End-of-Life Management of Shoes and the Role of Biodegradable Materials

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Abstract

The paper reviews the trends in the footwear sector regarding the amount of end-of-life waste produced and ways in which it is tackled. Existing reuse and recycling activities in the footwear sector are examined, and the use of biodegradable materials is investigated. The paper presents an integrated waste management framework by combining a mix of design and material improvements as well as reuse, recycling and energy recovery activities. The paper also discusses the implications of using biodegradable materials as a means of reducing the amount of end-of-life waste in the footwear industry and how this proactive approach compared against traditional end-of-life management approaches.

Keywords

End-of-Life Management, Shoes, Biodegradable Materials

1 INTRODUCTION

Unsustainable consumption and production patterns in the developed world have led to an increased generation of waste over many decades. Although local and national authorities, governmental agencies, manufacturers and the general public have come to recognise the importance of controlling waste at source, total waste elimination is not possible. There will always be some waste that cannot be prevented at source and so need to be treated at the end of its functional life. Considering the amount of end-of-life (EoL) waste generated every year, understanding and developing methods for EoL management are a major part of the overall waste management concern.

The footwear industry over the last years has placed significant effort in improving energy and material efficiency, as well as eliminating the use of hazardous materials during the production phase. However, the environmental gains and energy efficiency made in production are being overtaken by the considerable increase in the demand for footwear products, the so-called rebound effect [1]. Moreover, the useful life of shoes is relatively short and progressively decreasing as a result of rapid market changes and consumer fashion trends. This creates a large waste stream of worn and discarded shoes at the time their functional life has ended, and most of them are being disposed in landfills. Producer-responsibility issues and forthcoming environmental legislations, as well as increasingly environmental consumer demands, are expected to challenge the way the footwear industry deals with its EoL products.

2 RESEARCH BACKGROUND

2.1 Review of the Footwear Industry

The footwear industry is a diverse manufacturing sector which employs a wide variety of materials to make products ranging from different types and styles of footwear to more specialised shoes. Leather, synthetic materials, rubber and textile materials are amongst the basic materials most commonly used in shoe manufacture; each material has its own specific characteristics. Materials significantly influence, not only the life of the footwear but also the end-of-life treatment of the product. Approximately 40 different materials can be used in the manufacturing of a shoe [2]. However, the common material composition of a typical shoe is presented in Table 1.

Footwear Materials	Percentage (%wt)
Leather	25
Polyurethane (PU)	17
Thermoplastic Rubber (TR)	16
Ethylene Vinyl Acetate (EVA)	14
Poly (Vinyl Chloride) (PVC)	8
Rubber	7
Other (adhesives, metals, etc.)	7
Textiles and Fabrics	6

Table 1: Materials composition of a typical shoe. [3]

Nowadays, the shoe industry is facing many of the same challenges as the consumer products and food industries. To meet the needs of customers and be competitive, footwear companies must face two key challenges: being quick to market changes and stay relevant in order to identify or establish new consumer trends. This leads to a shorter life cycle of shoes, and an even increasingly shorter product development cycle for the footwear industry. A shorter life cycle of shoes means that more shoes have been produced over the years, so leading to a higher level of EoL waste by the footwear industry. From 1990 to 2004, worldwide footwear production has increased by 70% to around 17 billion pairs of shoes while by 2010 experts in the sector expect the global footwear output to reach 20 billion pairs [4]. Shoe production and consumption is definitely rising. Western Europe and United States consume 2 billion pairs of shoes each every year [4]. In the UK alone, more than 330 million pairs of shoes, with a total market value of more than £5 billion are consumed every year [5].

