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The environmental impact of end-of-life PVC flex banners and its potential upcycling opportunities

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ABSTRACT

PVC is used as a raw material for many products, especially in the production of flex banners. PVC flex banners used for advertising or marketing purposes have a short-term use [average up to 45 days]. PVC flex banners are usually annihilated, piled in landfills, incinerated, or buried under the soil, thus causing severe damage to the environment. This systematic literature review highlights the research carried out on this topic over the last two decades and discusses industry practices in producing PVC flex banners, the environmental impact of PVC flex banners due to annihilation, and reuse and recycling methods for PVC flex banners. One of these opportunities is upcycling, which is an important part of the reuse strategy. These flex banners can be reused in the fashion industry as upcycled products [high-value functional and aesthetic products] and accessories through zero-waste fashion production processes [especially used in pattern designing and cutting stages]. These include primarily bags and luggage, apparel, footwear, worker uniforms, and accessory upcycle products. Based on findings from the systematic review, it recommends a conceptual framework that emphasises the impact of end-of-life PVC flex banners and offers ways for reuse that avoid piling in landfills, incineration, and burying these wastes under the soil, reducing the impact on the environment. The studies suggesting the production of upcycling products from end-of-life PVC flex banners by the zero-waste fashion production process have not been sufficiently researched and reported, and they are a novel method of reusing resources.

Introduction

Polyvinyl chloride [PVC], is one of the five oldest and most widely produced general thermoplastic polymers in the world (Lewandowski and Skorczewska, 2022; Stichnothe and Azapagic, 2013; Zhou et al., 2013). Its characteristics, like low cost and high performance, combined with the wide range of products that can be obtained from different processing conditions and techniques, have made PVC a universal polymer (Ye et al., 2017). PVC has an important position regarding the opportunities it offers users, and its use is considerably high among all plastics. According to Plastics – the Fast Facts 2023 data prepared by Plastics Europe AISBL [International Non-profit Association based in Brussels, Belgium], it is seen that among all plastics, PVC production will have a significant share in the world and Europe in 2022. Among all plastics being produced, PVC production is 12.7 % worldwide and 9.1 % in Europe (Plastics Europe AISBL, 2023). According to Statista's 'Global Production Volume of Thermoplastics by Type 2020-2050′ data, 40.34 million metric tonnes of PVC were produced among all thermoplastic production in 2020. This production volume is expected to reach 59.30 million metric tonnes in 2050 (Statista, 2020). It can be noted from the Plastics-Fast Facts 2023 report that 400.3 million metric tonnes of plastics were produced in 2022. When these plastics are analysed on a polymer basis, 18.9 % of the production is composed of polypropylene [PP], 14.1 % of polyethene [PE] and 12.7 % of polyvinyl chloride [PVC] (Plastics Europe AISBL, 2023). Fig. 1 illustrates the world plastics production in 2022. According to this report [PVC 2024 report, Merchant Research and Consulting Ltd], the Asia Pacific region is the largest PVC-producing region, with more than half of the global total. North America and Europe follow this region. PVC-producing countries by production volume are China, the United States of America, Germany, Japan, and France. More than 65 % of global PVC demand comes from the Asia Pacific region, which is expected to maintain its high growth rate until 2033. In addition, it is thought that China and India will be mostly responsible for the growth of production in this region (Independent Commodity Intelligence Services, 2023; Merchant Research and Consulting Ltd., 2024). When the global PVC consumption data of

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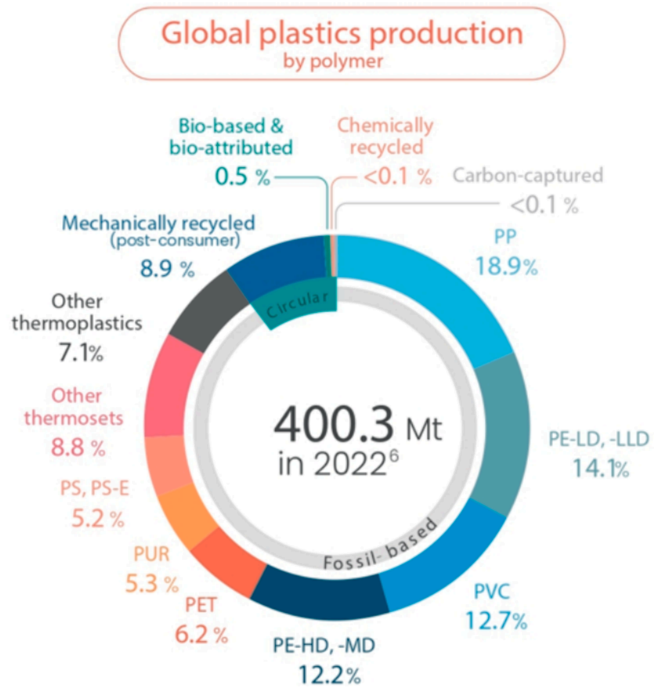

Fig. 1. World plastics production of 2022. (Plastics Europe AISBL, 2023).

Chemical Market Analytics for 2022 are analysed, it is seen that the leading countries in PVC production also play a significant role in PVC consumption. These data show that China has a very large consumption rate of 44 %, followed by the United States of America at 10 %, Western European countries at 9 %, and India at 8 %. Fig. 2 illustrates the world consumption of PVC-2022 (Chemical Market Analytics, 2022).

According to the research report [The Observatory of Economic Complexity, 2024], the top ten countries importing the most PVC in 2021 [million USD] are: India [$2,255.64], Turkey [$1.324.66], Italy [$979.79], Germany [$926.04], Brazil [$829.68], Vietnam [$772.90], Canada [$735.69], China [$671.65], Poland [$495.56], and Mexico [$491.18] (Statista, 2023). PVC is a highly durable material produced in various colours and shades, making it widely applicable in many areas (Ghosh et al., 2018; Hahladakis et al., 2020). PVC, which is classified as flexible and rigid, expands its usage area with its properties (Ait-Touchente et al., 2023; European Commission, 2022; Ghosh et al., 2018; Mulder and Knot, 2001; VinylPlus, 2017; VinylPlus, 2023). Fig. 3 illustrates the leading importers of polyvinyl chloride [PVC] polymer worldwide in 2021 country-wise.

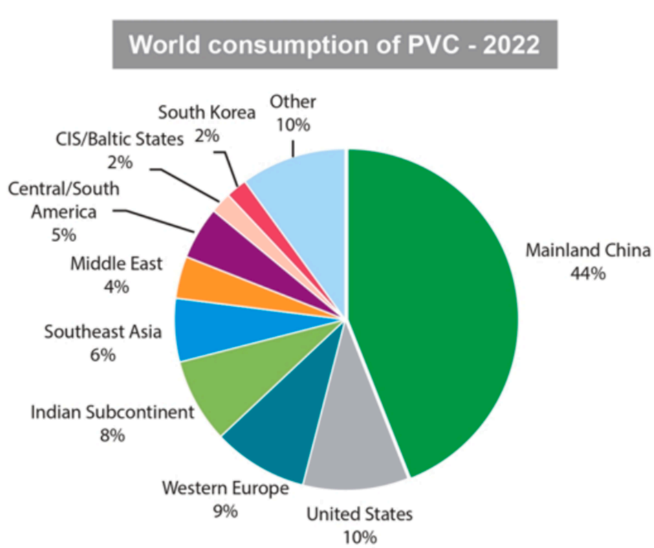

Fig. 2. World consumption of PVC-2022. (Chemical Market Analytics, 2022).

Ceresana's 'Polyvinyl Chloride [PVC] Market Report' also shares the distribution of demand for polyvinyl chloride [PVC] worldwide in 2021 by end-use sector. According to this research, flexible or rigid PVC is distributed as follows by sectors in 2021: 61 % construction industry, 9 % flexible packaging, 8 % rigid packaging, 7 % industry, 2 % transport, 2 % electrical and electronics, 12 % other (Statista, 2022). Due to its versatility, PVC has found applications across various industrial, technical, and household uses. In Europe, around two-thirds of PVC produced is used in building applications such as PVC window frames and other profile applications, pipes and fittings, flooring, electric cables and conduits, a variety of plastic linings, membranes, and waterproofing applications, and in coated fabrics (British Plastics Federation, 2024; VinylPlus, 2017). PVC is a linear and strong polymer with monomers arranged in a head-to-tail configuration. It is an industrially important chemical. Its durability makes it attractive for use in many areas, especially flex banners (Bac, 2021; Ghosh et al., 2018; Uttaravalli et al., 2021).

Flex banners are advertising tools frequently seen indoors and outdoors for advertising or information purposes and are printed by digital printing methods today. Flex banners attract customers because of their durability, accessibility, easy portability, and changeability (Ismail et al., 2014; Ragaert et al., 2019; Wongtanasuporn et al., 2019). Although banners made of acrylic [PAN], cotton [CO], polyester [PES], and polyethene [PE] materials are sometimes used for indoor and outdoor advertising and marketing products, they do not have as much usage rate as flex banners, whose primary material is PVC. In addition, other fabric banners cannot replace flex banners due to the disadvantages [cost, lifetime, and durability] of metal panels or LED screens. The duration of use of flex banners usually does not exceed 15–45 days, and these banners are replaced with new ones after the event is completed (Ghosh et al., 2018; Rao, 2018). For instance, flex banners are often preferred for announcing events or promotions. However, these banners are replaced by new banners before the current event is completed. The usage periods of the banners, which can be used structurally for more extended periods [average last up to five years], are shortened depending on the dynamics of advertising and marketing demands (Essex Banners, 2022; OC Signs, 2024; Vivid Ads, 2024). When advertising or marketing banners are examined, it is seen that these banners are created by using different materials together. These are usually composed of calcium carbonate [$CaCO_3$], polyvinyl chloride [PVC], polyester fabric, plasticisers, and additive constituents (Ghosh et al., 2018; Uttaravalli et al., 2021). These PVC flex banners are widely used as advertising or marketing banners today (Ragaert et al., 2019; Saravanan et al., 2015), because they are economical, can be digitally printed, are easy to use and durable. These banners made of PVC material are often referred to simply as vinyl banners (Bompa et al., 2021). The flex banners contain PVC layers laminated on polyester fabric (Mishra and Jain, 2019). Generally, woven or knitted fabrics are used to produce flex banners (Yang et al., 2022), but woven fabrics are less durable than knitted fabrics. Knitted fabrics are more popular than woven fabrics because of their durable mechanical properties (Luo and Hu, 2009) and undergo less deformation over time (Ziqi et al., 2022). Today, knitted fabrics are printed on digital printing equipment at a continuous length (A-Zen Academy, 2022). It is seen that tarpaulins made of these similar materials [flex banners are also included in this classification] are included in the 'pack tech [packaging textiles]' category of technical textiles, which are characterised as a special textile product (Annapoorani, 2018; Glampedaki, 2019; Ministry of Textiles, Government of India, 2014; Paul, 2019).

