, 9 book chapters, 5 books, 3 periodicals and 1 report. Using a chronological perspective,

shows the cumulative frequency of the number of reviewed publications since 1994 when the term, upcycling, was first used in a recorded form. The graph indicates the rapid growth of publication since 2008 after the steady growth between 1994 and 2007 (Fig. 1). This recent rise of publication corresponds with the publication trend in general books and theses as explained in Introduction.

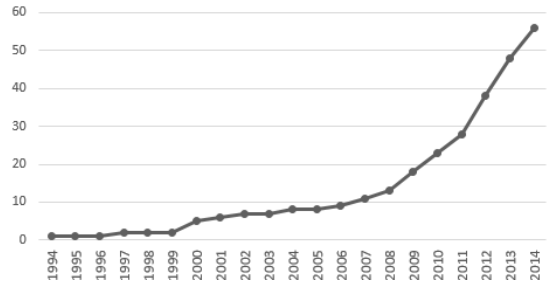

Fig. 1: Cumulative frequency of the number of the sampled publications

Conceptual papers or books appear to be the most popular form of publication (n=20; 36%). Other frequent approaches include case studies (n=12; 21%), experimental studies (9; 16%), and literature review & document analysis studies (7; 13%) (Fig. 2).

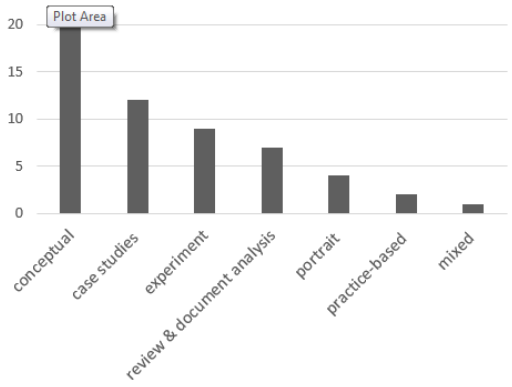

Fig. 2: Approaches adopted in the sampled publications

Fig. 3 presents the different subject areas of the reviewed publications. Engineering and technology is the major subject area (n=22; 40%) followed by design (17; 31%) and business (9; 16%). Other areas include waste management, general science, literature and lifestyle.

Fashion and textiles seem to be the main sector addressed, being cited in 14 publications (25% of the total). Plastics recycling (n=9; 16%) is the second most frequently published area followed by construction (4; 7%) and organic waste treatment (3; 5%) (Fig. 4). Nonetheless, the largest proportion of the sample does not specify any industry (n=16; 29%),

probably because the majority of the literature is theoretical and conceptual than based on empirical evidence (Fig. 2).

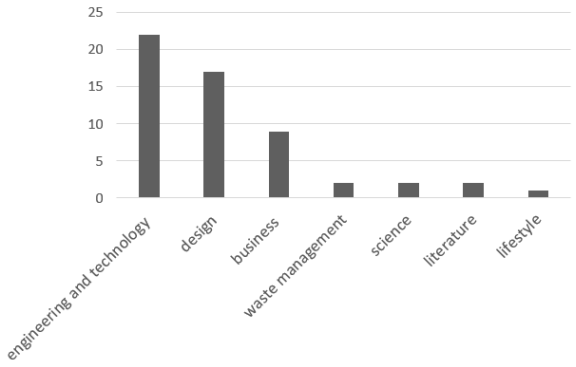

Fig. 3: Subject areas of the sampled publications

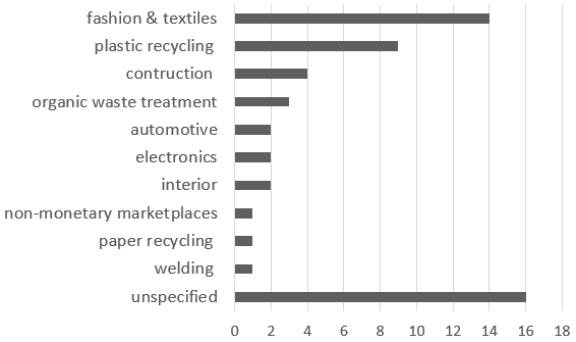

Fig. 4: Sampled publications distribution by industrial (sub)/sector

Fig. 5 shows different country origins of the literature sample. The USA, the UK, and Germany take the lead as single countries. North America (USA only 44%) and Europe (42%) are the main publication regions. Asia (11%) and Pacific Islands (3%) have played minor roles in publication on upcycling.

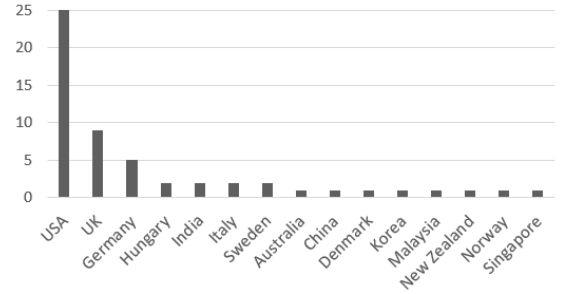

Fig. 5: Sampled publication distribution by country

B. Definitions of Upcycling

Nearly half of the publications (30/55) present explicit definition (or descriptive statements) of upcycling. Eight definitions [9], [10], [11], [12], [13], [14], [15], [16] originated from Braungart and McDonough [1]. The original description says, "A technical nutrient is a material or product that is designed to go back into the technical cycle, into the industrial metabolism from which it came. […] Isolating them from biological nutrients allows them to be upcycled rather than recycled – to retain their high quality in a closed-loop industrial cycle." [1, pp. 109-110]. The eight definitions similarly define upcycling as the process to maintain or upgrade materials' value and/or quality in their second life and beyond. Three papers pay more attention to products rather than materials , [9], [15], [16]. See Appendix A.