2.2 Environmental Issues in the Footwear Sector

General Environmental Concerns

There are many environmental pollution problems linked with the footwear industry. These occur both in the production of raw materials and with the footwear manufacturing itself. However, until recently the only major environmental concerns for the producers have been the use of hazardous materials and chemicals in shoes , and the air, water and solid waste emissions generated during the shoe production process. In fact, the most serious risks to the environment are to be found with suppliers of semi-finished products and components such as leather, which is produced by tanning. Especially, the use of chromium as tanning agent, which is highly toxic and a suspected carcinogen, has been a major environmental issue for the footwear industry over the last few decades [6]. The use of PVC also, has been reduced in the footwear manufacturing sector because it is claimed that when burned at low temperatures, it has the potential to form organo-chlorine substances, which are extremely toxic both for the environment and for human beings. Finally, solvents and other volatile organic compounds (VOCs), used in synthetic upper materials, leather finishing, adhesives and cleaners, are of major importance for the footwear industry since they contribute to the formation of ground-level ozone, an air pollutant harmful to human health as well as plant life [7]. Table 1 presents some if the major pollutants that linked with footwear materials and their processes.

Footwear Materials	Environmental Pollutants
Leather	Chromium, Aldehydes , Solvents
Synthetic Materials	Solvents, VOCs
Textiles	Process Chemicals, Biocides
Rubbers	Rubber Fume
PVC	Vinyl Chloride Monomer Cadmium, Plasticisers
Polystyrene	Styrene Monomer
Polyurethane	Isocyanates, (CFCs)
Adhesives	Solvents, VOCs, Chlorine

Table 2: Major Pollutants in the Footwear Industry [7]

In order to promote footwear products which have lower environmental impacts, the European Union (EU) recently has established the European Footwear Eco-Label scheme as a marketing and publicity tool for environmental-friendly shoes [8]. To be able to use the footwear eco-label some determined ecological criteria must be fulfilled. These criteria aim, in particular, at limiting the levels of toxic residues, limiting the emissions of VOCs and promoting a more durable footwear product.

However, the major environmental challenge that footwear industry is currently facing, is the enormous amount of waste generated at the end-of-life phase. Some 12 billions pairs of shoes produced worldwide every year, with most of them being disposed in landfills. Landfill sites can result in serious environmental pollution of groundwater and rivers, due to landfill leachate. Landfill space is also becoming extremely limited, especially in some European countries where available landfill space is non-existent. Finally, forthcoming product-related environmental legislation is expected to change the approach of the footwear industry regarding its EoL waste.

Landfill Restrictions

The EU Landfill Directive is the major driving force for the development of European waste management policies. This Directive clearly promotes the diversion of waste from landfills towards products and materials recycling using a variety of measures. The landfill restrictions introduced by the Article 5 of this Directive are very important, in particular the reduction in the amount of biodegradable waste going to landfill and the prohibition of landfilling for certain waste types [9]. According to a recently published report by the European Commission, most of the EU counties have introduced landfill restrictions and taken measures to reduce biodegradable waste going to landfills [10]. For example, since 1st June 2005, German landfills only accept biodegradable municipal waste that has been either incinerated or undergone mechanical and biological treatment. Austria has also introduced strict limits on the landfilling of organic wastes and no waste with an organic carbon content of more than 5% is going to landfill [11].

Furthermore, the UK Landfill Allowances and Trading Scheme Regulations (LATS) introduced in 2004, determines the percentage of certain waste type that regarded as biodegradable municipal waste. These biodegradable percentage range from paper, card and vegetable oils (potentially 100% biodegradable) through to **footwear**, furniture and textiles (50% biodegradable) to batteries, glass and metal waste (0% biodegradable) [12]. This means that certain types of materials such as leather, natural textiles, natural rubbers etc, which are extensively used by the footwear industry, will be soon required to be reused or recycled instead of disposal in landfill sites.