PVC-containing end-of-life products are the most common plastic waste (Zhao et al., 2022). As a result of this production, the amount of PVC increases significantly, and the problem of solid waste generated increases. PVC is not structurally soluble (Chan et al., 2023; Ritzen et al.,

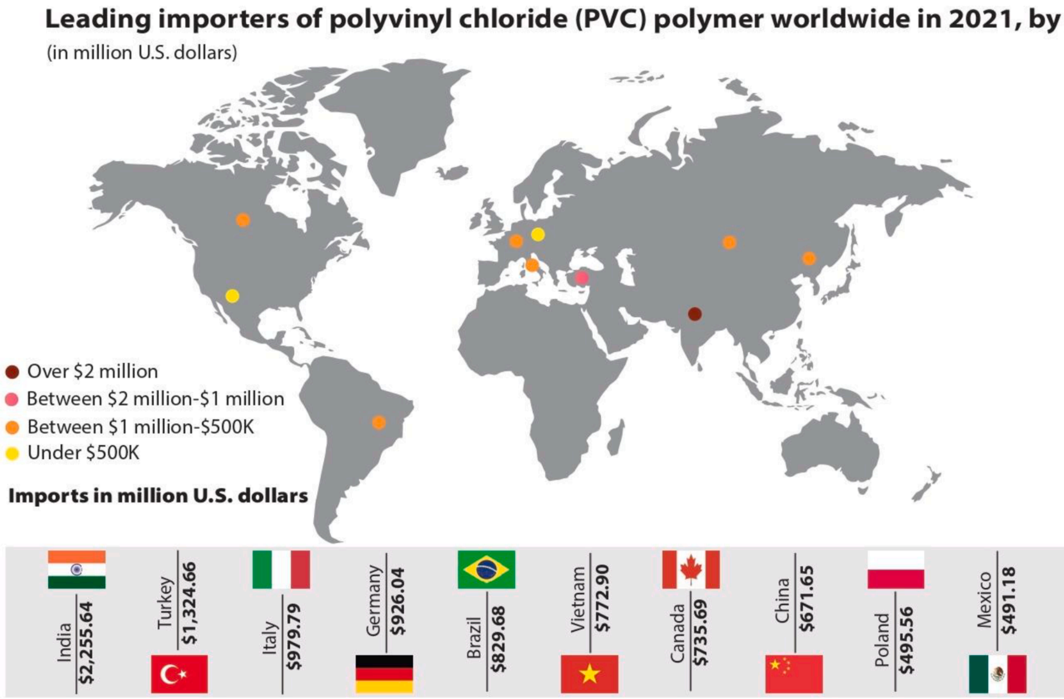

Fig. 3. Leading importers of polyvinyl chloride [PVC] polymer worldwide in 2021, by country. (Statista, 2023).

2023). Poor strategies for disposing of end-of-life products with PVC content also pose serious problems, such as piling in landfills, incineration, and burying under the soil. These products are largely disposed of by incineration where high temperatures are required [300 °C]. Incineration releases harmful substances such as sulphates and nitrates, reducing oxygen supply. These harmful substances are released into the air and soil (Hema Krishna and Swamy, 2016; Uttaravalli et al., 2021). This emission causes severe damage to both the environment and human health (Cepeliogullar and Putun, 2014; Jamialahmadi, 2020; Saeed et al., 2004). Recycling end-of-life products with PVC content is not biodegradable due to its structure, so it becomes clear that recycling is not a very easy process [especially end-of-life PVC flex banners]. Although PVC has a recycling potential of 79 % (Faraca and Astrup, 2019), the recycling process for PVC, which has different recycling methods, is a long, laborious, costly, and risky process compared to other plastic wastes. Each recycling process used for PVC has some advantages and disadvantages (Cepeliogullar and Putun, 2014; Cholake et al., 2018; Shibamoto et al., 2007; Uttaravalli et al., 2021; Yadav et al., 2018; Zhou et al., 2013). With the recycling of plastics with PVC content, these materials are mostly used as filling materials. In addition, it is seen that transforming these and similar materials into a fashion product with high added value by the upcycling method is not very common (Jang et al., 2012; Nayak et al., 2021; Park and Lin, 2020). This situation offers an opportunity for the reuse of end-of-life PVC flex banners in terms of the upcycling concept classified under sustainability. Upcycling is the process of combining end-of-life materials that have completed their life cycle and turning them into a high-value product with numerous economic opportunities. In this respect, upcycling is a creative reuse method. It transforms materials that have reached their economic life, unwanted materials, into new products for a better environment. Suggestions for using the upcycling concept in the fashion retail industry are still nascent (Bhatt et al., 2019; Brown, 2013; Cassidy and Han, 2013; Janigo et al., 2017). In particular, the United Nations [UN] has mentioned the concept of upcycling while promoting the 17 Sustainable Development Goals in its report 'Act Now for Zero-Waste Fashion', and the European Union aims to introduce circular materials and circular production processes for the utilisation of waste materials and to establish a new waste strategy by 2025 (Amicarelli et al., 2022; United Nations, 2019).

This systematic literature review discusses the potential upcycling opportunities offered by end-of-life PVC flex banners for advertising or marketing purposes. The detailed literature research evaluated industry practices in the production of PVC flex banners and the environmental impact of these banners. It can be noted that most materials used in flex banners are PVC (Ghosh et al., 2018; Ragaert et al., 2019; Saravanan et al., 2015; Uttaravalli et al., 2021; Vishnuvardhan et al., 2021). The review attempted to find out whether the end-of-life PVC flex banners can be upcycled in the fashion industry as previous literature attempts to upcycle in the engineering field (Bompa et al., 2021; Cholake et al., 2018; Mishra and Jain, 2019; Saravanan et al., 2015; Uttaravalli et al., 2021; Wongtanasuporn et al., 2019; Vishnuvardhan et al., 2021). Interestingly, only research comprehensively evaluated the production of upcycling fashion products from end-of-life PVC flex banners. Cuc and Secan (2024) analysed the environmental impact of waste advertising banners and proposed sustainable strategies to transform them into functional raincoats using a CAD [Computer-Aided Design] software. This can be explained by the fact that upcycling is a new concept and that the fashion industry and academia have not given it due attention in research and practice (Jain et al., 2021). There is a strong notion in the waste management hierarchy about being resource efficient. The review is structured as follows: Part two provides PRISMA [Preferred Reporting Items for Systematic Reviews and Meta-Analyses] guideline-based search data on the study methodology and related literature. PRISMA is a methodological approach that supports researchers in a systematic review to be clear and transparent in their review and helps with detailed reporting (Rethlefsen and Page, 2022). Part three presents the results and discussion [major constituents, production issues, environmental impacts, and waste generated by PVC flex banners] of the research on PVC flex banners. Part four discusses the potential upcycling opportunities of PVC flex banners for the fashion industry along with a framework to highlight various impacts within the lifecycle of PVC flex banners and the pathway to utilise the end-of-life PVC flex banners using a zero-waste fashion production process and elevating it to high-end fashion products.

Research methodology

Research theory and review criteria

This study used the systematic literature review [SLR] process to achieve its research objective. Systematic literature review is a research method and process for identifying and critically evaluating relevant research and collecting and analysing data from these studies (Snyder, 2019; Xiao, 2019). Systematic literature review [SLR] is recognised as an appropriate method for conducting a comprehensive literature review that evaluates and synthesises all existing studies to identify gaps in the research topic and to recommend future research (Prajapati et al., 2019; Rathnayake, 2024). Systematic literature review is convenient for minimising researcher bias regarding the inclusion or exclusion of studies and channelling how and to what extent the systematic literature review was performed through transparency (Karaosman et al., 2017). The main purpose of developing inclusion and exclusion criteria is to ensure that we only select the studies relevant to our systematic literature review (Busalim et al., 2022).