Three definitions of upcycling originated from an interview with Reiner Pilz [3], the first recorded use of the term. Pilz, in the context of architecture and interior design, said, "Recycling, I call it down-cycling. They smash bricks, they smash everything. What we need is upcycling, where old products are given more value, not less." [3, p. 14]. Citing this interview, Vadicherla and Saravanan [17] and Pak [18] view upcycling as an activity of creating newness or better quality from used or waste materials, while adding values. See Appendix A.

The definitions from 30% of the publications (18/55), without citations to either Braungart and McDonough, or Pilz, do not seem to be dissimilar to two original definitions. By the authors of 12 publications, upcycling is collectively considered as the (re)creation of new products (artistic, scientific or useful) with higher values and/or qualities [8], [19], [20], [21], [22], [23], [24] and a more sustainable nature [19] by converting, turning, transforming, or repurposing waste or used material/product [2], [21], [23], [25], [26], by reusing an object in a new way without degrading the material [25], [27], or by remanufacturing [28], [29], giving it another new life [25], [27] while reducing unnecessary resource expenditure [26]. See Appendix B.

Other six publications do not have a strong focus on product (re)creation as end result. Six rather loosely defined end results include: (1) something useful and more valuable [30]; (2) objects safe to recycle and organic materials safe to use [31]; (3) upgraded quality/value final products, feedstock, fuels, etc. [32]; (4) better incarnations of objects or raw materials with new life [6]; (5) products for multiple life cycles through remanufacturing or for 100% recyclability [7]; and (6) economically and environmentally improved performance material [33]. See Appendix B.

There are 19 publications which do not provide descriptive statements on what upcycling is, instead implying the meaning within the context. These publications also suggest that upcycling is about converting or transforming waste materials or products into high value and/or quality results either as products or materials. Despite this central idea, there are variations in use of language, focuses, and viewpoints by different subject areas and authors. The literature in the context of plastic recycling sees upcycling as upgraded recycling as opposed to downcycling (for example see [34], [35], [36], [37]). For example, Dobrovszky [38] explains that polymer fraction can be added with fibre reinforcement and quality improver additives during recycling process to increase the value and quality of plastics. The literature in fashion and textiles, not surprisingly, focuses on textile waste in order to 'refashion' [39] or 'resurface' [40] it, or make more valuable new products [41], [42]. Some authors pay more attention to package waste [43], [44]. Some see upcycling in a general context for waste materials recovery [45] or high value commodity recreation [46]. Some authors emphasize the importance of design assistance and the integration of bio-

inspiration concepts [47]. Some argue that remanufacturing is the key solution for transforming downcycling into upcycling of electronics [29]. Albinsson and Perera [48] see upcycling in the context of consumer activity. See Appendix C.

C. Trends in Upcycling Practices

Even though the term, upcycling, is a neologism, Szaky [2] suggests that it has existed for thousands of years as an individual practice of converting waste or used objects into higher value/quality objects. Szaky explains that reuse and upcycling were common practices around the world before the Industrial Revolution and are now more common in developing countries due to limited resources. Recently, however, developed countries have paid more attention to object/product upcycling in commercial perspectives [2], [43], [44] due to the current marketability and the lowered cost of reused materials [17]. In the United States, for example, the number of commercial products by product upcycling increased by more than 400% in 2011 [44]. The scope of products produced by upcycling varies: rugs from fabric scraps, refashioned clothes, remade furniture, soaps and fertilisers (and energy) from organic waste, artistic objects from scrap metal, and even a whole building from reused components from deconstruction among many others [8], [9], [15], [17], [26], [27], [45]. The creation of jewellery, bags, clothes, and other fashion items by upcycling, in particular, is also called 'trashion' [8], [26]. Competitions have been organised around trashion; numerous websites are promoting and selling commercially upcycled products; and a number of digital and printed resources explaining how to upcycle at home are available [13].

Braungart and McDonough [1], [5], [49] stress the importance of initial design which takes into account future upcycling. For example, a minimal amount of glue in assembly is recommended for quick and easy disassembly for safe and easy repair, reconfiguration, return, reuse or recycling. The Cradle to Cradle Products Innovation Institute [50], therefore, administers the Cradle to Cradle CertifiedTM Product Standard which guides designers and manufacturers through a continual improvement process for products in terms of material health, material reutilisation, renewable energy and carbon management, water stewardship, and social fairness. Braungart [10] also adds the dimension of leasing and take-back systems for more effective reutilisation of materials by manufacturers. A number of the world's largest companies have made some of their products Cradle-to-Cradle certified, and integrated upcycling in their businesses, such as Steelcase, Herman Miller, Berkshire Hathaway's Shaw Industries, Ford, Cherokee, and China's Goodbaby [5].