Producer Responsibility Issues

In most countries, managing EoL waste has long been and, in most cases, still is the responsibility of governmental agencies and local authorities. Once products reach the end of their functional lives, producers play no role in collection, recycling or disposal of those EoL products. This approach has started to change with the emergence of a producer responsibility concept. This concept was first introduced in Germany with the 1991 Packaging Ordinance which required manufacturers and distributors to take back packaging from consumers and ensured that a specified percentage is recycled. Producer responsibility legislation was introduced into the EU waste policy with the 1994 Packaging Directive and since then has spread to most industrialised countries. In 2000, the European Commission passed a Directive requiring its Member States to institute a producer responsibility program for end-of-life vehicles (ELV) while an additional Directive for Waste Electronics and Electrical Equipment (WEEE) is expected to be adopted soon by all EU Member States. This concept of broadening manufacturer's responsibility for products beyond their useful life into the post-consumer phase, also concerns closing the loop with respect to materials use and waste management at the end-of-life phase, while providing a source of financing to offset the cost disadvantage of recycling versus disposal and energy recovery. In this context, take-back and producer responsibility legislation is expected to affect the footwear sector similarly to what has happen in other consumer product sectors, e.g. with the implementation of the ELV and WEEE Directives.

2.3 Reuse and Recycling Activities in the Footwear Industry

Footwear industry's response to increasing problem of EoL waste has been negligible. In fact, only one major shoe manufacturer, Nike Inc, has been taken measures to manage its waste. Nike's "*Reuse-A-Shoe*" programme is the only product take-back and recycling scheme established by a shoe manufacturer. This programme has been operating for over a decade in the United States and also just started operating in the UK, Australia and Japan [13]. Their reuse and recycling programme involves a series of collection points in retail centres where people can deposit their worn-out and discarded athletic shoes. The shoes are then collected and taken to a central recycling facility where they are ground up and shredded, producing a material called "*Nike Grid*", which can be used in surfacing for tennis and basketball playgrounds or running tracks. According to NIKE, since its inception in 1993, "Reuse-A-Shoe" programme has recycled more than 16 million pairs of worn-out and defective athletic shoes in total [13]. Currently, this programme has an annual recycling goal of about 125,000 pair of shoes in the United States and supported by the National Recycling Coalition, a US-based non-profit organisation promoting recycling and sustainable development activities.

Another form of reuse activity in the footwear sector is the collection and distribution of worn or unwanted shoes to developing countries. Reuse schemes are mainly supported by charity organisations, local authorities and municipalities such as the Salvation Army Trading Company Ltd. (SATCOL), Oxfam and others. In the UK, SATCOL alone with its 2,300 banks, door-to-door collections and donations, has managed to collect around 971 tonnes of worn or unwanted shoes during the year 2000-2001 [14]. These shoes are usually deposited in specially designed collection units, the so-called 'shoe banks', based at recycling stations, schools, charity shops and other participating outlets. The shoes are collected and sorted for suitability. Shoes that can be refurbished and reused are usually sold to companies and individuals in developing countries, who can recondition the shoes and then sell or freely distribute them on to local population. At least one private company in the UK, the European Recycling Company Ltd, specialises in shoe recycling having an established network of 3,000 shoe recycling sites in the UK [15]. However, there is a strong debate about such reuse activities in terms of their overall environmental damage and their economic consequences for the local communities. It has been argued that collection and distribution of worn or unwanted shoes in developing countries just diverts end-of-life waste from the developed world to poor countries with no infrastructure to deal with the extra waste. According to Wicks et al, re-distribution of second hand products into developing countries may also lead to net economic damage to the local economies due to 'dumping' of cheap used footwear [16].

2.4 The Role of Biodegradable Materials in Footwear Production

A material is deemed biodegradable if it undergoes degradation by biological activity under specific environmental conditions to a defined extent and within a given time [17]. Currently there are several types of biodegradable materials that being used by the footwear industry. Natural biodegradable materials such as leather, natural rubber etc. and biodegradable polymers made from starchy crops such as maize and potatoes, developed as a "green" alternative to conventional petrochemical-based polymers. Hybrids, for instance incorporating biopolymer fibres.