This systematic literature review [SLR] synthesises relevant literature to explore possible upcycling opportunities for end-of-life PVC flex banners in the fashion industry provides an overview of previous studies and identifies research gaps. The studies covered in a systematic literature review [SLR] are academic studies that include both qualitative and quantitative findings. The systematic literature review seeks to answer four main research questions. These research questions are as follows: [**1**] What are the environmental issues of end-of-life PVC flex banners? [**2**] What are the barriers to re-utilising end-of-life PVC flex

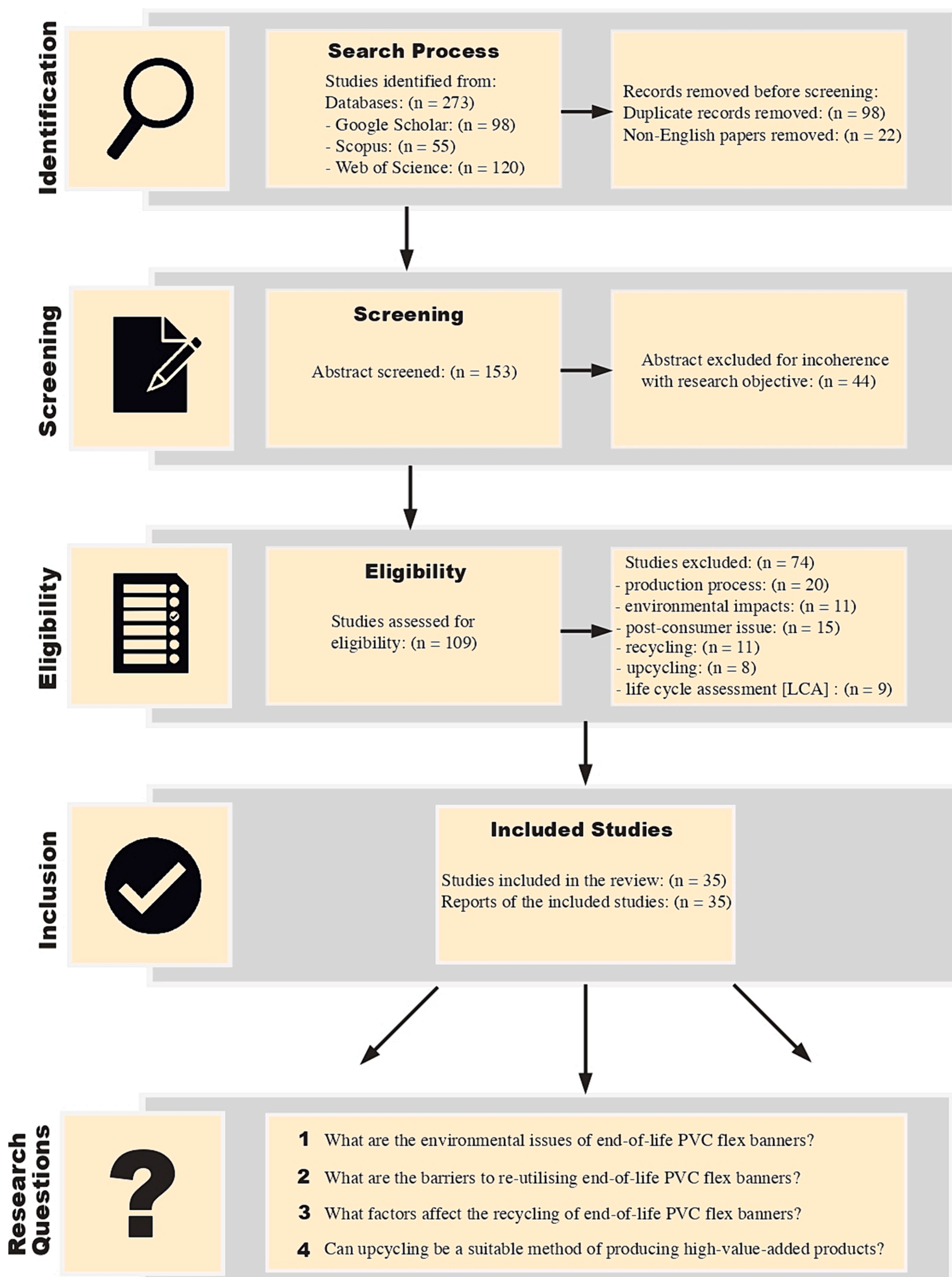

Fig. 4. PRISMA guideline-based flowchart used for the article screening process with the research questions.

banners? [3] What factors affect the recycling of end-of-life PVC flex banners? [4] Can upcycling be a suitable method of producing high-value-added products? Fig. 4 illustrates the PRISMA guideline-based flowchart used for the article screening process with the research questions.

Review limitations and eligibility

The systematic literature review discussed publications related to the topic 'the environmental impact of end-of-life PVC flex banners and its potential upcycling opportunities' in this systematic literature review. Here, the word 'end-of-life' refers to flex banners that are wasted and no longer in use. The literature review was conducted using the keywords between 15th Jan and 15th April 2024. The research was conducted through databases defined as internationally recognised, reputable, and high-quality research aggregators. These are the 'Google Scholar', 'Scopus' and 'Web of Science' databases. Publications up to 2024 were screened and only studies were reported in English. In addition, studies addressing the production of PVC flex banners, their main components, environmental sustainability, ecological concerns, and waste management, as well as studies on the recycling and reuse of end-of-life PVC flex banners, were evaluated. The types of writings searched for collected literature were published online, peer-reviewed research articles, and conference proceedings. The bibliography also includes research articles, review articles, books, electronic books, book chapters, reports of organisations and website articles. Table 1 shows the inclusion and exclusion criteria prepared by the scope of the systematic literature review.

The keywords were searched in two stages: first, only the terms 'PVC flex banner' and 'PVC' which should be present in titles, keywords and/or abstracts, were searched; and second to verify the robustness of the search, keywords: [**a**] production-related OR [**b**] environmental impact OR [**c**] post-consumer issue OR [**d**] recycling OR [**e**] upcycling OR [**f**] life cycle analysis [LCA]; AND [**1**] PVC OR [**2**] PVC flex banners were used across the different databases for searching relevant publications. In the first step, called the identification step, 273 academic publications have been accessed. The research strings have been pre-searched within article titles, abstracts, and keywords, to create a first database of metadata including authors' names, articles' titles, year of publication, journal, and digital object identifier [DOI]. Two authors [K.S., P.D.V.] independently screened all the records, reviewed full-text research articles and conference proceedings, and determined their eligibility to be used in the systematic literature review. During the identification stage, many articles were deleted because of duplicates [n = 98], not written in the English language [n = 22] or abstracts were excluded for incoherence with the research objective [n = 44] and 109 records were selected for in-depth screening. At this stage, 74 academic publications have been excluded because they do not follow the aims and scope of the research. Later, this number was reduced to 35 academic publications after carefully reviewing the contents of the articles. The relationship of the included academic publications [research articles and conference proceedings] with the identified keywords is presented in Table 2 and is organised alphabetically. The topics were identified during the systematic literature review process.

Table 1
Inclusion and exclusion criteria.

Inclusion Criteria	Exclusion Criteria
Research articles, conference proceedings.	Review articles, mini-review articles, books, e-books, book chapters, reports of organisations, newspaper articles, magazine articles, website articles, and short communications.
Articles published between 2000 and 2024.	Articles were published during the selected period.
Academic databases: Google Scholar, Scopus, and Web of Science.	Articles published out of the selected databases.
Written in the English language.	Written in the non-English language.
Focus on only PVC flex banners.	There is no focus on the other banners, e.g., other fabrics, metal, LED, etc.

Results and discussion

Production issues and structure

Flex banners used for advertising and marketing purposes have a three-layer laminated structure in which a knitted fabric with polyester content is sandwiched between films consisting of calcium carbonate [$CaCO_3$] and polyvinyl chloride [PVC] resins, plasticisers, and additives. The flexibility provided by PVC makes digital printing on flex banners even more possible. This printing process is carried out in CMYK [Cyan, Magenta, Yellow, and Key] format with plotters (Saini et al., 2023). Flex banners are generally classified according to their intended use and purpose. Flex banners usually have a thickness range of 200–400 g/m^2, depending on their quality (Mishra and Jain, 2019; Vishnuvardhan et al., 2021). The most preferred thickness for flex banners is 250 g/m^2 (Ghosh et al., 2018). Flex banners, which are also resistant to water, mould, fire, ultraviolet [UV] rays and freezing weather, vary in thickness and size according to the area where they are used (Saravanan et al., 2015). In line with the demand, flex banner manufacturers are making flex banners, which are generally designed as front light and backlight, cost-effective, and long-lasting (Uttaravalli et al., 2021).

The flex banners, which can be hung on an existing installation, fixed to a floor, or freely swinging, consist of three main ingredients and other chemicals. These can be listed as calcium carbonate [$CaCO_3$], polyvinyl chloride [PVC], polyester fabric, plasticisers, and additives according to their usage rates. The composition percentage of a flex banner is usually 36 % calcium carbonate [$CaCO_3$], 33 % polyvinyl chloride [PVC] resin, 18 % polyester fabric, 9 % plasticisers and 4 % additives by weight (Ghosh et al., 2018; Uttaravalli et al., 2021). As stated before, the most used flex banners are 250 g/m^2, and the upper PVC film forming this flex banner is 100–120 g/m^2, the lower PVC film is 85–95 g/m^2 and polyester fabric is 35–40 g/m^2 (Ghosh et al., 2018).

Based on production methods, PVC flex banner is classified into three types, namely, flex banner with blade scraping method, PVC flex banner with calendering method, and legal PVC flex banner (Jutu Technologies Ltd., 2023; Uttaravalli et al., 2021). According to Haining Guangyu Warp Knitting Co., Ltd., a major PVC flex banner manufacturer in China, these production methods are explained as follows (Haining Guangyu Warp Knitting Co., Ltd., 2020). [**a**] Blade scraping is also called PVC-coated flex banner (Guangzhou Fortune Digital Technology Co., Ltd., 2023). The knife-scraping method for PVC flex banner is to apply liquid PVC slurry uniformly to both the front and back sides of the base cloth with several anti-squeegee blades, then completely combine them into a whole through a drying process, and then cool to form. Currently, the width of the PVC flex banner of this process can reach five metres (Haining Guangyu Warp Knitting Co., Ltd., 2020; Saravanan et al., 2015). As the manufacturing process is complex, the production equipment is expensive, such products are mainly imported into the Chinese market, and the price is relatively high. The most representatives are Ultralon from Germany, Uniflex from South Korea, and Sioen from Belgium (Guangzhou Fortune Digital Technology Co., Ltd., 2023). [**b**] Calendering: The calendering method is to fully agitate various raw materials, such as PVC powder and liquid plasticiser, and then bond with the base cloth into a whole by the pressure of a high-temperature hot roller (Ghosh et al., 2018; Haining Guangyu Warp Knitting Co., Ltd., 2020). However, limited by the equipment, the width is generally not more than three metres (Saravanan et al., 2015). 645 and 945 flex banners developed by 3 M company from South Korea are produced with this process; in addition, Lexi flex banner developed by LG company from South Korea is also the representative of this kind of process (Guangzhou Fortune Digital Technology Co., Ltd., 2023). [**c**] Legal PVC:

Table 2
List of included studies and related variables.