D. Benefits

Many authors generally agree that upcycling provides reductions in environmental impact [13], [23], [47], [51] or contributes to a higher environmental value or performance of products [15], [25], [33], [52]. Braungart and McDonough [1] says industrial upcycling alters linear progression 'from cradle to grave' by material reutilisation in safe, perpetual cycles, which therefore eliminates the concept of waste and reduces toxic materials in biosphere. Similarly, some authors pay more attention to the role of upcycling in solid waste reduction [23], [25], [26], [32] or at least in delaying the addition of waste to landfill [8] or saving landfill space [51]. Product (re)creation by upcycling also eliminates the need for a new product [2], therefore reducing new raw materials use and conserving the natural resources [25], [33] as well as reducing energy usage [33], which leads to greenhouse gas emissions reduction [15]. Comparatively, upcycling uses less energy than recycling [2], [25], [53]. When upcycling is done at home, it can be even more environmentally friendly than industrialised upcycling, in avoiding any transportation of the products [2]. Likewise, upcycling as upgraded recycling on a small scale and decentralised processes (e.g. using RecycleBot[5] technology) could save more embodied energy than if it were centralised [34].

Along with environmental benefits, general economic benefits are also commonly stated by many authors. Some view economic benefits largely in cost savings in new product production [32], [39], [54] or in new stock material production [36], [55]. In art, craft and design education, upcycling is also an easy and economical way of getting materials for student projects [27]. The economic benefit is not limited to cost savings but also includes new profit opportunities by increasing the aesthetic values of existing products [25], giving uniqueness to the design [56], improving material quality or value (e.g. reinforcement, adding aroma, etc. to polymers) [37], [54], [55], and providing other added values to materials or products [15], [32], [47], [57]. The uniqueness of upcycled products in textiles and fashion items is one of the most important purchasing criteria for mainstream customers [56], hence upcycled products in those markets often carry the names of high street brands [8]. Acknowledging this, product upcycling has gradually come to be recognised as a viable business opportunity [13], [56]. Big corporations can also upcycle facades in their building for rebranding companies [52]. Apart from the industrial (or institutional) level, household upcycling can also be economically beneficial for consumers by fulfilling needs with fewer financial resources and having a potential niche market opportunity [6], [58], [59].

Social benefits are rarely discussed in the literature, although Bramston and Maycroft [26] suggest that upcycling practitioners gain an opportunity to develop inherent understanding of objects, merge disciplines, cultures and experiences, and create subjective and individual beauty while keeping the sentimental value of a used product. Szaky [2] explains how object upcycling has been used to help alleviate poverty in developing countries. Other possible social benefits related to human psychological wellbeing were summarised by Sung and colleagues [59] as experience benefits (the upcycling process as a meaningful journey and learning experiences), empowerment benefits (unlocking potential, and becoming more capable and self-reliant), a sense of a community through upcycling networks if any, and burning stress and relaxing, primarily citing Frank [6], Lang [58] and Gauntlett [60].

[5] An open source hardware tool for distributed recycling, able to convert post-consumer plastic waste to polymer filament for 3D printing [34].

E. Drawbacks and Barriers

For industrial upcycling, both as upgraded recycling and as remanufacturing, some authors assert that a systemic approach (i.e. whole supply chain change, recycling networks, multidisciplinary approach) is required [5], [28], [32] to make upcycling truly work. Companies need to have a system which tracks the material flow during the lifecycle of each product they produce, and plans for how to take back and reutilise them for another product [5]. This system necessarily entails the design for easy disassembly, cleaning, reconditioning and reassembling for remanufacturing [28]. Such a systemic approach is not easy to achieve due to a number of issues as follows. Technical issues include (1) possible trade-offs between current value and quality of the materials or products and future upcyclability (e.g. durability/reliability vs. how easy to disassemble) [52]; (2) immature upcycling streams of different technological capacity with inability to handle all types of materials [20]; (3) difficulties and inefficiencies in collecting, cleaning, sorting, drying, and homogenising [37], [52], [61]; and (4) inconsistent supply of materials with controlled quality (in terms of composition and impurities) and process complexity [32]. These issues may be likely to discourage big companies to make a systemic change. For instance, Chanin, an eco-friendly fashion company owner, states that upcycling in the textile industry works well on small and focused projects on a local basis but remains impractical on a large scale [61].

Other issues appear to be mostly related to low awareness or knowledge level of upcycling. McDonough and Braungart [5] claims that companies have fear that the changes are either impossible or too costly, or that they do not have enough information for a change. Misunderstanding and misinterpretation of the terms and concepts related to upcycling might also lead to unintended negative environmental consequences [5].[6] Eder-Hansen and his colleagues [20] mentions that consumers' lack of awareness of an option for their products' end of life could be another serious barrier.

Munroe and Hatamiya [36] listed systemic issues slowing the adoption of upcycling specifically in construction industry. The issues include restrictive codes and standards, lack of trained deconstruction workers, lack of specialised tools, need for new architectural design and construction practices, lack of economic disincentives for dumping, need for permitting incentives and risks in the deconstruction process.

For individuals as consumers, artists, makers, or entrepreneurs, there are different issues which might make upcycling less attractive. Szaky [2] gives some examples of potential problems: (1) relatively low-volume solution for waste reduction/prevention compared with the total volume of waste; (2) small current market size; (3) the niche status of upcycled products (i.e. not appealing to everyone); and (4) the limited number of consumers who are willing to separate and clean waste (e.g. packaging) for upcycling purposes. Bramston and Maycroft [26] adds that individuals also find access difficult to many complicated and process-intensive production methods, and that the outputs from consumers can therefore often be underdeveloped or unrefined.