Natural rubber used for shoe soles, and leather used in upper shoe materials are naturally occurring biodegradable biopolymers. However, to provide stability and good properties in service, these materials have been chemical modified to produce cross-linked stable structures. The reversibility of such cross-linking has been studied, for instance several patents have been published in the last decade for the devulcanisation of rubber – although there is little evidence of these patents being turned into effective industrial processes. Therefore there is a need to produce materials which are stable in service but then will readily breakdown when no longer wanted,. This requires some subtle approaches to providing 'temporary' stabilisation for service. There is an increasing number of synthetic biopolymers coming on to the market, but at a price. And then there is the argument: why throw any material way if can be successfully recycled – the choice of a stabilisation system for long service life again requires subtlety of concept. Biodegradable fillers are commonly utilised in polymers to improve so-called biodegradation, although both UV and hydrolytic attack are required to bring about some types of reduction of materials to safe by-products.

Also, in recent years, a wide range of biodegradable polymeric materials from rubbers to thermoplastic materials have been developed to be used as construction materials and adhesives in the footwear industry. According to Abbot et al, biodegradable materials that based on polypeptides offer the most potential for use as adhesives while bio-polymers based on polysaccharides and polyhydroxyalkanoates offer wider potential for use in coatings, films and fibres [7]. Few materials, however, have become commercially available in the footwear industry. For example, Biopol™, which is a biodegradable thermoplastic material, is currently used by the footwear industry in similar applications as polypropylene or polyethylene. However, there are considerable technical and economic challenges to be overcome before these type of materials are widely used in production of shoes.

In reality "biodegradation" is not the only means by which of organic materials can be reduced to small molecular species. Therefore, the term "environmental degradation" should is more relevant, and encompass all scenarios leading to degradation/reduction of organics to simple, harmless molecules. Reduction of materials based on natural or synthetic polymers to small harmless (environmentally friendly) molecules is known to utilise a number of mechanisms for breakdown:

a) Hydrolysis and other water related effects.

Water as the universal solvent may be expect to attack polar organic materials, such attack being in the form of swelling or in some cases partial or complete dissolution. In undergoing this, facilitate attack by biological agents. However, it is evident from leather recovered at archaeological sites, that water-logged and specifically acidic water (e.g. peat) conditions are effective in preserving cross-linked collagen.

b) Oxidative effects.

Polymers are prone to oxidative attack especially at elevate temperatures. Specific in-chain repeat groups and side groups being more liable to attack than other, e.g. *tert*-methyl side groups (e.g. in polypropylene). Landfill sites will probably operate in largely anaerobic conditions – but note: sewerage works employ highly aerobic conditions to destroy certain bacterial agents.

c) Ultra-violet attack.

Organic materials left exposed to sunlight (both direct and indirect exposure), are susceptible to breakdown because they readily absorb UV. Degradation is by mechanisms similar to those that promote thermo-oxidative attack. Degradation is then dependent on the organic's molecular structure.

d) Microbial attack.

Here bacteria, either naturally occurring or synthesised, is used to digest the organic to any of a variety of small molecular materials: from CO_2/H_2O to agriculture mulches/fertilisers.

e) Enzymic attack.

By use of specific enzymes, a biochemical reaction is used to reduce a polymeric structure to smaller molecules.

It is quite clear from the examination of older landfill sites, that unless carefully designed, built and having the necessary environmental "reagents" present to promote breakdown of materials, waste organic materials can remain in an inert, unchanged state over long periods of time.

3 RESEARCH ACTIVITIES

3.1 Waste Management Framework for Shoes

Effective management of EoL waste is a rather complex issue made up of many components. Although there is no blueprint that can be applied in every industrial sector, the European Commission has set up a waste hierarchy framework which specifies the order in which waste management options should be considered, based on environmental impact. Based on this hierarchy, an integrated waste management framework for footwear products has been developed and presented in Figure1. This proposed framework divides the waste management options for shoes into two major approaches: proactive and reactive. Proactive approaches include all measures that are taken with the aim to reduce or minimise waste at the source. Reduction of waste, also referred to as waste minimisation, is a proactive approach because simply, waste which is avoided needs no management and has no environmental impact. On the other hand, reactive approaches include all the other waste management options which act in response to the waste problem when the useful life of the product has ended. Reactive waste management approach is also referred as End-of-Life Management.