Number	Authors	List of included studies and related variables								
		Type of Study	**1**	**2**	**a**	**b**	**c**	**d**	**e**	**f**
1	Bac, 2021	Research Article	●			●	●	●		
2	Bicergil and Atilgan Turkmen, 2023	Research Article	●		●	●				●
3	Bompa et al., 2021	Research Article		●			●	●		
4	Chan et al., 2008	Research Article	●		●					
5	Chen and Bai, 2023	Research Article	●			●		●		
6	Cholake et al., 2018	Research Article		●				●		●
7	Ciacci et al., 2017	Research Article	●				●			
8	Cini, 2019	Research Article		●					●	
9	Cuc and Secan, 2024	Research Article	●	●	●	●	●	●	●	
10	Daniels, 2009	Research Article	●		●					
11	Evode et al., 2021	Research Article	●		●		●	●		
12	Faraca and Astrup, 2019	Research Article	●					●		
13	Hennebert, 2022	Research Article	●			●		●		
14	Jamialahmadi, 2020	Conference Proceeding	●					●		
15	Kang et al., 2024	Research Article	●					●		
16	Leadbitter, 2002	Research Article	●			●				
17	Lewandowski and Skorczewska, 2022	Research Article	●		●		●	●		
18	Lu et al., 2023	Research Article	●					●		
19	Miliute-Plepiene, 2021	Research Article	●				●	●		
20	Mishra and Jain, 2019	Research Article		●	●		●	●		
21	Mulder and Knot, 2001	Research Article	●		●	●		●		
22	Nakem et al., 2016	Conference Proceeding	●					●		●
23	Nava, 2020	Research Article	●				●		●	
24	Ragaert et al., 2019	Conference Proceeding		●			●	●		●
25	Saini et al., 2023	Research Article		●		●				
26	Saravanan et al., 2015	Research Article		●	●		●	●	●	
27	Saravanan and Sridhar, 2019	Research Article		●			●	●		
28	Stichnothe and Azapagic, 2013	Research Article	●			●	●	●		●
29	Vishnuvardhan et al., 2021	Research Article		●	●		●	●		
30	Wongtanasuporn et al., 2019	Conference Proceeding		●			●		●	
31	Xu and Gu, 2015	Conference Proceeding		●			●		●	
32	Yadav et al., 2018	Research Article		●	●	●	●	●		
33	Ye et al., 2017	Research Article	●		●		●	●		●
34	Zhao et al., 2022	Research Article	●				●	●		
35	Zhou et al., 2013	Research Article	●					●		

Note: **1:** PVC, **2:** PVC flex banner, **a**: production-related, **b**: environmental impact, **c**: post-consumer issue, **d**: recycling, **e**: upcycling, **f**: life cycle analysis [LCA].

It is also called laminated flex (Guangzhou Fortune Digital Technology Co., Ltd., 2023). By gluing PVC flex banners, the upper and lower layers are formed into a PVC film. This film is heated and pressed under the pressure of a heat roller and then cooled and shaped. The most prominent feature of this process is that it has excellent ink absorption (Haining Guangyu Warp Knitting Co., Ltd., 2020). This kind of flex banner currently has more than 50 % market share in China (Guangzhou Fortune Digital Technology Co., Ltd., 2023).

Polyvinyl chloride [PVC]

PVC can be rigid, flexible, transparent, or opaque (Braun, 2001; Garcia et al., 2006; VinylPlus, 2017; Yadav et al., 2018; Yarahmadi et al., 2003). Due to its structure, PVC can be combined with various additives to produce both flexible and rigid thermoplastics (Titow, 1990). In addition, it can be moulded in almost any size and shape (Cholake et al., 2018). PVC, which is a kind of synthetic resin, is a durable material that attracts much attention and finds use in a wide range of applications in daily life (Bac, 2021; Ye et al., 2017). According to VinylPlus – PVC Recycling Technologies 2017 and VinylPlus – Flexible PVC in Our Daily Life 2023, PVC is used in the event of climate emergencies, health, construction, architecture, building applications, sport and leisure, art, culture and design, industry, and transport (VinylPlus, 2017; VinylPlus, 2023). In 1872, Eugen Baumann synthesised PVC (Daniels, 2009; Mulder and Knot, 2001). In the early 21st Century, it started to be converted into commercial products with the cooperation of Ivan Ostromislensky and Fritz Klatte. Later, Waldo Semon mixed this material with various additives to give it a plastic consistency. In 1950 and afterwards, its use started to increase considerably and entered our living spaces (Ciacci et al., 2017; Semon and Stahl, 2006). PVC, which is frequently used in the production of advertising or marketing banners, is the third most widely produced synthetic plastic polymer in the world today after polyethene [PE] and polypropylene [PP] (Stichnothe and Azapagic, 2013; Uttaravalli et al., 2021). PVC is recognised as a universal polymer due to its properties, versatility, and low cost (Cholake et al., 2018).

Calcium carbonate [$CaCO_3$]

Calcium carbonate [$CaCO_3$] is a common substance found in rocks such as the minerals calcite and aragonite, especially in chalk and limestone, eggshells, gastropod shells, shellfish skeletons and pearls (Struminska-Parulska, 2015). The shells and skeletons of some organisms are composed of calcium carbonate. For example, about 95 % of eggshells are $CaCO_3$. It makes up more than 4 % of the Earth's crust and can be found in almost every region. Natural forms include chalk, limestone, and marble, which are chemically identical. However, they differ in many other respects, such as purity, whiteness, thickness, and homogeneity. They result from the sedimentation of the shells of crustaceans, corals, and snails that were fossilised millions of years ago (Ghosh et al., 2018). $CaCO_3$ is a fine, white, odourless, tasteless, and microcrystalline powder (Al Omari et al., 2016). It is a mineral widely used in the paper, plastic, paint and coating industries as a coating pigment and padding material because of its special white colour after grinding to micronized sizes. Its brightness and light scattering properties are highly valued. For this reason, it is also important to use it in the production of flex banners (Ghosh et al., 2018). Due to the poor toughness and unstable thermal properties of PVC, which is the most important material of flex banners, $CaCO_3$ is the most basic filler material used in the production of flex banners like other plastics and gives rigidity to these banners (Hess, 2001; Jiang et al., 2018; Jimoh et al., 2017).

Plasticisers and additives

Plasticisers are integral components of PVC formulations and serve to increase the flexibility, processability, dispersibility and durability of the material (Ait-Touchente et al., 2023). According to IUPAC [International Union of Pure and Applied Chemistry], plasticisers are described as a substance or material added to a plastic to increase its flexibility, processability or stretchability (Bocque et al., 2015). Plasticisers are used to make PVC [and other materials] flexible (Daniels, 2009). In this way, products including medical equipment, roofing, cables, flooring, tents, tarpaulins, and advertising or marketing banners can be produced (Ebewele, 2000; VinylPlus, 2023). The primary role of such substances is to lower the glass transition temperature [Tg], the second-order transition temperature, and improve the flexibility and processability of polymers (Vieira et al., 2011). As in other PVC products, the plasticisers used in flex banners are used with substances called phthalates. Phthalates are used with materials such as heavy metals in PVC products, although concerns and even controversy remain about their use and their impact on human health and the environment (United States Environmental Protection Agency, 2012; Pielichowski and Swierz-Motysia, 2006; Sunny et al., 2004; Zero Waste Europe, 2021).

Phthalates are environmental pollutants used in industry as plasticisers and additives in cosmetics. They are characterized as dangerous for the environment and living health, especially by mixing into air, water, and soil (Net et al., 2015) and are classified as Endocrine Disrupting Chemicals [EDC] in healthcare. Studies indicate that phthalates disrupt the human endocrine system and cause health problems such as decreased sperm quality and infertility, respiratory diseases, childhood obesity, neuropsychological disorders, type two diabetes, endometriosis and leiomyoma, breast cancer and growth problems (Hlisnikova et al., 2020; Katsikantami et al., 2016; Singh and Li, 2012; Wang and Qian, 2021). However, Benjamin et al. (2017) reported that the rate of exposure to phthalates in living organisms has not been fully determined. They also noted that although phthalates have low volatility, they are emitted as gas. It added that the United Nations [UN] Environment Program has been very careful about the effects of phthalates on the environment and human health and has classified phthalates as a global threat.

Fabric used in the PVC flex banners

Polyester is a category of polymers containing an ester functional group in each repeat unit of its main chain (Kopnick et al., 2000; Mighani, 2012). Polyester, mainly polyethene terephthalate [PET] is now widely used for textile fibres, technical fibres, films, and bottles because of its good mechanical properties, thermal stability, and low production costs (Yang and Kim, 2007). Polyester is the most widely used man-made synthetic material as a stand-alone fibre or in blends with natural or other fibres. Polyester fabrics have gained an important place in textiles due to their excellent physical properties, such as tensile strength, wrinkle recovery angle and biological resistance (Gulrajani et al., 2008). With its characteristics, polyester is frequently preferred in the textile industry to produce knitted fabrics, either alone or blended with other fibres (Hallet and Johnston, 2014; Smelik, 2023). Polyester has good properties for a wide range of textile products. Depending on the molecular orientation, combinations of moderate strength and high break extension or high strength and moderate break extension give a high work of rupture (Hearle, 2001). Polyester is a medium-weight fibre with a density of 1.39 g/cm^3 and consists of polyethene terephthalate [PET] polymers. Compared to other fibres, polyester is heavier than nylon but lighter than cotton. It is chemically inert to most chemicals, hydrophobic, and has good strength and resistance (Ghosh et al., 2018). Polyester fabrics, produced using the knitting technique, have good strength and durability and are mostly preferred in the production of flex banners. Knitted fabrics used for flex banners use warp knitting technology, which involves stitching high-tenacity polyester yarn on the warp side and feeding the weft yarn via a weft-carrier device. The warp-knitted structure of the flex banner textile ensures strength and durability, while the warp-knitting machine offers high production capacity. Today, these knitting machines are called RS2 (3) MSUS Biaxial Machines and are mainly used to produce flex banners, glass fibre geogrid, and other industrial textiles. The biaxial warp knitting machine, also called the weft insertion warp knitting machine, is a highly advanced textile machinery with speeds that can reach up to 1300 rpm [revolutions per minute]. Raschel weft insertion warp knitting machine RS2 (3) MSUS refers to a high-speed flex banner warp knitting machine with a weft insertion carriage, which forms a weft insertion structure by carrying parallel yarns horizontally. Raschel biaxial fabrics are widely used as flex banners as well as grids, home textiles and outerwear (A-Zen Academy, 2022).