[6] For example, misinterpretation of closed loops could lead to the conclusion that it is okay to design an toxic product in the first place as long as it could be reconfigured into another toxic product [5].

IV. SUMMARY AND DISCUSSION

A. Descriptive Analysis

The cumulative frequency of the sampled publications demonstrated a recent surge of publication on upcycling since 2008. Two major approaches adopted – conceptual and case studies – also validated that the area of upcycling is relatively new and unexplored because, in general, when there is little previous knowledge, conceptual papers tend to appear more frequently [62], and case studies are considered to be an appropriate choice for study [63], [64]. The subject areas implied that upcycling has been understood mainly in the context of engineering, technology, design and business.

The industrial (sub)/sector distribution presented more research interest in fashion & textiles and plastic recycling. Fashion, in particular, is all about change, encouraging consumers to dispose of old products and buy more new [65], and thus, paradoxically has more market potential through upcycling. Taking into account that nature of fashion coupled with mainstream customers' purchasing criteria (e.g. seeking uniqueness) [56], it is not surprising that academics and practitioners in fashion and textiles have published more literature on upcycling. The sampled publications also showed a strong focus on thermoplastics recycling probably due to the following reasons: (1) recent increase in the volume of the general plastic waste as a modern phenomenon and its negative environmental impacts [23], [51]; (2) high recyclability unlike thermosets [66]; and (3) the ease of processability and the flexibility in forming or shaping after recycling [17]. Besides fashion & textiles and plastic recycling, academic publications have not paid sufficient attention to, for instance, housewares, furniture, jewellery and accessories even though a lot of individual upcycling practices appear to be taking place in households to create these products as shown on numerous internet websites and blogs. The trend in practical upcycling books publications (53% of the sampled books categorised as 'craft and hobbies' and 10% as 'house & home DIY') also reflect such contemporary household practices. Future study on individual upcycling should therefore pay more attention to these product categories.

The literature distribution by country displayed the major role of the USA and several European countries in publication. This could be due to socio-cultural factors such as excessive consumerism and high volume of waste, and therefore more concerns about and interest in environmental issues than mere production efficiency and profitability in these affluent Western countries.

B. Synthesis: Upcycling Definitions, Trends in Practice, Benefits, Drawbacks and Barriers

Despite variations among definitions, there were two dominant viewpoints in the sampled publications. One is

based on material recovery of which the major aim is to maintain value and quality of materials safely in their second life and beyond by the improved recycling or remanufacturing. The other focuses on product (re)creation for higher values and qualities by transforming, repurposing or refashioning waste or used materials/products either by companies or by individuals. Would it be better to clarify such differences by saying, for example, 'industrial upcycling based on recycling', 'industrial upcycling based on remanufacturing', 'individual upcycling based on product re-creation', etc.? Such clarification may help avoid any confusion or misinterpretation. Similarly, the broad range of words used to define upcycling obscures the clear picture. How is upcycling fundamentally different from or similar to reuse, recycle, repurpose, remanufacture, refashion, resurface, transformation, etc.? Is it a trendy term to say improved or better reuse, recycle, or remanufacture? Or do all those words simply represent 'how' to achieve upcycling? An investigation into the clearer relationship between upcycling and more traditional ways of resource reutilisation may help to clarify where upcycling really stands. Value and quality, despite the common use in almost every definition, may sound ambiguous for many especially when used in the context of product (re)creation. It is because value can be assessed differently by individuals, and one of the important quality dimensions of certain products may include newness. Consequently, whether or not a certain activity or process satisfies the definition of upcycling would probably depend on product categories and how buyers or consumers perceive the value and quality of the outputs created by upcycling.

Practices in material recovery appeared to emphasise the importance of initial design and process innovation in companies for high upcyclability and safety. Yet industrial practices – who is doing what, when, where and how, and how (un)/successful it is – remained largely unknown. Practices in product (re)creation with used materials at the individual level were claimed to be deep-rooted collective human behaviours; yet how they have evolved over time, and how they can be harnessed at the household level to make bigger impacts has not been investigated. The commercial perspective of product (re)creation is recently acknowledged and the known scope of new products by upcycling is broad. Market potential (or profitability) of most of these product categories, however, is still questionable. Trashion, upcycling in fashion, seemed to be one of the successful examples, but scalability has not yet been proved. Considering the infancy of the upcycling-based market, feasibility and marketability studies focusing on specific industry and product category would be required.

The benefits of upcycling were discussed on the basis of the three pillars of sustainability – economic, environmental and social sustainability. Most publications referred to environmental and/or economic benefits but far fewer discussed social benefits. Environmental benefits included solid waste reduction (and prevention), landfill space saving, raw materials use reduction, energy use reduction, and greenhouse gas emission reduction. Economic benefits included cost savings and new profit opportunities for manufacturers, entrepreneurs and consumers. Social benefits in developing countries are mostly poverty alleviation and, in developed countries are more relevant to psychological well-being and socio-cultural benefits based on individual upcycling. These benefits, however, are mostly generic and descriptive rather than specific and quantified unless the papers deal with technical aspects of the upcycling process. More empirical research is needed to show how significant the environmental impact is through upcycling. When adding up negative environmental impacts from new materials, toxicity, energy, waste and emissions possibly involved in the process of upcycling (from collection of the used materials to (re)production and (re)distribution) to positive environmental impacts in a quantifiable way, is it still far better than any other ways of waste treatment for every product in every industry? Cost-benefit analysis with real-life cases (of design change, process innovation, new ventures, etc.) would be able to further confirm or dispute the cost-saving and profit generation potential. Social benefits are especially underexplored and it is hard to quantify the real impact. More structured longitudinal studies to monitor the social impacts in groups of people might help shed light on this relatively unknown area.