The key difference between proactive and reactive approaches is timing. EoL management is an after-the-event approach while proactive approaches have an "anticipate and prevent" philosophy to deal with waste.

3.2 Proactive Approaches

In general, it makes far more sense to reduce or even minimise waste than to develop extensive treatment schemes and techniques to ensure that the waste poses no threat to the environment. Waste minimisation activities range from product and material changes, to process changes, to changes in methods of operations [18]. Although there is a wide range of proactive waste management activities, there are two major improvement methods that could be applied in the footwear industry in order to reduce or even minimise waste at the source, design and material improvements.

Design Improvements

Waste minimisation strategies should start at the beginning of a product's life cycle, here in the product design phase using eco-design improvements. Eco-design improvements in the footwear sector could have significant impact on environmental quality and could reduce the amount of materials needed, thus reducing the amount of waste that need to be handled at the end of the lifecycle. Also a footwear product which is designed for ease of disassembly will make reuse and recycling of its components and parts easier, thus reducing the amount of materials disposed into landfill.

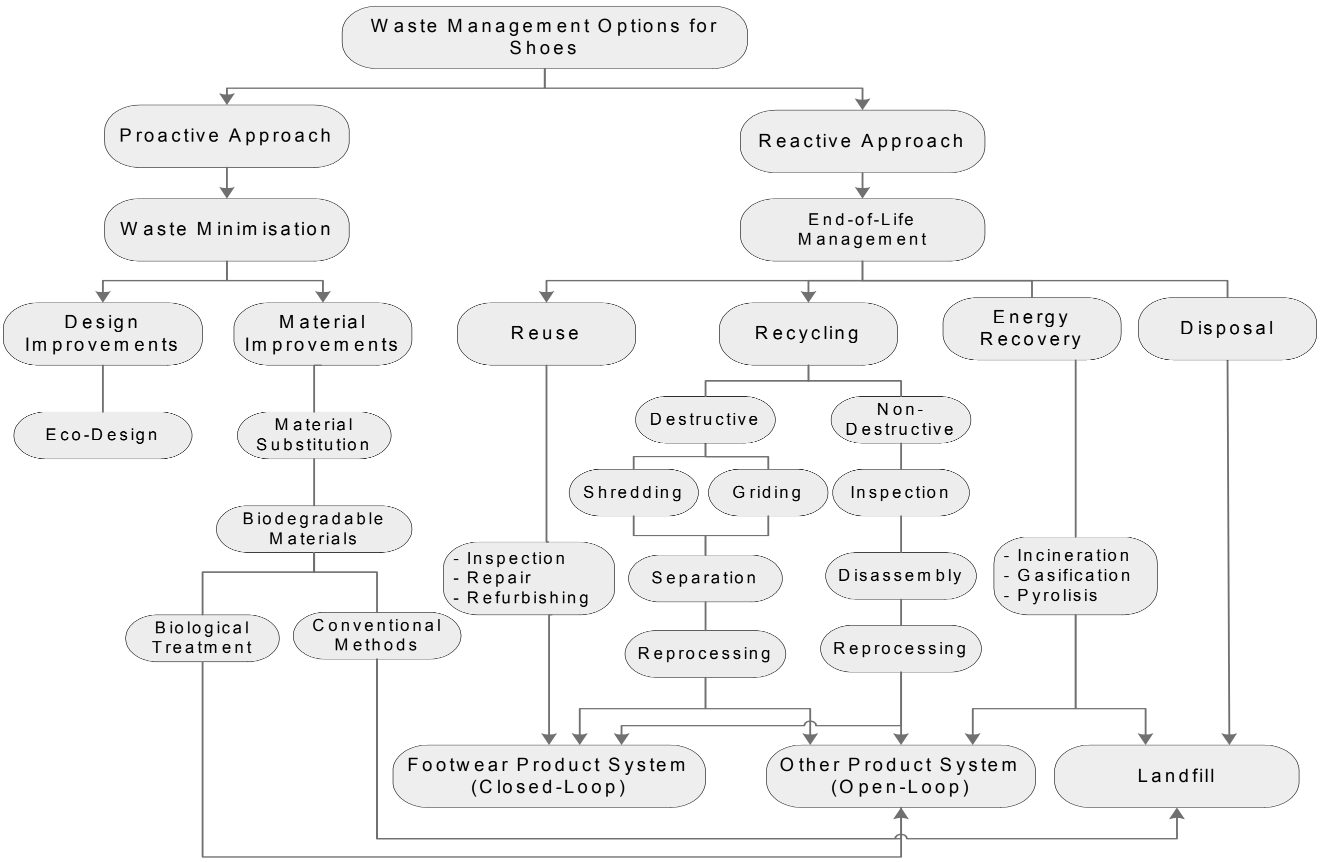

Figure 1: Waste Management Framework For Footwear Products

Material Improvements

The environmental properties of a product can be improved by simply choosing different materials. Material substitution is a proactive approach which can achieve significant reduction of waste, under certain circumstances. In the case of the footwear industry, biodegradable materials can substitute conventional materials in order to improve the environmental properties of shoes. The two most important features that distinguish biodegradable materials from conventional petrochemical materials are their potential biodegradability or compostability at the EoL phase and the use of renewable resources in their manufacture as further discussed in section 3.4.

3.3 Reactive Approaches (End of Life Management)

Total waste elimination is not possible. There will always be some waste that cannot be prevented at the source. Where waste material is produced, an optimal EoL treatment option must be selected with the lowest possible risks to human health and the environment. Each EoL management option brings different impacts to different parts of the environment.