Microfibre polyester-based knitted fabrics offer excellent flexibility and stability due to their finer structure, thus providing better mechanical properties. These polyester yarns have a very low hairiness, which does not create a tendency to shed lint and increases the efficiency of the knitting machine (Srinivasan et al., 2007). Among the various production methods [woven, knitted, and nonwoven], knitting technology has recently made a significant contribution to the production of biaxial knitting fabrics. Research has revealed some unique properties, such as high energy absorption, good impact resistance, structure formability even in complex shapes, and cost-effectiveness, making knitted structures an acceptable choice for technical applications. In this respect, biaxial knitted fabrics produced with polyester yarns used in the production of flex banners show exceptionally high strength compared to normal knitted structures (Hasani et al., 2017).

Environmental impacts

Plastic waste is divided into industrial and municipal classes, which differ in application areas, properties, and disposal processes (Cepeliogullar and Putun, 2014; Zhao et al., 2022). Traditional methods such as landfilling or incineration of plastic waste, which are constantly increasing, are not suitable for all plastic wastes, and the choices used in the disposal of these wastes cause unforeseen hazards for the environment (Ellen MacArthur Foundation, 2016; Ellen MacArthur Foundation, 2022; Panda et al., 2010; Paradela et al., 2009). The disposal of PVC waste, which constitutes a part of plastic waste and is increasing daily, also brings important environmental problems. Because most of the chlorine in municipal solid waste, which is plastic, comes from PVC (Evode et al., 2021; Saeed et al., 2004). While PVC is only 0.7 % of the total waste processed by municipal incinerators, the material contributes 40 % to 70 % of the chlorine input. Thus, the basis is prepared for high dioxin emissions (VinylPlus, 2021). The largest use of chlorine gas is the formation of PVC worldwide. Overall, 16 million tonnes [40 % per year] of chlorine production are used in daily human activities (Evode et al., 2021). Shibamoto et al. (2007), in their study titled 'Dioxin formation from waste incineration', discussed that dioxins, which are a persistent pollutant for the environment, are released because of the incineration of PVC due to their chlorine content (Kaleka and Thind, 2020; Tuomisto, 2019). Dioxins accumulate at low levels and are toxic (VinylPlus, 2021). When PVC is incinerated, chlorine is converted to hydrochloric acid [HCl]. As hydrochloric acid [HCl] is an acid gas, the incineration of PVC waste causes it to contribute to acid rain. It is seen that the residues arising from the cleaning of furnace chimneys in facilities where PVC waste is incinerated pose a serious problem in terms of environment and health. It especially causes harmful effects on human skin and eyes and increases the risk of cancer and heart diseases (Verma et al., 2016). These residues consist of heavy metal-laden fly ash and acid gases, especially in the form of hydrochloric acid [HCl] and sulphur dioxide [SO_2] (VinylPlus, 2015). If PVC wastes are to be incinerated, it is recommended that this process be carried out very consciously and meticulously in facilities that comply with the standards to minimise environmental damage (Buekens and Cen, 2010). However, the chemical residues that emerge when PVC is incinerated threaten the environment and human health in any case.

Landfilling is seen as another method of disposing of general PVC waste. Long-term landfilling of PVC waste can cause fatal explosions and fires due to leaking landfill gas. In addition, chlorine leaching into the soil can cause significant environmental damage by leaching into water [lakes, rivers, seas, and oceans] and soil over time (Buekens and Cen, 2010; Evode et al., 2021). Today, much PVC flex banner waste also ends up in landfills or is otherwise disposed of or stockpiled. Improperly managed waste can block drains and waterways, creating coding and breeding grounds for mosquitoes and diseased animals (Babaremu et al., 2022; Kehinde et al., 2020). The adverse effects of these wastes on the environment and human health are well known. The accumulation of waste leads to the formation of greenhouse gases and the possibility of leaching into soil and water. For PVC, storage options are increasingly limited due to rising costs (Cholake et al., 2018; VinylPlus, 2021). World Health Organization [WHO] states that the dioxins produced by the incineration or landfilling of PVC waste threaten the environment and the health of living organisms [plants, animals, and humans]. It states that it accumulates in other food chains, especially in the adipose tissues of animals. In addition, it is stated that more than 90 % of dioxins, which are highly toxic, poison humans through food [meat, milk, fish, and other sea creatures]. Living organisms can be exposed to dioxins, even if not through food. It is recommended that processes and inspections be carried out by local and government authorities to prevent exposure to living beings (World Health Organization, 2023).

Dioxin content is of great concern for environmental pollution. It proves that these concerns about the adverse health effects of dioxin arise from contamination around incinerators and industrial waste sites. It is also confirmed by reports that workers in these facilities are exposed to dioxin. The toxicity of dioxin is extremely high, and much attention is paid to its effects on fertility and growth. This is because children's growth is highly sensitive to dioxin, and the effects are often irreversible (Yonemoto, 2000). Adults, children, and infants are exposed to dioxin in various ways. Foetuses and new-born infants are the most vulnerable group, especially those exposed to high levels of dioxin through breast milk. Some people are exposed to higher amounts of dioxin because of their nutrition or occupation [workers in the pesticide industry or hazardous waste incineration plants]. Short-term exposure to high levels of dioxin is known to damage liver function and cause chronic inflammatory skin conditions with cysts and dark acne. Long-term exposure is related to disorders of the nervous, immune, fertility and endocrine systems. The International Agency for Research on Cancer [IARC] and the World Health Organisation [WHO] have classified dioxin as a carcinogenic substance based on many human and animal epidemiological data (Marinkovic et al., 2010). In addition, in Europe and the United States, dioxin levels exposed during the perinatal period in sample groups have been found to cause permanent effects in infants. Some of the effects seen include health problems such as intelligence quotient [IQ] and behavioural disorders, deterioration of blood cells and reduced lung function (Tusscher et al., 2004). In animals, they cause diseases and abnormalities in a range of wildlife species, including certain bird species, fish, and mammals. Some fish species, especially sea bream, are reported to be exposed to dioxin due to their dietary habits. They are of global concern because they can evaporate from the soil and travel by air, transporting long distances from the point of production to release (Kanan and Samara, 2018; Mikolajczyk et al., 2020). So, it can be noted that when PVC is incinerated, it can cause more harm to human and animal health.

The production of PVC flex banners does not produce harmful emissions if appropriate conditions are provided and necessary precautions are taken (Ghosh et al., 2018). However, in production processes where the necessary precautions are not taken, it may release large amounts of solids, air, water, and other harmful environmental toxins (Oncel et al., 2017). In addition to emissions during print production, there may also be potential for emissions afterwards. Poor-quality chemical dyes used in the printing phase may be especially toxic and carcinogenic (Yadav et al., 2018). For this reason, ensuring specific environmental and health standards when producing PVC flex banners is very important for manufacturing enterprises. However, in the last decade, several associations have been established in Europe [Plastics Europe, VinylPlus], Asia [Asean Vinyl Council, Vinyl Environmental Council], North America [The Vinyl Sustainability Council] and Australia [The Vinyl Council of Australia] to oversee production processes in a sustainable context. It is seen that these associations shape PVC production and support recycling by paying attention to environmental awareness and human health issues within the scope of sustainability. For example, The Vinyl Council of Australia has reported that environmental, health and safety impacts have been considered and addressed in the development and launch of a new PVC product for the Australian market (The Vinyl Council of Australia, 2023). According to VinylPlus, one of these organisations, no cases of angiosarcoma have been reported in people who started working in the PVC industry after the implementation of measures to reduce exposure to Vinyl Chloride Monomer [VCM] (European Chemical Agency, 2023). In its final report published in 2022, the European Commission widely classified PVC as non-hazardous based on the argument that the additives are bound to the polymer matrix, do not migrate, and are, therefore, not bioavailable (European Commission, 2022). According to the 'Progress Report 2022' published by VinylPlus (2022), PVC has been analysed in terms of life cycle analysis [LCA] and eco-efficiency and is said to have good environmental performance. In addition, PVC products, thanks to their unique properties and qualities, can make a positive contribution to various targets of the United Nations [UN] 17 Sustainable Development Goals [SDG].