Drawbacks and barriers of upcycling were identified as many and varied, depending on the level of the upcycling (industrial vs. individual), types of industry, and contextual situations (e.g. market dynamics, regulations and policies, socio-cultural background, etc.). In order to ensure the success of upcycling – in terms of environmental, economic and social impacts – more case studies (industry- and product/material-specific) are required to list systemic issues to tackle.

C. Reflections on Research Methodology

After descriptive analysis and synthesis of the results, the author reflected on the research methodology and found out a discrepancy in the search results between "upcycle" or "upcycling" and "upcycle" OR "upcycling" on Google Scholar. Keyword combination search with 'OR', 'or', 'AND' and 'and' was conducted in December, 2014 to check the discrepancies on all databases used in this study (Appendix D.). The results indicate that half of the databases used for the study are case-sensitive: Google Scholar, Taylor & Francis, IEEE, Elsevier and Emerald recognise 'or' as 'AND' or 'and' instead of 'OR'; whereas Springer, Scopus, Web of Science, Metapress and Wiley recognise both 'or' and 'OR' as literally or. Elsevier is one particularly unique database which not only recognises 'or' as 'AND/and' but also yields more results from 'or/AND/and' rather than from 'OR'. This unexpected discrepancy could seriously undermine the generalizability of the research findings. Acknowledging the differences in each database in terms of its search system, and the adverse consequence of not knowing the differences from the onset of the study, any future literature review should consistently use 'OR' instead of 'or' to ensure accurate results from databases with different search systems. How each academic database varies from each other in terms of the major algorithms applied to the search system, and how relevant and accurate the results are accordingly would be a very important future study for researchers in all fields of studies.

V. Conclusion

This paper reviewed 55 publications on upcycling from 1994 to 2014 and contributed to the body of knowledge by giving a broad overview of general trends in publication and current understanding of definitions, trends in practices, benefits, drawbacks and barriers of upcycling.

Directions for future research areas were identified such as: (1) comparative study to clarify the fundamental differences/similarities between upcycling and other similar constructs; (2) more investigation into value and quality to refine the definition; (3) case studies of real-life industrial practices in material recovery; (4) historical study on individual upcycling as deep-rooted collective human behaviours; (5) research into the potential of households as a group of sustainable producers and consumers based on individual upcycling; (6) feasibility and marketability studies focusing on specific industry and product category; (7) more empirical research to measure the quantifiable environmental impact; (8) cost-benefit analysis with real-life cases; (9) structured, longitudinal study to monitor social impact; and (10) industry- or product/material-specific case studies to list systemic issues hindering upcycling.

Regarding the limitations of this study, the issue of a search results discrepancy on a number of databases was addressed in the discussion. Another limitation is that the keyword-based identification of the publications might have excluded relevant literature with the concept of upcycling but without the exact term. For instance, Braungart and McDonough more often use the term, Cradle to Cradle, to indicate material recovery instead of upcycling, and the Ellen MacArthur Foundation uses the term, 'circular economy,' which seems to describe a systemic approach for industrial upcycling. That being said, part of the suggested future research above – probably (3), (6), (7), (8), and (10) – could be already under scrutiny by the researchers working on Cradle to Cradle or circular economy.

It follows that we cannot claim that our findings can be generalised beyond the reviewed literature body. Nevertheless, we believe that this first literature review on upcycling has contributed towards a generic understanding of the neologism, upcycling, and how it has been understood and practiced, and revealed a number of unexplored avenues worth investigating.

Appendices

Appendix A. Definitions Originated from Braungart and/or McDonough or Pilz (sorted by year and then author names)

Nine Definitions originated from Braungart and/or McDonough				
	Reviewed literature	Authors	Year	Definition
1	*Cradle to cradle.* 1st ed. New York: North Point Press	Braungart, M. and McDonough, W.	2002	Biological nutrients are useful to the biosphere, while technical nutrients are useful for what we call the technosphere, the systems of industrial processes. […] Products can be composed either of materials that biodegrade and become food for biological cycles, or of technical materials that stay in closed-loop technical cycles, in which they continually circulate as valuable nutrients for industry. […] A technical nutrient is a material or product that is designed to go back into the technical cycle, into the industrial metabolism from which it came. […] Some of them are toxic, but others are valuable nutrients for industry that are wasted […] in a landfill. Isolating them from biological nutrients allows them to be **upcycled rather than recycled** – to retain their high quality in a closed-loop industrial cycle.
2	The wisdom of the cherry tree. *International Commerce Review*	Braungart, M.	2007	Instead of downcycling [….] focuses on maintaining (or upgrading) resource quality and productivity through many cycles of use (and in doing so, it achieves 'zero waste' along the way)
3	Rebecca Early upcycles style. *Fiberarts*	Hemmings, J.	2009	A term coined by William McDonough and Michael Braungart […] based on the idea that an object's second (and third and fourth…) life can enjoy increased, not decreased value
4	*Socialised transport: Increasing travel mode diverstiy through open-source vehicle design, upcycling, natural production and distributed production methods.* Canberra, Australasian Transport Research Forum.	Richardson, M., Vittouris, A., and Rose, G.	2010	A term used for reusing waste resources to make new products of an equal or greater value than the product they were recovered from
5	'Upcycling' organic waste in a world of thinly distributed resources. *Waste Management & Research*	Lasaridi, K. and Stentiford, E.	2011	Returning them [waste] back to the material flows in the economy in high value uses, in a cradle-to-cradle approach
6	Improving the environmental performance of biofuels with industrial symbiosis. *Biomass and Bioenergy*	Martin, M. and Eklund, M.	2011	Braungart et al. (2007) similarly refers to this type of activity as "upcycling" products and wastes and giving further value to them