Reuse

Reuse can be practised with the use of products that designed to be used a number of times. Direct reuse of shoes with minimal processing is a possible EoL option but there are a few variables that need to be considered such as the condition of the shoe at the end of their life, the collection and distribution system as well as the purpose of its use.

Recycling

Recycling involves the reprocessing of end-of-life footwear products, parts or materials, either into the same product system (closed loop) or into different ones (open-loop). The end-of-life waste is therefore re-introduced back into the market through a series of processes that can be divided into two major methods: destructive and non-destructive. Destructive methods, like shredding, could be used to transform shoes into other useful materials. End-of-life shoes are being collected and taken to recycling facilities where they are shredded without separation into material types, in order to produce materials that used in secondary applications such as surfacing for roads, playgrounds and running trucks. Nike's "Reuse-A-Shoe" programme, see above, is the most recognized, and probably the only destructive recycling programme in the shoe industry. Non-destructive methods involve the dismantling of shoes to recover saleable and reusable components and to isolate materials for further recycling and disposal. Non-destructive methods generally include inspections, disassembly, replacing and repairing shoe parts and components and finally re-assembling into a new product that could be used inside or outside the footwear sector. However, disassembly of EoL shoes is not an easy task due typically to the large amount of adhesive used to join shoe parts together along with stitching techniques. New technologies must be employed to aid the eventual disassembly process, for example the use of water-soluble adhesives and the use of construction techniques that require less stitching.

Energy Recovery from Waste

EoL waste can be recovered in order to generate heat and electivity. Energy recovery from waste includes a number of established and emerging technologies such as incineration, gasification and pyrolysis. In the case of leather waste, gasification technology has been applied for heat generation and chromium recovery. For example, a 50kg/h leather waste gasification unit has been installed at Pittards plant in Leeds, UK with good results [19]. At the moment, however, such gasification units accept only raw solid waste directly form the tannery production and not finished leather products such as shoes.