Life cycle analysis [LCA]

Life cycle analysis [LCA] is a method covering the extraction and processing of raw materials, production, distribution, utilisation, recycling, and final disposal. It provides a quantitative assessment of the consumption and disposal of materials by the system. Energy saving and efficient energy utilisation are very important factors to consider in any production process (Ghosh et al., 2018; Ilgin and Gupta, 2010; Sun et al., 2024). To systematically understand the environmental impacts of PVC, data from the Higg Materials Sustainability Index [MSI], a cradle-to-door materials scoring tool supported by life cycle analysis [LCA] data and methodology, is considered to ensure our global value chain's participation in environmental sustainability. The Higg Index [currently called Wordly] is a platform established by the Sustainable Apparel Coalition [SAC] to assess the environmental and social sustainability of materials used in textile, apparel, and footwear production (KPMG International Limited, 2023; Radhakrishnan, 2015). Sustainable Apparel Coalition [SAC] was formed in 2009 with the understanding that change in the fashion industry would be achieved by recording metrics to assess the impacts of climate change (Palomo-Lovinski, 2024). The Higg Materials Sustainability Index [MSI] is a quantitative tool underpinning the impact of materials, trims, and packaging used in apparel, footwear, and home textiles. It is a cradle-to-gate material assessment tool to engage product design teams and the global supply chain in environmental sustainability (Sustainable Apparel Coalition, 2020). The Higg Materials Sustainability Index [MSI] consists of five life cycle indicators to help the apparel industry inform material selection at the design stage (Prado et al., 2021). When the Higg MSI data is analysed, PVC is positioned under the foam, plastics, coatings, and laminations categories. These data are described by the Higg MSI as follows: [**a**] for PVC foam Global Warming [4.48 kg CO_2 equivalent/kg], Eutrophication [1.34 kg PO_4 equivalent/kg], Water Scarcity [0.457 m^3/kg], Resource Depletion/Fossil Fuels [5.75 MJ/kg], and Chemistry [6.29 units]; [**b**] for PVC plastics, Global Warming [4.01 kg CO_2 equivalent/kg], Eutrophication [1.18 kg PO_4 equivalent/kg], Water Scarcity [0.424 m^3/kg], Resource Depletion/Fossil Fuels [5.26 MJ/kg], and Chemistry [6.10 units]; and [**c**] for PVC coatings and laminations, Global Warming [3.50 kg CO_2

equivalent/kg], Eutrophication [0.646 kg PO_4 equivalent/kg], Water Scarcity [0.084 m^3/kg], Resource Depletion/Fossil Fuels [6.78 MJ/kg], and Chemistry [3.02 units]. When compared to other synthetic materials like acrylic [PAN], cotton [CO], polyester [PES], and polyethene [PE] fabric, PVC has a relatively lower impact on the environment (Higg Index MSI, 2024). The above materials were compared because they are widely used for advertising and marketing after PVC.

Ghosh et al. (2018) carried out detailed research on the life cycle analysis [LCA] of PVC flex banners. This study includes some data on the resource requirements to produce 1 kg PVC flex banner. These data are defined as follows: [**a**] polyester cock, husk and limestone used for heating purposes: 500 cal/kg of PVC flex banner, [**b**] grinding and separation: 0.3 kW, [**c**] downstream power consumption: 0.3 kW, [**d**] energy required for the production of 1 kg of polyester fabric: 0.6 kW, [**e**] energy required for the production of 1 kg of PVC flex banner: 0.8 kW, [**f**] water consumption for the production of 1 kg of PVC flex banner: recyclable, [**g**] emissions during the production of 1 kg of PVC flex banner: no harmful emissions. In addition, the requirement for fuel for the transportation of 1 kg of PVC flex banner was determined as 0.123 l/kg.

Post-consumer usage

Environmental sustainability links to utilising less harmful raw materials and the recycling or reuse of materials (Han et al., 2017a). Recycling and reuse of solid waste materials is now recognised as an integral part of solid waste management in many parts of the world (Bari et al., 2012). It is common to believe that flex banners cause serious environmental problems due to their intensive use. Since they are not biodegradable, it is extremely important to adopt innovative and environmentally friendly strategies that encourage the reuse of PVC flex banners (Ghosh et al., 2018).

In this context, as with other plastics, it is very important to bring up reuse suggestions other than piling PVC flex banners in landfills, burying them under the soil or incineration. PVC waste, including PVC flex banners, appears to have advantages and drawbacks in annihilation methods and recycling (Awasthi et al., 2017; Lu et al., 2023). However, it is not possible to ignore the advantages of reuse for PVC flex banners, which constitute a significant portion of PVC waste (Uttaravalli et al., 2021). The advantages and drawbacks of annihilation, recycling, and reuse of end-of-life PVC flex banners are discussed in Table 3.

Because these wastes affect the earth, air, and water quality, as well as the health of animals and humans, waste management systems such as landfills, incineration, recycling, pyrolysis, and bioremediation are generally preferred for plastics. However, not all these methods are possible for every plastic waste (Evode et al., 2021; Zhao et al., 2022). Although it is seen that recycling or reuse methods are possible for PVC waste, it is encountered that it is possible to use some of these methods for PVC flex banners.

Table 3
Advantages and drawbacks of annihilation, recycling, and reuse of end-of-life PVC flex banners.

	Methods	Advantages	Drawbacks
Post-consumer usage	***Piling in landfills***	Convenience Low cost	It affects land, water, animal life and public health.
	Incineration	Energy recovery Space saving	It affects the air quality, animal life, and public health.
	Burying under the soil	Disposal and space-saving	It affects land, water, animal life as well as public health.
	Recycle	Circular economy Sustainability	Energy consumption is high. Low commodity value. Medium-level water consumption.
	Reuse	Circular economy High value Sustainability	Medium-level water consumption.

Recycling

Recycling is the process of transforming objects that have expired and become waste into a different product by subjecting them to physical or chemical processes and continuing to use them in their new function. During the recycling process, a complete change occurs in the structure of the product, and it evolves into a completely different product compared to the previous one (Fletcher, 2008; Marsh and Lu, 2024; Pandit et al., 2020). Like most materials with plastic content, PVC waste is very suitable plastic for recycling. With the increasing awareness of PVC recycling, 813.266 tonnes of PVC waste were recycled in Europe in 2022. When PVC wastes are analysed, window profiles and related products, flexible PVC [including flooring, roofing and waterproofing membranes, coated fabrics, and films], pipes and fittings, and other rigid [including rigid PVC films] are classified from high to low recycling quantities (VinylPlus, 2023). In general, the recycling of PVC waste can be classified as mechanical recycling and chemical recycling (Bucknall, 2020; Jamialahmadi, 2020; Mulder and Knot, 2001; Nicholson et al., 2022; Ragaert et al., 2019, Sadat-Shojai and Bakhshandeh, 2011; Tang, 2023). It is possible to use primary and even secondary PVC wastes in recycling and with the development of technology, new suggestions for recycling are offered (Qi et al., 2024). However, recycling PVC-coated banners is not easy. The biggest obstacle to recycling flex banners is separating the PVC coating from the polyester fabric, which is a technical and economical challenge (Cholake et al., 2018).

Some PVC wastes are suitable for chemical recycling technology [chemical recycling methods are pyrolysis, gasification, liquid–gas hydrogenation, viscosity breaking, steam or catalytic cracking, etc.] (Al-Salem et al., 2009; Zhao et al., 2022), but it is not very common for PVC flex banners due to their drawbacks (Lu et al., 2023; Ragaert et al., 2017; Sun et al., 2003). In the chemical recycling process, which is very costly, PVC undergoes thermal degradation and produces hydrochloric acid [HCl], chlorinated organic compounds and toxic heavy metals (Lu et al., 2023; Zakharyan et al., 2020). This makes mechanical recycling attractive for flex banners (Ghosh et al., 2018; Lewandowski and Skorczewska, 2022; Seki et al., 2014). With current technological developments, it has become possible to separate the PVC compound of flex banners from the polyester fabric. As a result of this separation, the PVC compound and polyester fabric are individually subjected to mechanical recycling. A mechanical shredding machine is used in this recycling process. As a result of this process, PVC and $CaCO_3$ components are on one side and short polyester fibres on the other. These materials are also used in the production of new products with different life cycles, including footwear, geotextiles, canal linings, flooring, PVC sheets for construction and agricultural applications, ropes, pipes, mattress/pillow fillings, etc. (Ghosh et al., 2018; Seki et al., 2014). In addition, it is seen that there are studies on the use of flex banners in the construction sector by completely disintegrating them (Bompa et al., 2021; Cholake et al., 2018; Mehta et al., 2023; Mishra and Jain, 2019; Saravanan et al., 2015). Scrap flex banners are also used, especially in road construction (Ghosh et al., 2018).

Reuse

Reuse refers to using the material/products again, and the reuse method starts with the assumption that the materials that are used in our lives can be re-sourced rather than creating waste. The most important part is the design process, which starts with the decision to use waste materials for positive purposes. The purpose of reuse can be divided into two categories, upcycling and downcycling, and this approach contributes to the circular economy with an environmentalist approach that minimises the amount of waste (Abdul-Rahman, 2014; Jain et al., 2021; Kabirifar et al., 2020). Waste reuse involves taking any product or a portion of a product and reusing it in its original form for a different function (Bui et al., 2022). Especially in today's intensive production and consumption, sustainable alternative solutions contribute significantly to reducing waste, fully utilising available materials for social and economic benefits and protecting the environment (Ghosh et al., 2018). It is seen that end-of-life PVC flex banners offer some reuse opportunities. The flexibility, water resistance, high strength, high abrasion resistance, and long life of these flex banners are transformed into upcycling or downcycling products and enter the reuse cycle (Uttaravalli et al., 2021). These can be either upcycling products [bags, sitting mats, etc.] with a high design value or downcycling products [roof cover, food grain cover, lorry cover, etc.] with limited design value and utility only (Ghosh et al., 2018).

Recommendations

Upcycling potential of the PVC flex banners in the fashion industry

Cobo et al. (2018) categorised the hierarchy of waste evaluation procedures as follows: [**a**] reuse of the products, [**b**] recycling of the materials, [**c**] incineration, and [**d**] landfill. In this hierarchical category, the concept of upcycling, classified below reuse is necessary for a clean environment and economic cycle and is becoming more and more important day by day (Stanescu, 2021). Upcycling is a concept specifically used to limit the amount of textile and fashion products entering the waste cycle. This concept is a creation solution that allows the reuse of products that are considered to have completed their life cycle by the user (Bhatt et al., 2019). The movement to transform something useless into something useful is a sustainable solution that requires little energy and eliminates the need for a new product from raw materials (Szaky, 2014). Upcycling is described as a relatively new term positioned under sustainability. It is the process of using materials [especially textile and garment products] that have reached the status of waste at the end of their life cycle to create a new product of higher quality (McDonough and Braungart, 2013; Dwikesumasari et al., 2024; Sung et al., 2020). Upcycling not only conserves the resources used in the production of materials but also adapts them to a life cycle. In addition, it enables one to gain value by interpreting knowledge and skills (Murray, 2002). Upcycling helps to give new life to old products or wastes for the second time (Nayak et al., 2021). It is important to consider that the upcycling design process differs from regular design based on the parameters of the waste materials (Aus et al., 2021).