7	Trashion: The return of the disposed. *Design issues*	Emgin, B.	2012	The term used by architect and designer William McDonough and chemist Michael Braungart and refers to "the process of converting an industrial nutrient (material) into something of similar or greater value, in its second life"
8	Upcycle to eliminate waste. *Nature*	Braungart, M.	2013	Recycling to improve a material's value
9	Cradle to cradle. In: S. O. Idowu, N. Capaldi, L. Zu & A. D. Gupta, eds. *Encyclopedia of corporate social responsibility* . Berlin: Springer	Sherratt, A.	2013	With cradle to cradle, all the components of a product feed another product, the earth or animal, or become fuel: products are composed of either materials that biodegrade and become food for biological cycles or of technical materials that stay in closed-loop technical cycles, continually circulating as valuable nutrients for industry.

Three definitions originated from Pilz

	Reviewed literature	Authors	Year	Definition
1	Reiner Pilz. *Salvo*	Kay, T.	1994	Recycling, I call it down cycling. They smash bricks, they smash everything. What we need is upcycling, where old products are given more value, not less.
2	All energy is borrowed terraforming: A master motif for physical and cultural re(up)cycling in Kim Stanley Robinson's Mars Trilogy. *Green Letters: Studies in Ecocriticism*	Pak, C.	2014	Upcycling in order to create newness in ways that add value.
3	Textiles and apparel development using recycled and reclaimed fibers. In: S. S. Muthu, ed. *Roadmap to sustainable textiles and clothing: Eco-friendly raw materials, technologies and processing methods2.* Hong Kong: Springer	Vadicherla, T. and Saravanan, D.	2014	The process of converting waste materials into new materials or products of better quality, for better environmental values.

Appendix B. Definitions without Citations to Braungart and/or McDonough or Pilz (sorted by year and then author names)

Definitions with limited end result of products/goods for consumers through upcycling

	Reviewed literature	Authors	Year	Definition
1	Implementing deconstruction in the United States. In: C. J. Kibert & A. R. Chini, eds. *Overview of deconstruction in selected countries* . Rotterdam: in-house publishing	Kibert, J., Chini, R., Languell, L., and Rinker, M. E.	2000	Create value added products, provide new businesses and manufacturers with quality
2	Trash or treasure? Controlling your brand in the age of upcycling. *Trademark world*	Anderson, A.	2009	The creation of jewellery, fashion and other objects assembled from used and thrown-out items, such as product packaging. As a results, these upcycled goods often carry the names of high street brands.
3	Upcycling: Converting waste plastics into paramagnetic, conducting, solid, pure carbon microspheres. *Environmental science & technology*	Pol, V. G.	2010	The conversion of a waste material(s) into more valuable product(s). This product can be purely artistic, scientific, or anything simply useful.
4	Buying fabrics. In: *Sew eco: Sewing sustainable and re-used materials.* London: A & C Black Publishers Ltd.	Singer, R.	2010	Using something that was a waste material to make something of a higher value.
5	Enacting the never-was: Upcycling the past, present, and future in Steampunk. In: J. A. Taddeo & C. J. Miller, eds. *Steaming into a Victorina future: a steampunk anthology.* Lanham, Maryland: Scarecrow Press	Barber, S. and Hale, M.	2012	The creation of forms from waste materials that attempt to be of a higher quality and more sustainable nature than the compositional elements from which they were derived.
6	*The nice consumer: Toward a framework for sustainable fashion consumption in the EU,* Copenhagen: BSR.	Eder-Hansen, J., Kryger, J., Morris, J., and Sisco, C.	2012	The process of incorporating waste or useless products into new ones of higher value, for example by sending unwanted denim jeans to facilities which break them down and incorporate them in new products
7	Sustainable green chemistry for better living: A challenge of 21st century. *International Archive of*	Garg, A.	2012	Taking waste and turning it into something of value – the ubiquitous plastic