Disposal

Disposal of waste is often regarded as the last resort waste management option with the highest environment impact. Most of the EoL footwear waste is going to landfill sites in which are deposited. However, not all waste can be prevented or recycled and there will always be some waste to finally be disposed off in landfills or even just thrown away.

3.4 End-of-Life Management Options for Biodegradable Materials

There are two established methods for the end of life management of biodegradable materials: biological treatment and conventional methods. Biological treatment includes both aerobic (composting) and anaerobic digestion. Aerobic composting of biodegradable materials generates carbon dioxide, water and methane as well as some form of compost, which can be used as a fertilizer. Whilst all three are greenhouse gases, carbon dioxide and water do not contribute to additional atmospheric loading, while it is argued methane does. Indeed some biodegradables may also produce hazardous by-products as soil contaminants. It has also been recently recognised for fast cycle composting, the biodegradables have to be held at 50 to 60°C. So if biodegradable products are to be composted, they must meet stringent quality criteria. Dedicated standards and certification schemes have been established for verifying the compostability of biodegradable products. Anaerobic digestion, on the other hand, is a process where biodegradable material is broken down in the absence of oxygen in an enclosed vessel. The process produces carbon dioxide, a biogas and solids/liquors known as digestate which can also be used as fertiliser. However, anaerobic digestion can be problematic as some of the biodegradable materials are known to be non-biodegradable under anaerobic conditions, another possible problem with PLA [20]. It should be noted that the EU Landfill Directive recognises biological treatment activities as a form of recycling.

Biodegradable waste materials can also be treated using conventional methods, such as incineration and landfilling. Incineration may be a solution in the case of no available biological treatment. Mass burn incineration of biodegradable materials generates carbon dioxide, water, and ash, with the release of thermal energy. However, in the case where renewable resources used, thermal recovery is carbon dioxide neutral. There is the possibility with the combustion of composite structures that metals may be concentrated and recovered. Biodegradable materials also could be send to landfill, where broke down to produce a powerful greenhouse gas, methane. As previously mentioned, the EU Landfill Directive requires a considerable reduction to the volume of biodegradable materials being sent to landfill and even such materials are being excluded from landfilling by law.

4 CONCLUSIONS

Forthcoming legislative requirements and market pressures are expected to force the footwear industry towards measures to deal with its end-of-life waste. Recycling and product recovery activities for footwear products need to be identified to ensure that landfilling is reduced and hazardous substances do not enter the environment or impact on human health while the economic value of the end-of-life materials, components and products is recovered. Proactive waste management activities such as material substitution will not, in the short term, be able to solve the issues connected to current EoL waste generation. This highlights the need to direct considerable efforts on reactive end of life management initiatives improving the treatment of waste currently generated, especially those focusing on the encouragement of reuse, recycling and energy recovery of footwear products.

In this context, this paper presented an integrated waste management framework for the footwear industry based on proactive and reactive waste management options, the composition of which is determined by the availability of end-of-life shoes and by access to recycling facilities. The use of biodegradable materials and their end-of-life implications are also being discussed. Compostability of biodegradable materials together with the use of renewable resources, of animal or plant origins, in their manufacture provide some positive aspects in terms of their end-of-life management consequences. On the other hand, if landfilled, biodegradable materials produce methane, a powerful greenhouse gas. In fact, when send to landfill, biodegradable materials lose their environmental benefit and become a non-benefit in terms of the EU Landfill Directive objectives. Furthermore, climatic variations play an important role in the biodegradability of materials which makes the application in the footwear industry not suitable for every type of shoes. Therefore, it the authors opinion that the use of biodegradable materials is a viable solution for certain types of shoes and components but they cannot be used in all the types of shoes and, definitely do not provide the ultimate solution to solve the EoL waste problem of the footwear industry. The use of biodegradable materials in shoe manufacturing is a long-term solution compared with recycling and product recovery which is a short-term end of life management option. However, the use of biodegradable materials needs to be further examined, especially with many types of biomaterials at the research and development stages at present.

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