McDonough and Branguart (2002) also stated that upcycling is an improved version of recycling and explained it as a cradle-to-grave process developed to reduce waste. The upcycling process includes factors such as environmental awareness, creativity, and innovation, which results in a sustainable and innovative product. In addition to the environmental and economic implications of saving resources and minimising waste, upcycling fashion designs means that product availability before upcycling is extended, and the good properties of variable raw materials are maximised (Lee, 2023). For example, downcycling produces cleaning cloths from waste t-shirts, while upcycling transforms waste t-shirts into products with added value, such as unique handmade rugs (Vadicherla et al., 2017). The most significant difference between upcycling and recycling is that a textile or fashion product is transformed into a new product with a creative perspective without being subjected to a physical or chemical process. The difference between upcycling and downcycling is defined as obtaining a textile or fashion product with high added value. Upcycling aims to produce a valuable textile or fashion product without involving a chemical process (Caldera et al., 2022; Vats and Rissanen, 2016).

Today, chemical-containing plastic products are made reusable by recycling and used in the textile and fashion industry (Fletcher, 2008; Fletcher and Grose, 2012; Juanga-Labayen et al., 2022). However, this is mostly achieved by processing these plastic products through various chemical processes [by melting them into filaments or yarns] (Shibamoto et al., 2007; Tshifularo and Patnaik, 2020). Recycling of plastics with PVC content reveals that these materials are mostly used as filling materials in the industry. Mechanical recycling is the most suitable recycling method for end-of-life PVC flex banners (Ghosh et al., 2018). Because the chemical recycling method is not suitable and not preferred for end-of-life PVC flex banners due to both the cost and the release of harmful chemicals (Ragaert et al., 2017; Solis and Silveira, 2020; Thiounn and Smith, 2020). In mechanical recycling, end-of-life PVC flex banners are shredded into small pieces and these materials, which are mostly used as filler materials, cannot be used to make a value-added product (Bompa et al., 2021; Cholake et al., 2018; Mehta et al., 2023). Thus, end-of-life PVC flex banners create an opportunity to produce value-added products for upcycling, which is part of the reuse method. The upcycling method for end-of-life PVC flex banners supports mechanical recycling and can make a significant contribution to the management of plastic-containing waste such as PVC flex banners (Sandin and Peters, 2018; Williams and Shaw, 2017).

Transforming these plastic materials into a fashion product with added value through the upcycling method is not very common (Jang et al., 2012; Muniyasamy and Dada, 2021; Park and Lin, 2020). It is revealed that the usage suggestions regarding upcycling, which is a creative reuse method, explained as the process of transforming by-products, waste materials, and useless or unwanted products into new products for a better quality or better environment, are not at the desired level in the fashion industry (Bhatt et al., 2019; Brown, 2013; Cassidy and Han, 2013; Han et al., 2017b; Janigo et al., 2017).

End-of-life advertising or marketing banners made of PVC material, a kind of plastic derivative, are suitable for fashion accessories, including bags, suitcases, and wallets. We can see that Freitag, a fashion brand that produces different upcycled fashion products from end-of-life lorry tarpaulins, is the most supportive of a similar point of view. There are reports that some industries have used end-of-life tarpaulin materials in creating products for the fashion industry (Muller, 2001; Xu and Gu, 2015).

The upcycling process involves using end-of-life PVC flex banners in the fashion industry. During the upcycling process, with careful planning at the design stage, less waste is generated and in addition, low energy and resources are consumed, making it more resource-efficient and sustainable. In this upcycling process, end-of-life PVC flex banners go through processes such as collecting, cleaning, and drying, classifying material grades [colour, pattern, and thickness], pattern designing, cutting and sewing to become high-value products (Cini, 2019; Muller, 2001; Xu and Gu, 2015). In addition, the cutting methods of end-of-life PVC flex banners are also an important factor in efficient waste management. Pattern design and cutting processes should also include a sustainable understanding to avoid generating waste again. Although some fashion brands offer a solution to using end-of-life PVC flex banners by making smaller accessories such as key rings, and lanyards from cutting waste, this may not be sustainable and resource-efficient because it is not possible to utilise every cut piece (Muller, 2001). In this case, the zero-waste fashion production process can provide an even more environmentally friendly approach. It recommends the utilisation of all waste parts in the cutting and sewing stages (ElShishtawy et al., 2022; Enes and Kipoz, 2019; McQuillan, 2020; Niinimaki, 2013). In this zero-waste fashion production process, there are three methods – [**a**] planned chaos, in which garment blocks are used as fixed guidelines; [**b**] geo cut, which is based on using geometrical shapes such as squares, triangles, and circles; [**c**] cut and drape, a combination of random, fluid cutting and draping (Aakko and Niinimaki, 2013; McQuillan, 2011). Potential fashion and accessory products can also be created with end-of-life PVC flex banners using computer-aided pattern systems technology in the zero-waste fashion production process (McQuillan, 2019; Ramkalaon and Sayem, 2021; Saeidi and Wimberley, 2018). Fig. 5 below illustrates the potential opportunities for end-of-life PVC flex banners which can be used in the fashion industry with a zero-waste fashion production process.

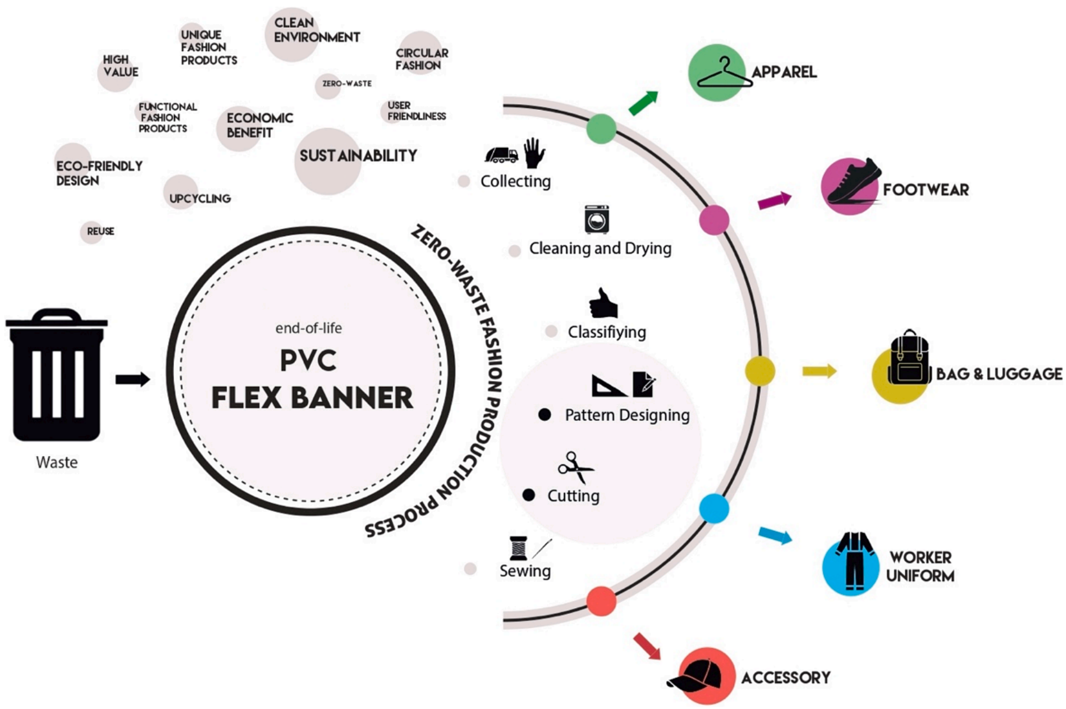

Fig. 5. Potential opportunities end-of-life PVC flex banners can create in the fashion industry with a zero-waste fashion production process.

End-of-life advertising or marketing banners made of PVC flex banners, which can be classified as post-consumer waste (Kamble and Behera, 2021), create a potential upcycling opportunity for product groups such as apparel [coats, jackets, jumpsuits, parkas, raincoats, trench coats, and windbreakers], footwear [boots, flip-flops, flats, sandals, shoes, and trainers], bag and luggage [backpack, briefcase, clutch, handbag, luggage, make-up bag, pencil case, purse, tote bag, and wallet], worker uniform [boilersuit and gloves for construction workers, fishermen, and gardeners] and accessory [belt, brooch, cap, gloves, hat, key ring, umbrella, and watch strap]. It also highlights the environmental impact at every stage of the production process and ways to minimise the environmental impact of end-of-life PVC flex banners. Creating unique products with sewing techniques to be used in the production of fashion products using PVC flex banners with the upcycling method is a unique approach and avoids the need for annihilation and is environmentally friendly.

It is possible to make these surfaces even more valuable with techniques like applique, embroidery/crochet, laser cut, patchwork, rib, and quilting (Prendergast, 2014; Wolf, 1996; Zoe, 2005) to be applied to PVC flex banners. Because a well-chosen sustainable material can be transformed into a good upcycling fashion product with different techniques. This fashion product with high design value can also become a luxury product (Brown, 2013; Burns, 2024). The transformation of creative surface works obtained with these and similar techniques (Singer, 2013) into a fashion product creates an opportunity for fashion brands (Van Erp, 2011). Thus, increasing the number of upcycling fashion brands and offering a solution to waste that would otherwise threaten the environment through end-of-life PVC flex banners is recommended. The classification and framework for the recycling/reuse of end-of-life PVC is shown in Fig. 6.