	Applied Sciences and Technology			bag and converting it into useful nanotubes
8	*Upcycling: Re-use and recreate functional interior space using waste materials.* Dublin, Education, International conference on engineering and product design.	Ali, S., Khairuddin, F., and Abidin, Z.	2013	The process of converting waste materials or useful products into new goods […] reusing an object in a new way, without degrading the material it is made from [53]. […] the process relates with the recreation of used materials or also known as waste materials to recreate and giving it another new life or function without having to spend much in getting new materials **Invalid source specified.**.
9	Designing with waste. In: E. Karana, O. Pedgley & V. Rognoli, eds. *Materials Experience: Fundamentals of Materials and Design.* Oxford: Butterworth-Heinemann	Bramston, D. and Maycroft, N.	2013	Amalgamation of all processes [...] as a potentially viable option in the search to reduce any unnecessary resource expenditure. […] an opportunity for discarded and waste products to be transformed into new, reconfigured, repurposed, and enhanced items.
10	The art of upcycling: Welding trash into treasure. *Welding Journal*	Gomez, M.	2014	Reusing an object in a new way without degrading the material it was made from. When an object is upcycled by heating and welding, adding other objects to create a form of artistic expression, you cycle up toward another purpose.
11	*Manufacturing or remanufacturing? Decision management and success factors.* Berlin, Fraunhofer IZM.	Steinhilper, R., and Hieber, M.	2014	Remanufacturing for reuse
12	*Outsmart waste: The modern idea of garbage and how to think our way out of it.* San Francisco, CA: Berrett-Koehler Publishers, Inc.	Szaky, T.	2014	An emerging trend whereby one sees value in both the composition and the form of an object. […] repurpose a waste object by valuing the material from which it is made and the form that the material is in. Example: sewing juice pouches together to make a backpack.

Definitions with a variety of end result of upcycling

	Reviewed literature	Authors	Year	Definition
1	*Upcycling wastes with biogas production: An exergy and economic analysis.* Venice, Venice 2012, Fourth International Symposium on Energy from Biomass and Waste.	Martin, M. and Parsapour, A.	2012	By adding value to the material, economic and environmental performance can be improved, which is called upcycling.
2	*Sustainable operations and closed-loop supply chains.* New York: Business Expert Press.	Souza, G.G.	2012	Designing products for multiple life cycles (as in design for remanufacturing), or products designed according to the Cradle-to-Cradle philosophy that ensures ease of disassembly and 100% recyclability.
3	*Living simple, free & happy: How to simplify, declutter your home, reduce stress, debt & waste.* Georgetown, Ontario: Betterway Books.	Frank, C.	2013	Way to give old, unwanted objects new life, either as better incarnations of their original selves or as raw materials than can be rebuilt in a different way to serve a new function.
4	Upcycling waste polypropylene into graphene flakes on organically modified montmorillonite. *Industrial & Engineering Chemistry Research*	Gong, J., Liu, J., Wen, X., Jiang, Z., Chen, X., Mijowska, E., and Tang, T.	2014	The process of converting waste materials into something useful and more valuable.
5	Gift, design and gleaning. *Design Philosophy Papers*	Stoekl, A.	2014	Total reuse, made possibly by technical devices designed for disassembly and complete utilisation, objects that can be separated into chemicals safe to recycle and organic materials that can be actually be used, safely as fertiliser.
6	Upcycling waste plastics into carbon nanomaterials: A review. *Journal of Applied Polymer Science*	Zhuo, C. and Levendis, Y. A.	2014	Upcycling process, as the quality/value of the final products is upgraded, and there are studies and reviews on

				related topics, such as upcycling plastics into chemicals for monomer feedstock, fuels, etc.

Appendix C. 19 Descriptions Suggesting the Meaning of Upcycling from the Context (sorted by year and then author names)

	Reviewed literature	Authors	Year	Description
1	Electron beam surface modifications in reinforcing and recycling. *Nuclear Instruments and Methods in Physics Research*	Czvikovszky, T. and Hargitai, H.	1997	The upcycling (upgrading recycling)
2	*Remanufacturing - the key solution for transforming 'downcycling' into 'upcycling' of electronics.* Denver, 2001 IEEE INTERNATIONAL SYMPOSIUM ON ELECTRONICS AND THE ENVIRONMENT.	Steinhilper, R. and Hieber, M.	2001	Remanufacturing - the key solution for transforming 'downcycling' into 'upcycling' of electronics. […] Remanufacturing is recycling by manufacturing 'good as new' products from used products.
3	Deconstruction of structures: an overview of economic issues. *International Journal of Environmental Technology and Management*	Munroe, T. and Hatamiya, L.	2006	Recycling in the context of deconstruction has been subdivided into two categories: 'downcycling' and 'upcycling'. Downcycling refers to reprocessing a material into a material of lesser economic value and lower potential for future reuse or recycling. […] For example, large redwood, oak or hardwood beams can be upcycled by milling them into smaller but more valuable and more widely useable new building products.
4	Condensation kinetics of polyphthalamides. II. Polyesters and diamines. *Polymer Engineering and Science*	Hellmann, E., Malluche, J. and Hellmann, G.	2007	A simple, economically attractive process of upcycling postconsumer polyethylene terephthalate (PET) waste to polyphthalamides
5	*Using fashion as a platform to engage & excite.* Berlin, 6th International Conference of The Consumer Citizenship Network.	Tobiassen, T.	2008	Upcycling – making what was considered textile waste more valuable than for example shoddy or second-grade textile material
6	*Resurfaced: Using laser technology to create innovative surface finishes for recyclable, synthetic textiles.* Loughborough, Cutting Edge: Lasers and Creative Symposium.	Goldsworthy, K.	2009	Resurface low grade recycled felts in order to 'upcycle' them to a higher value material product
7	*Textiles: The sustainability of research.* Liverpool, Futurescan: Mapping the Territory.	Politowicz, K.	2009	'Upcycle' UK textile waste into new products and services
8	Effect of organic loading and retention time on dairy manure fermentation. *Bioresource technology*	Coats, E., Gregg, M. and Crawford, R. L.	2011	Upcycle the material to high value commodities
9	Upcycling of polymer waste from automotive industry. *Periodica Polytechnica Mechanical Engineering*	Dobrovszky, K.	2011	Upcycling, where the polymer fraction can be added with fibre reinforcement and quality improver additives
10	Remediation: Discussing fashion textiles sustainability. In: A. Gwilt & T. Rissanen, eds. *Shaping sustainable fashion: Changing the way we make and use clothes.* s.l.:Routledge	Farrer, J.	2011	Source, upcycling and remanufacturing for waste materials recovery.
11	Case study: Upcycling materials for fashion. In: A. Gwilt & T. Rissanen, eds. *Shaping sustainable fashion: Changing the way we make and use clothes.* London: Routledge	Fraser, K.	2011	Broken, damaged and redundant objects can be refashioned and value added through the process of upcycling, which […] relies on the use of decorative textile techniques such as printing and embroidery.
12	*The future life cycle of intelligent facades.* Louvain-la-Neuve, PLEA 2011 - Architecture and Sustainable Development, Conference Proceedings of the 27th International Conference on Passive and Low Energy Architecture.	Martin, C. and Stott, C.	2011	Glass recycling is widespread and very efficient. Unfortunately, not all glass is the same, and certain architectural glass is difficult to upcycle.
13	Alternative marketplaces in the 21st century: Building community through sharing events.	Albinsson, P. and Perera, B.	2012	Un-consumption (i.e. post-consumption activities such as upcycling, reuse, recycling, etc.) […] we find that many

	Journal of Consumer Behaviour			consumers deliberately engage in alternative consumption, with their families, friends, and even strangers, through upcycling, reducing, reusing, recycling, repairing, and redistributing possessions through sharing, donating, and ridding
14	Comparative pyrolysis upcycling of polystyrene waste: thermodynamics, kinetics, and product evolution profile. *Journal of Thermal Analysis and Calorimetry*	Mo, Y., Zhao, L., Chen, C., Tan, A. and Wang, J.	2012	Pyrolysis is one important way to treat polystyrene waste and upcycle it into useful materials. […] Pyrolysis is an upcycling process for polystyrene waste, converting it into feedstock for PHA manufacture.
15	Keep the door open: Innovating toward a more sustainable future. *Journal of Product Innovation Management*	Slotegraaf, R. J.	2012	Use exiting package waste to develop new products that are as desirable as traditional equivalents (i.e., upcycling)
16	*Distributed recycling of post-consumer plastic waste in rural areas.* Boston, MA, Materials research society symposium proceedings.	Kreiger, M., Anzalone, G. C., Mulder, M. L., Glover, A. and Pearce, J. M.	2013	Two recent open-source hardware technological developments, 3D printers and RecycleBots, offer a new approach to polymer recycling (or upcycling), encompassing the potential for distributed processing to high-value added products, which reverses the historical trend towards centralised manufacturing and recycling facilities.
17	'+ design - waste': a project for upcycling refuse using design tools. *International Journal of Sustainable Design*	Santulli, C. and Langella, C.	2013	Upcycling of waste through new possibilities offered by design with the assistance and the integration of bio-inspiration concepts.
18	Converting polyethylene waste into large scale one-dimensional Fe3O4@C composites by a facile one-pot process. *Industrial & Engineering Chemistry Research*	Zhang, J., Yan, B., Wan, S. and Kong, Q.	2013	Polyethylene-based waste plastics need hundreds of years to degrade in atmospheric conditions, so innovative upcycling processes are necessary in addition to traditional recycling services.
19	Talking trash: 'Upcycle' to recycle. *Packaging Digest*	Hartman, L. R.	2014	TerraCycle 'upcyles' used packaging from Kraft Foods and others that's often deemed 'unrecyclable'. […] TerraCycle, in the launch of a packaging-reclamation programme for 'upcyclable' items in which the packaging is 'upcycled' into new consumer products available at retail stores.

Appendix D. Discrepancies in Search Results on Different Databases (on 16th December 2014)

	"upcycle" OR "upcycling"	*"upcycle" or "upcycling"*	*"upcycle" AND "upcycling"*	*"upcycle" and "upcycling"*
Springer	123 (items)	123	1	1
Google Scholar	About 2,130	155	155	155
Scopus	62	62	3	3
Web of Science	42	42	2	2
Metapress	10	10	1	1
Taylor & Francis	14	2	2	2
IEEE	2	1	1	1
Elsevier	0	0	0	0
Emerald	12	1	1	1
Wiley	0	0	0	0
	"sustainable" OR "design"	"sustainable" or "design"	"sustainable" AND "design"	"sustainable" and "design"
Elsevier	112 journals 57 books 4 online tools	112 journals 162 books 10 online tools 1 book series	112 journals 162 books 10 online tools 1 book series	112 journals 162 books 10 online tools 1 book series
Wiley	11,817	11,817	496	496
	"sustainable" OR "production"	"sustainable" or "production"	"sustainable" AND "production"	"sustainable" and "production"
Elsevier	122 journals 57 books 4 online tools	122 journals 162 books 10 online tools 1 book series	122 journals 162 books 10 online tools 1 book series	122 journals 162 books 10 online tools 1 book series

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