Tomorrow: What direction for the future?

It is predicted that the usage rate of PVC flex banners, which are used very effectively for advertising and marketing purposes today, will continue to increase even more in the next 10 years, owing to their usage advantages. The potential increase in the use of PVC flex banners, which are phased out in a very short period, will continue to threaten a clean environment and the health of living organisms [human, animal, and plant] through the generation of large amounts of solid waste (Evode et al., 2021; Shibamoto et al., 2007; Verma et al., 2016). When PVC flex banners are evaluated, it is seen that the annihilation processes of the banners after they become waste [piled in landfills, incinerated or buried under the soil] are of more concern in terms of environmental factors compared to the production and use stages. In this respect, the annihilation of PVC flex banners that become waste brings along a critical problem for the future of developing countries with an increasing population rate. To reduce this problem, especially the European organisations [Plastics Europe AISBL and VinylPlus] have studied the re-evaluation of PVC waste problem in the recycling processes (Plastics Europe AISBL, 2023; VinylPlus, 2015; VinylPlus, 2017; VinylPlus, 2021; VinylPlus, 2022; VinylPlus, 2023). However, the recycling method is not ideal for PVC flex banners because it is only suitable for mechanical recycling, and it produces products that do not have high added value [mostly filling material]. In this respect, the upcycling method for end-of-life PVC flex banners is a suitable method from both an environmental and economic point of view. End-of-life PVC flex banners with a zero-waste fashion production process in line with the upcycling method can be brought to the fashion industry with potential upcycling products. This upcycling proposal, part of the waste management process, provides a roadmap for the future, and some suggestions for the future are discussed below.

Businesses that produce and supply PVC flex banners, as well as consumers who frequently use these banners, should be aware of the safe disposal of end-of-life PVC flex banners. They need to know the dynamics of upcycling and explore ways to be creative and or send it to organisations that can transform them into high-value products and prevent solid waste generation. PVC flex banners are used extensively by municipalities, shopping centres, museums, and universities. Because these institutions organise hundreds of activities a year. The easiest and most accessible means of information to publicise these events are PVC flex banners. Before the end of an event, these posters are replaced with new ones and included in the waste process. To implement better waste management processes, it may be appropriate for governments to

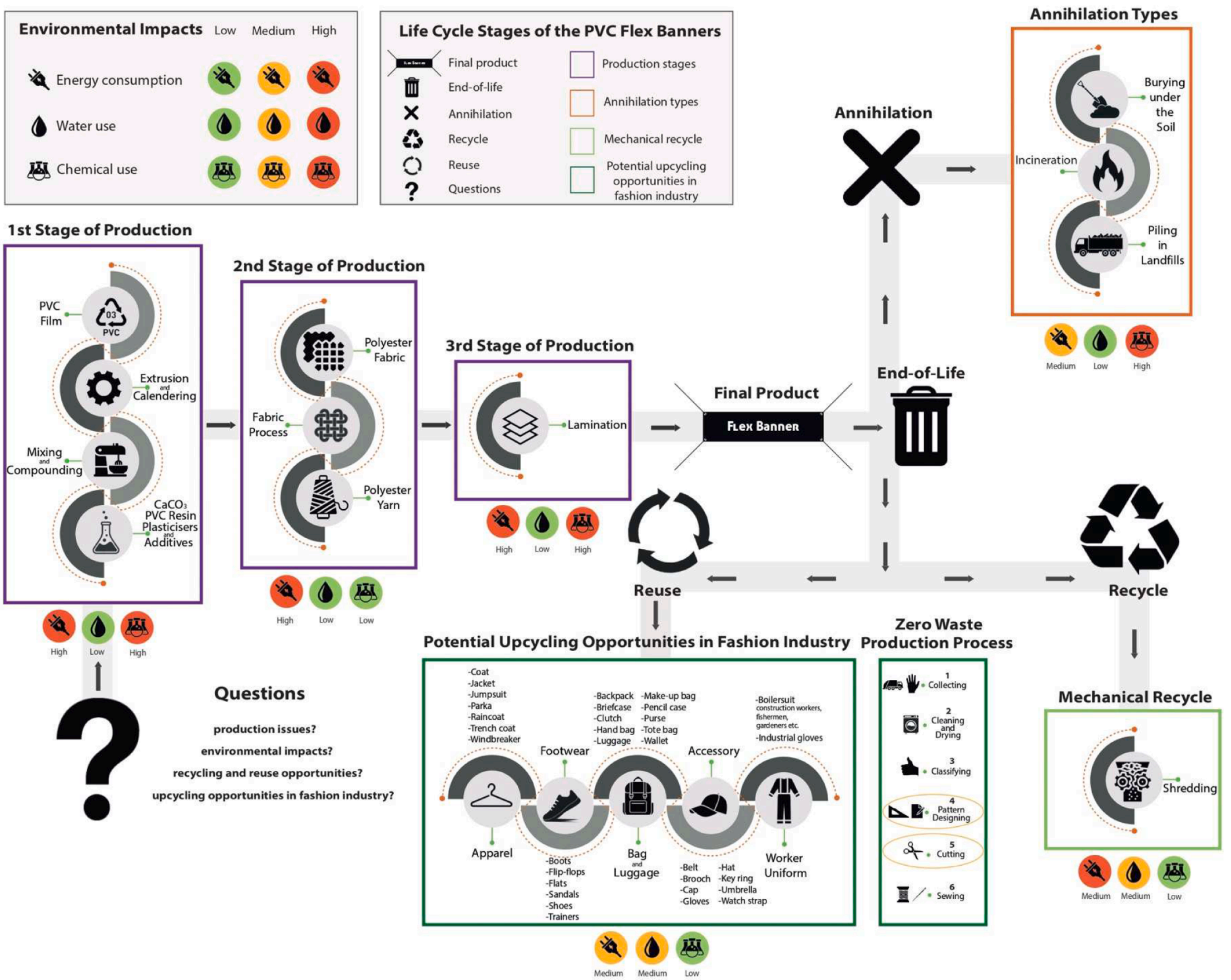

Fig. 6. A framework to show how flex banners can be used to reduce environmental impact. (Large-scale anticipated environmental impacts [energy use, water use, and chemical use] were used and levelled for each stage of the process).

implement policies in line with the United Nations [UN] 17 Sustainable Development Goals and take steps to support the upcycling of end-of-life PVC flex banners sent to recycling centres.

Conclusion

Flex banners are advertising tools frequently seen indoors and outdoors for advertising or information purposes and are printed by digital printing methods today. The production and use of PVC flex banners is increasing daily due to their usage times and features. Flex banner usage will increase even more in the years ahead when advertising and marketing processes are essential. The market trend and demand for PVC are forecasted to grow mainly in Asia-Pacific. Flex banners are widely consumed in marketing and advertising and are considered an alternative to other fabric banners, metal panels, and electronic LED screens. This is also due to its portability, accessibility, and durability. One of the main concerns is its limited shelf-life; unlike its rival electronic screens, which can be reused again, flex banners can quickly become waste products in a shorter time frame. Since PVC uses plasticisers such as phthalates in the production process to increase flexibility, stretch, and durability, it can be considered harmful to health and the environment. The disposal methods for end-of-life PVC flex banners, like piling in landfills, incineration or burying under the soil, have been highlighted in the systematic review as having a severe environmental impact. This is due to its chlorine content and the release of high dioxins into the soil, which is toxic. In addition, during the burning of flex banner waste, residue from the chimneys can contain heavy metal-laden fly ash and acid gas in the form of hydrochloric acid and sulphur dioxide, causing severe environmental and health problems.

PVC flex banners are more likely to release solids, air, water waste and other environmental toxins that harm the environment during annihilation. The ultraviolet [UV] curing with mercury lamps used during the production process also causes ozone emissions. Due to these issues, several initiatives by organisations [Vinyl Councils] globally have attempted to lower the impact on human health and the environment, mainly to reduce exposure to vinyl chloride monomers. The European Commission widely classified PVC as non-hazardous as the additives used do not migrate, and VinylPlus [Europe] reported that the life cycle analysis assessments of PVC are eco-efficient and possess good environmental performance. Since PVC flex banners have a limited shelf life or use in advertising, the possibility of recycling or reuse has been highlighted, such as mechanical or chemical recycling. One of the challenges in recycling banners is separating the PVC coating from the polyester fabric. However, with technological developments, it is now possible to separate the polyester fabric from the PVC coating, which can be mechanically shredded.

Upcycling offers end-of-life PVC flex banners further opportunities to use in the supply chain by adding higher value to the finished product using innovative and creative ideas and skills without chemical processing. The systematic review recommends some of the potential applications as apparel [coats, jackets, jumpsuits, parkas, raincoats, trench coats, and windbreakers], fashion footwear [boots, flip-flops, flats, sandals, shoes, and trainers] and travel accessories [bag and luggage]. In addition, utilising zero-waste fashion production during cutting and sewing can ensure these flex banners are consumed sustainably in the development of high-value-added fashion products. The framework indicates the environmental impact of flex banners during the production process particularly during the annihilation process as well as during landfill. The review recommends an urgent need for upcycling of PVC-based products, suggesting an ideal solution to conserve resources and utilise them at the highest value, thereby reducing the imminent concern about the impact on health and the environment, which otherwise would annihilate [pile up, incinerate or bury] the end-of-life PVC flex banners. It is also recommended to implement policies among stakeholders to increase awareness of the upcycling of PVC flex banners, which would facilitate efficient recycling of end-of-life PVC flex banners in the future.

CRediT authorship contribution statement

Kenan Saatcioglu: Writing – original draft, Visualization, Resources, Investigation, Formal analysis. **Prabhuraj D. Venkatraman:** Writing – review & editing, Validation, Supervision, Methodology, Conceptualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Kenan Saatcioglu reports financial support was provided by the Scientific and Technological Research Council of Turkey (TUBITAK). If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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